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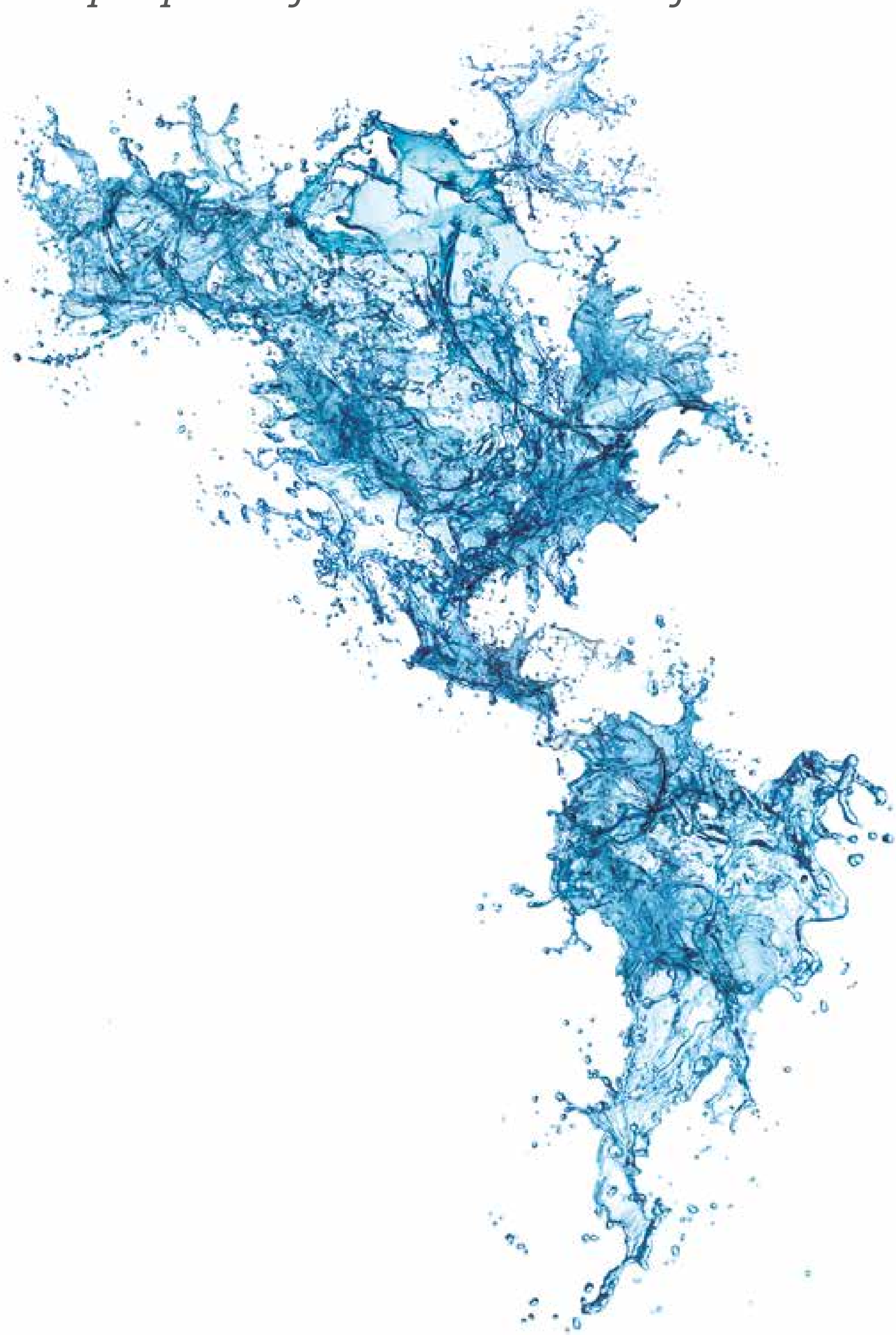
A perspective from the Academies of Sciences



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Translation
Suzanne D. Stephens (Argentina, Chile, Mexico, Canada, Honduras, Panama, Costa Rica, Dominican Republic, Peru and Toronto) and **Alejandra Huete** (Cuba and El Salvador)

Graphic Design
Víctor Daniel Moreno Alanís
Francisco Ibraham Meza Blanco

Original Cover Design
Francisco Ibraham Meza Blanco

Graphic Design Support
Osiris López Aguilar, Mariana Guerrero del Cueto, Tania Zaldivar Martínez, and **Roberto Flores Angulo**

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Rodolfo Gambini, President

Venezuela
Academy of Physical, Mathematical and Natural Sciences of Venezuela
www.acfiman.org.ve
Claudio Bifano, President

IANAS Water Focal Points

Argentina
Dr. Raúl A. Lopardo
National Water Institute

Bolivia
Dr.Fernando Urquídi
National Academy of Sciences of Bolivia

Brazil
Dr. José Galizia Tundisi
International Institute of Ecology

Canada
Dra. Banu Ormeci
Carleton University

Grenada
Dr. Martín ST. Clair Forde
St. George's University, Grenada

Chile
Dr. James McPhee
Advanced Mining Technology Center
University of Chile

Colombia
Dr. Gabriel Roldán
Colombian Academy of Exact,
Physical and Natural Sciences

Costa Rica
Dr. Hugo Hidalgo
University of Costa Rica

Cuba
Dra. Daniela Mercedes Arellano Acosta
National Institute of Hygiene, Epidemiology
and Microbiology, Havana, Cuba

Dominican Republic
Ing. Osiris de León
Comission of Natural Sciences and
Environment of the Science Academy

El Salvador
Dr. Julio Cesar Quiñones Basagoitia
Member of the Global Water Partnership

Guatemala
Ing. Manuel Bastarrechea
Academy of Medical, Physical
and Natural Sciences of Guatemala

Honduras
Dr. Marco Blair
National Academy of Sciences of Honduras

Mexico
Dra. María Luisa Torregrosa
Latin American Faculty of Social Sciences

Nicaragua
Dra. Katherine Vammen
Nicaraguan Research Center for Aquatic Resources
National Autonomus of Nicaragua

Panama
Dr. José R. Fábrega
Faculties of Civil and Mechanical Engineering
at the Technological University of Panama

Peru
Dra. Nicole Bernex
Geography Research Center Pontifical Catholic
University of Peru

Uruguay
Dr. Daniel Conde
Sciences Faculty
Universidad de la República

USA
Dr. Henry Vaux
Univesity of California

Venezuela
Dr. Ernesto J. González
Sciences Faculty
Central University of Venezuela

Coordinators and Authors

Argentina

Raúl Antonio Lopardo
National Water Institute

Jorge Daniel Bacchiega
National Water Institute

Luis E. Higa
National Water Institute

Bolivia

Fernando Urquidi-Barrau
National Academy of Sciences of Bolivia

Brazil

José Galizia Tundisi
International Institute of Technology

Carlos Eduardo Morelli Tucci
Universidade Federal do Rio Grande do Sul

Fernando Rosado Spilki
Centro Universitário Feevale

Ivanildo Hespanhol
Universidade de São Paulo

José Almir Cirilo
Universidade Federal de Pernambuco

Marcos Cortesão Barnsley Scheuenstuhl
Brazilian Academy of Sciences

Natalia Andricioli Periotto
Centro de Ciências Biológicas e da Saúde

Canada

Banu Örmeci
Carleton University

Michael D'Andrea
Water Infrastructure Management Toronto

Chile

James McPhee
Advanced Mining Technology Center
University of Chile

Jorge Gironás
School of Engineering
Pontifical Catholic University of Chile

Bonifacio Fernández
School of Engineering
Pontifical Catholic University of Chile

Pablo Pastén
Department of Hydraulic and Environmental
Pontifical Catholic University of Chile

José Vargas
Chilean Hydraulic Engineering Society

Alejandra Vega
Pontifical Catholic University of Chile

Sebastián Vicuña
UC Global Change Center

Colombia

Gabriel Roldán
Colombian Academy of Exact
Physical and Natural Sciences

Claudia Patricia Campuzano Ochoa
Antioquia Science and Technology Center

Luis Javier Montoya Jaramillo
National University of Colombia-Medellin

Carlos Daniel Ruiz Carrascal
School of Engineering of Antioquia

Andrés Torres
Javeriana Pontifical University-Bogota

Jaime Andrés Lara Borrero
Javeriana Pontifical University-Bogota

Sandra Lorena Galarza Molina
Javeriana Pontifical University-Bogota

Juan Diego Giraldo Osorio
Javeriana Pontifical University-Bogota

Milton Duarte
Science and Engineering Research Group

Sandra Méndez-Fajardo
Javeriana Pontifical University-Bogota

Costa Rica

Hugo G. Hidalgo
University of Costa Rica

Ángel G. Muñoz
International Research Institute for Climate and Society at Columbia University

Carolina Herrero
Ph-C Ingenieros Consultores

Eric J. Alfaro
University of Costa Rica, School of Physics

Natalie Mora
University of Costa Rica, School of Physics

Víctor H. Chacón
Municipality of Perez Zeledon, C.N.E.

Darner A. Mora
National Waters Laboratory

Mary L. Moreno
International Center for Economic Policy for Sustainable Development at the National University of Costa Rica

Cuba

Daniela de las Mercedes Arellano Acosta
National Institute of Hygiene, Epidemiology and Microbiology, Havana, Cuba

L.F. Molerio-León MSc.
GRANIK HOLDINGS Ltd
(Dominican Republic)

Eduardo O. Planos Gutiérrez
Cuban Meteorology Institute

Dominican Republic

Osiris de León
Comission of Natural Sciences and Environment of the Science Academy

El Salvador

Julio Cesar Quiñones Basagoitia
Member of the GWP

Grenada

Martin ST. Clair Forde
St. George's University, Grenada

Brian P. Neff
St. George's University, Grenada

Guatemala

Manuel Basterrechea
Academy of Medical
Physical and Natural Sciences of Guatemala

Carlos Roberto Cobos
Engineering Research Center

Juan Carlos Fuentes
National Electrification Institute

Norma Edith Gil Rodas de Castillo
Oceans and Aquiculture Studies Center CEMA
University of San Carlos, Guatemala-USAC

Jeanette Herrera de Noack
Environmental Law Alliance Worldwide

Ana Beatriz Suárez
Ecological and Chemical Laboratory, S.A.

Honduras

Marco Antonio Blair Chávez
National Academy of Sciences of Honduras.

Manuel Figueroa
National Academy of Sciences of Honduras.

Mexico

María Luisa Torregrosa y Armentia
Researcher in the Latin American Faculty of Social Sciences-FLACSO

Blanca Jiménez-Cisneros
Water Sciences Division and Secretary of UNESCO

Jacinta Palerm
Graduate Level, Mexico-COLPOS

Ricardo Sandoval Minero
Sextante Consulting Services, S.C.

Karina Kloster
Autonomous University of Mexico City

Polioptro F. Martínez Austria
University of the Americas, Puebla

Jordi Vera Cartas
Fondo Golfo de Mexico A.C

Ismael Aguilar Barajas
Monterrey Institute of Technology

Nicaragua

Katherine Vammen
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Yelba Flores Meza
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Selvia Flores Sánchez
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Iris Hurtado García
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Mario Jiménez García
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Francisco J. Picado Pavón
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Gustavo Sequeira Peña
Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN)

Panama

José Rogelio Fábrega Duque
Technological University of Panama

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Elsa Lilibeth Flores Hernández
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Gerencia de Hidrometeorología de ETESA

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Peru

Nicole Bernex Weiss
Geography Research Center Pontifical Catholic University of Peru

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United States of America

Henry J. Vaux
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Uruguay

Daniel Conde Scalone
School of Sciences
University of the Republic

Adriana Piperno de Santiago
School of Architecture
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Federico Quintans Sives
School of Sciences
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Venezuela

Ernesto José González
School of Sciences
Central University of Venezuela

María Leny Matos
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Eduardo Buroz
Andrés Bello Catholic University

José Ochoa-Iturbe
School of Engineering
Andrés Bello Catholic University

Antonio Machado-Allison
Academy of Physical, Mathematical and Natural Sciences of Venezuela

Róger Martínez
Simón Bolívar University

Ramón Montero
Institute at the Central University of Venezuela

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Katherine Vammen (Nicaragua)
Co-Chair of the IANAS Water Program

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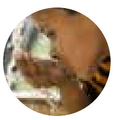

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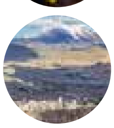

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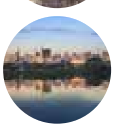

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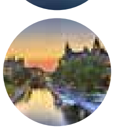

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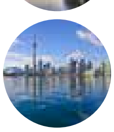

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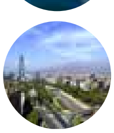

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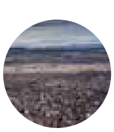

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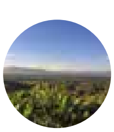

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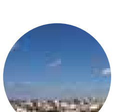

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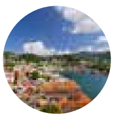
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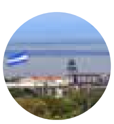
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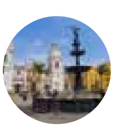
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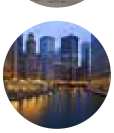
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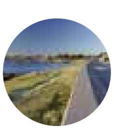
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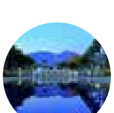
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Preface

Water is literally the stuff of life. It is absolutely essential for human health, for food production and for sanitation as well as for a host of other uses. A clear understanding of present and future sources of water and of strategies for the effective management of water resources is in the interest of every country. The challenge is urgent because human population demands, as well as climate change, make once secure sources uncertain. Moreover, water projects are often large and expensive and take many years to complete, so future planning is crucial. Accordingly this volume aims to provide a science-based assessment of key water resource issues on a country-by-country basis for 20 countries of the Americas. The goal of IANAS is for this volume to serve as a valuable reference for policy makers, government officials and planners who will have to meet the challenges associated with our water future.

IANAS is the Inter American Network of Academies of Science (www.ianas.org). IANAS includes all the science academies of the Americas and it has access to the best scientific minds of our region. The goal of IANAS is to bring evidence based science to policy makers and to build scientific capacities in our hemisphere. IANAS achieves this goal by advancing investments in human resources for science and by focusing on key resource challenges. This volume is the second in a series on water, published in both Spanish and English, and intended to reach a wide policy audience. The first volume offered a broad assessment of the status of water resources in the Americas. This second volume addresses the fundamental problem of urban water challenges. The Hemisphere of the Americas is among the most urbanized of regions on the globe and urban water needs are pressing. IANAS intends that this volume make a valuable contribution to a key challenge facing all of our countries.

Michael Clegg
Co-Chair IANAS, USA

Juan Asenjo
Co-Chair IANAS, Chile

Urban Waters in the Americas

Blanca Jiménez Cisneros
Director of the Division of Water Sciences and Secretary of the International Hydrological Programme of UNESCO

The UNESCO International Hydrological Programme (IHP) started in 1975 as a continuation of the International Hydrological Decade (1965-1975). IHP is implemented through phases to adapt its activities to the world's changing needs for the sustainable management of water. The program and its activities are defined through an in-depth consultation coordinated by the IHP Secretariat and the IHP Regional Hydrologists among 169 IHP National Committees, the category 1 UNESCO–IHE Center for Water and Education, the 28 regional and international UNESCO category 2 Water Centers, the 35 UNESCO Water Chairs and other relevant IHP partners and UN water related agencies.

In 2014, the IHP-VIII entered in its 8th Phase, which is dedicated to addressing the global, regional and local challenges to achieve Water Security. Among the six themes of IHP-VIII, the fourth is "Water for Human Settlements of the Future", covering among other issues Urban Water.

Today, 750 million people lack access to safe water and many millions more have access only to a deficient service. At the same time, urbanization is growing rapidly. In the next 40 years, cities are expected to receive 800,000 additional inhabitants each week. At the global level, since 2011 for the first time in human history the human population lives in majority in cities. This and the absolute or partial lack of services for people already living in cities combined with population and economic growth have been and will continue to be the factors that demand a higher degree of and improved management of urban water. Also, the aging of urban hydraulic infrastructure is evident in many cities and will require significant investments for its renovation. Worldwide rapid urbanization demands new ways to conceive and operate public services, including those for water. New approaches are required to optimize the joint management of water, land use and energy, as well as to decrease the water footprint of cities and to control the transportation of contaminants into water and the transfer of pollutants among water, soil and the urban air. Among the regions with an important urbanization rate, The Americas, and notably Latin America, emerges. This latter region has the highest global rate of urban inhabitants with more than 72% of its population living in cities. No wonder that urban water management in the region is an issue, sometimes well solved, sometimes less so.

This book describes the situation of urban water management in 20 countries: all North and South American ones, and a significant number from Central America and the Caribbean region. To produce it a unique network of multidisciplinary scientists was created which in total 94 involved authors. The book is unique not only for this reason, but also because it covers, for the first time, in an integrated but flexible framework aspects never looked at before in urban water management on the American continent. Among those are water quality, water reuse, urban aquifers, rainwater management, urban floods, human and environmental health issues, and, of course, climate change. Through this multi-directional orientation, the book reveals that the challenges for urban water security extend to cities in all countries. Alongside the continuum of economic considerations, inequity of access to services are a concern, investments to renovate the urban water infrastructure need be planned, the problems of urban floods and poor water quality keep growing, and there is the urgent need to create cities resilient to climate change.

In conjunction with IHP's approach, this book promotes bridging of science and policy by starting a dialog between science and policy makers. The book is a useful tool provided by scientists, *inter alia* for policy-makers because it was produced using an interdisciplinary approach, by combining the knowledge of scientists with the experience of water utility professionals and by applying it to solve practical problems relevant to society. A particularly noteworthy aspect of this book is the importance given to the role of outreach and creating a knowledgeable, participating public, is transparently informed about problems and involved in solutions. This underlines the requirement for, on one hand, effective communication skills among the specialized water community to convey scientific aspects to the non-scientific community. On the other hand, it highlights the need to provide reliable information for societies on public water problems and create accountable governance systems that engage with the public on the planning and implementation of projects.

Because of its content and scope, this book is fully in line with the purposes of IHP-VIII. In addition, the book has contributed to IHP key tasks, by (a) mobilizing scientific and innovation networks, (b) strengthening the interface between scientists and decision makers, and (c) contributing to the development of institutional and human capacities. No doubt, this publication is an excellent result of the efforts of the Inter-American Network of Academies of Sciences, in collaboration with the National Academies of Sciences and the countries that have contributed to the book. IHP is very proud to have supported this work through its network and to promote its dissemination and use among the Member States.

Water in Urban Regions

José Galizia Tundisi
International Institute of Ecology
São Carlos, Brazil

Urbanization is a worldwide phenomenon. Most of the human population currently lives in urban regions, with populations ranging from 10.000 to 50.000 inhabitants, to millions of people in metropolitan cities.

The health and quality of life of these urban inhabitants depends on a series of factors and natural phenomena, such as climate, geological features, hydrological cycles, plant cover and biodiversity.

Intensive land use caused by the expansion of the urban area impacts human health and reduces green areas to a few isolated spots.

A city's water resources are a key component in all the complex environmental conditions sustaining the urban population. Water availability, quality and security are all interlinked in urban regions due to the following factors: in many Latin American cities, good-quality drinking water does not reach all communities, especially in periurban areas; pollution and contamination, resulting from intensive land use and the lack of wastewater treatment and eutrophication due to nonpoint and point sources of nutrients. Water security is related to both water availability and pollution.

How then does one transform an urban region or city into a livable environment?

First of all, the complexity of a city or large urban region must be understood. This is a task for future generation of scientists, and researchers, who will apply the science of complex systems to urban regions.[1]

Second, cities are dependent on resources far away from the urban area: water, food, fibers and timber are usually brought in due to the disruption of ecosystem services in the urban agglomerate.

Third, the network of roads, building and infrastructure disconnects people from nature.

It is essential to restore urban ecosystems. Green cities must build up, protect and promote natural parks, riparian forests and wetlands, clean rivers and lakes in order to provide sites for education and water resource conservation, restore urban biodiversity and reconnect people with nature.[2]

These actions will guarantee groundwater recharges and the availability of drinking water, and improve the humidity in the air due to the evapotranspiration of vegetation in natural parks and riparian forests.

Restoration of nature in the cities will promote healthy, attractive urban environments, improve the quality of life and provide better opportunities for employment and education. The water cycle in this context is of extreme ecological, economic, and social importance.

1. Reid W. et al 2010. Earth System Science for Global sustainability: grand challenges. Science vol. 330, pp. 916-917.
2. Tundisi J. G. 2005. Green cities. Letter to the Editor. Science. Brazilian Academy of Sciences, Leopoldina Nationale Akademie, Germany. 2014. Water in Urban Regions. 29 pp.

A Quick Look At

Urban Water Challenges in the Americas
A Perspective from the Academies

Katherine Vammen
Co-Chair of the IANAS Water Program

Can the problems of urban water supply and sanitation be solved with better management?
Can access to safe drinking water be improved?
Can the challenge of improving sanitation and wastewater management be met?
Can water related health problems and water-borne disease be better addressed in urban areas?
What are the water related challenges in adapting to climate change for urban areas and how can they be met?
What are good models and concepts for helping to improve water management in urban areas?

These questions and others are addressed in the present volume which is focused on the urban water problems of the Americas. Urban water problems are especially important since more than 60% of the world population lives in cities and this number is increasing every year. Moreover, according to United Nations statistics the Americas are among the most urbanized regions of the world (> 80%). Urbanization goes hand in hand with intensification in the use of **water resources for human needs**; in turn, hydrological systems play a role in the development and growth of cities not only as a source of drinking water but also for the deposition of wastes. ***Urban Water Challenges in the Americas*** describes and analyzes the problems of water in urban centers in 20 countries of the Americas: spanning from South America, Central America, Mexico and the Caribbean to the United States and Canada. This unique examination of the countries of the Americas, each with different water resources characteristics, diverse levels of economic and social development, varying problems related to water quality and quantity and different experiences with water management, is a contribution from the Interamerican Network of Academies of Science (IANAS). The goal of the volume is to aid in the search for solutions to the challenges of properly managing water resources in urban areas as described in the 20 chapters of this book. Evidence from both developed and developing countries shows that to be effective the management of water resources must extend beyond the city to include the surrounding watersheds from which the water comes.

This book is organized into country chapters but each one emphasizes the following topics:

- Water resources in urban areas and the impacts on water from urbanization.
- The adequacy and accessibility of water supply services in urban areas.
- The adequacy of wastewater management in urban areas.
- The importance of appropriate urban water services for community health.
- The potential impacts of climate change on water resources and water services in urban areas.

Special themes from many of the countries include:

- Urban Systems and Water: Brazil.
- Conservation and Water Reuse as Management Tools: Brazil.
- Urban Impact due to Rise of Groundwater: Argentina.
- Governance and Sanitation Sector Management: Chile.
- Sustainable Rainwater Management in Cities: Chile and Grenada.
- Aspects of Island Aquifer Management in Wet Tropical Zones: Cuba.
- Special problems of water supply on islands: Grenada and Cuba.
- Historical Development of Water Supply and Urbanization: Uruguay.
- Rainwater Management and Planning in cities: Uruguay.
- Addressing the problems of water scarcity: Managing Water Demand: USA.
- Biological Water Quality in Water Treatment Plants: Panama.
- Reutilization of Waste Waters: Colombia.
- Analysis of Vulnerability to Climate Change of Principle Nicaraguan Cities
- Population Growth and the Structuring of Cities: Mexico.
- Climate Change and Urban Disaster Risk: Peru.
- Extreme Climate Events in the City of Guatemala.
- Hydro-Climatic Projections for Central America: Costa Rica.

Case study on urban water management

An especially instructive Case Study on best practices associated with Urban Water Management in Toronto, Canada is also included.

This unique collection of experiences with urban waters in the Americas rests on a wide geographical representation that includes differences in water resource availability and levels of economic development. The analyses herein offer the opportunity to draw lessons stemming from the commonalities and differences among the countries of the Americas. Also, it highlights the fact that a significant diversity of water management schemes will be required to manage water effectively.

Urbanization and water resources

Urbanization in the Americas ranges from 50% to 94% of the population in Latin-America and North America, respectively, in 2012 according to the WHO and UNICEF report on Drinking Water and Sanitation (2014). Some Caribbean Islands such as Grenada have lower levels (39%), but the degree of urbanization is increasing. This phenomenon has been observed globally and applies across the Americas, ranging from developed countries with large and stabilized urban populations, to developing countries where patterns of urbanization are steadily growing (UN, 2009). Urbanization concentrates competition for the use of water resources into a small space. This allows for efficiencies in water use, but it also imposes special demands associated with water transport, water quality maintenance and the management of excess water from storm events, among other challenges. If the human needs for healthful domestic living conditions are to be met and if economic development is to prosper, more efficient methods for the management of the urban water resources are essential.

In general urbanization requires more water per unit area while producing wastes, including wastewaters and solid wastes that tend to degrade water quality and that must be managed. Urbanization also tends to degrade local watersheds and their surrounding areas through deforestation and increases in impervious areas.

Urbanization and impacts on water resources in urban zones

Urbanization has not been accompanied by adequate planning and foresight in most countries. Environmental impacts are accounted for in advance only infrequently with resulting adverse effects on the environment including water resources. Examples include: 1) Inappropriate land use and deforestation in the watershed and surrounding areas of urban centers leading to erosion which then brings heavy sedimentation into the cities and contaminates sources of water; 2) Uncontrolled discharges of domestic and industrial wastewaters into surface waterbodies and coastal areas; 3) Lacking hygienic habits of the population and inappropriate management of solid wastes deposited into sources of water or city drainage systems; 4) Contamination of ground and surface water from different sources: mining, hydrocarbon spills from industry and contamination from storage of fuel tanks at service stations as well as pesticide runoff from agricultural activities from the surrounding watershed; 5) Impairment of recharge to urban aquifers due to reduction of green cover (forests, wetlands, riparian forests) and impermeable infrastructure associated with urbanization and more.

Water supply services and sanitation

In the last decades the access to potable water and treatment of waste water in cities of the Americas has improved. The coverage of *water supply systems* in the majority of cities has reached levels that fulfill the Millennium Development Goals of the United Nations for improved drinking water sources and it is important to highlight that Latin America and the Caribbean have the highest drinking water coverage of the developing world. However, as observed in the analysis provided in each country´s chapter, there are still serious problems with the coverage for improved sanitation in cities varying from 57 to 100% according to the WHO and UNICEF report on Drinking Water and Sanitation (2014). An exception is Chile where there has been rapid improvement in sanitation coverage in the last decade such that all collected wastewaters are treated. A combination of factors has made this possible, including Chile´s economic stability, institutional restructuring and significant investments in the context of utility privatization. Despite this success, important challenges remain, such as access to sanitation service in peri-urban unincorporated communities.

Adequate water supply services are generally available throughout the developing countries of Latin American and the Caribbean. The problems are centered more on the continuity of services, the need to repair massive leaks in the existing distribution systems and the need to regulate and enforce controls on illegal connections which affect the efficiency in delivery of water and the economic capacity of the water supply companies to make investments in improving services. Faulty distribution systems have also caused problems in Canada and the United States where there is a need to replace old systems and undertake new programs of renewal and innovation. The case study of Toronto presents some management steps being undertaken to finance and improve distribution systems.

The lack of adequate monitoring of water quality for contaminants, together with new emerging sources of contamination, is identified as a major problem in both developed and developing countries. It is also important that the microbiological safety of water in most countries is not secure because the detection of viral and protozoan pathogens is not included in standard water monitoring protocols.

It is important to mention that some improved sanitation systems still cause contamination of water sources originating from the same system. Many countries report examples of septic tanks from urban areas and new urban developments that contaminate groundwater sources used for drinking water. Also the majority of developing countries reported massive problems due to the discharge of waste waters into rivers and the ocean without treatment. It has also been reported that 15% of waste waters do not receive even basic primary treatment. Some Central American countries report many cases where Oxidation ponds treating domestic waste waters discharge into surface waterbodies which consequently undergo strong eutrophication and loss of water quality for human consumption and irrigation.

The cities of Latin America and the Caribbean islands are affected by the informal growth of peri-urban areas (usually due to migration from rural areas or consequences of climate change crisis in rural areas) which have little or no water coverage or sanitation. These areas have the highest rate of water-borne disease and a significant incidence of contamination of water sources. These peri-urban areas will require special attention if healthful drinking water supplies and adequate sanitation services are to be provided to the local residents.

For the United States and Canada, urban water issues are focused on the need for improving maintenance and renewal of systems. The deterioration of quality in source waters and of course the water scarcity crisis require innovative financial, technological and "demand management strategies" to reduce loss of the resource and "maintain levels of reliability".

Urban water and health

The increase in coverage of water and sanitation in urban zones has had a positive influence in the reduction of waterborne diseases (bacterial and vector born) in developing countries of the Americas. Further improvements in the continuity of services, and the renewal and better maintenance of distribution systems would further reduce the probability of waterborne diseases. Where water supply and sanitation reaches only part of the population or is completely absent, the environment is favorable to the development and spread of waterborne diseases. Peri-urban and informal settlements are particularly at risk.

Climate change and impact on water resources in cities

Cities are more vulnerable to extreme climate events especially due to failures in planning for growth and modernization of water distribution systems, coupled with inadequate drainage systems that can be overwhelmed by intense precipitation events. All countries have reported changes in precipitation patterns accompanied by changes in land use in surrounding urban watersheds and changes in soil use from deforestation which creates increases in erosion and brings heavier sediment loads into cities. The geographical characteristics of Central America make it especially vulnerable to climate change and higher evapotranspiration rates have been observed due to the gradual increase in temperatures. There have been reports from many countries in North, Central and South America of droughts that have caused severe crises in the provision of potable water forcing authorities to ration irrigation and give priority to human consumption. Special examples of drought management and organizations of the water supply in cities are mentioned for the USA in California and northeastern Brazil. Also most countries have documented the occurrence of extreme events of intensive rains causing flooding in urban areas, owing to inadequate drainage systems. Examples of better planning for the reform of urban drainage systems are presented for Uruguay and concrete management examples are given in the Case Study of Toronto, Canada.

Water reuse

Climate change and especially drought situations have made the reuse of waste water more important than ever for cities. New technologies to prepare waste water for reuse are described and these can also contribute to reduction in the deposition of raw sewage into receptor bodies of water in cities. The use of domestic sewage, liquid residues from industrial effluents, agricultural runoff and brackish waters could prove to be a viable alternative source of water for certain uses. The storage and reuse of rain water has been implemented in some countries. It was emphasized that the monitoring of the quality of water for reuse is fundamental in order to guarantee the appropriate quality.

Effectiveness of water institutions and legal aspects

In most countries, progress has been made with the establishment of Water Authorities and specific legislation governing water resources and water management. For some countries the effectiveness of these institutions is not yet adequate and the existing laws are not being enforced in an effective way to promote good water management in urban areas.

Improving water management and institutional planning and oversight

Most countries are conscious that the management of water in cities has been fragmentary and has not considered the infrastructure for urban water management in a holistic fashion. One proposal would entail incorporating, into one organizational unit, all elements of urban water management: supply of potable water, collection and treatment of wastewater, and storm drainage and urban flood control. A watershed based planning approach is advocated to mitigate the water quality and quantity impacts of wet weather flows, including water pollution, flooding, and stream erosion; and which would help better direct urban growth away from high risk areas such as flood plains and embankments. The case study of Toronto shows the integration of urban water management into one institution following the amalgamation of a number of municipal governments. It was emphasized in all countries that proper urban water management must include watershed management within urban and surrounding rural areas.

Argentina

Obelisk of Buenos Aires, historic monument and icon of icon of that city, located in Plaza de la Republica, Buenos Aires, Argentina. Photo credit: © iStock.com/dolphinphoto.

"Despite its vast territory, humid regions in Argentina only occupy a quarter of its surface and are inhabited by over two thirds of its inhabitants. Arid zones account for 60% of the area of the country, and are home to just 6% of the population. This ratio between water and population is exactly the opposite to that of the majority of Latin American countries"

Urban Water on the American Continent: the case of Argentina

Raúl Antonio Lopardo
Jorge Daniel Bacchiega
Luis E. Higa

Summary

This chapter characterizes the availability and distribution of water resources, with an emphasis on their uneven spatial distribution. It analyzes population growth in recent years, noting that over 90% of the total live in urban areas. It describes the various catchment for water supply and studies the current level of coverage in the country's main cities. Although there are high percentages of drinking water coverage, over 90% in the principal cities, the level of sanitation is uneven, with indices varying between 35% and 80%. The chapter also mentions the organization of the provision of drinking water service, where there is a federal regime that implies the existence of specific norms and regulations for each province, which multiplies the number of providers in the country, bringing the total to 1,830.

The chapter also undertakes an analysis of the existing situation in the urban conglomerate of Greater Buenos Aires, home to over 12 million persons, with high levels of coverage. It focuses on the treatment and the level of reuse of wastewater. Lastly, it specifically analyzes two significant impacts linked to water resource management and rising water tables, and the impact of excess precipitation on urban centers.

1. Introduction

Water resources in Argentina are unevenly distributed, with 2/3 of its territory consisting of arid and semiarid regions, and only 1/3 with abundant mainly surface water bodies, accounting for 84% of the country's available water. Surface water resources are estimated to have an average flow of approximately 26,000 m³/s (Pochat, 2005). Given Argentina's population of 40,117,096 inhabitants recorded in the National Population, Household and Housing Census 2010 (INDEC, 2012), this means an annual renewable water supply ratio of approximately 20,500 m³/s per inhabitant .

Though this is considerably above the 1,700 m³/inhabitant/year that has been adopted as the water stress or "Falkenmark Indicator" (White, 2012), it does not accurately reflect the real supply of surface water in Argentina. Despite the significant global water supply, there are some negative balances between potential demands and water availability in certain parts of the country. Moreover, one should recall that there are very diverse population densities in the various hydrographic basins (INDEC, 2012), and consequently certain provinces, including Tucumán and Córdoba, have an annual water availability per inhabitant below the hydric stress limit.

Figure 1 is a map of Argentina divided into the 23 provinces and the city of Buenos Aires, which is not a province but rather an autonomous city. It also shows the location of the aforementioned provinces in the center of the country.

Figure 1. Political Map of Argentina

Figure 2. Map of basins and hydrographic groups (2010 Atlas, INA)

Figure 2 is a map of the principal water basins and hydrographic groups. Both maps are taken from the *2010 Atlas, Surface water basins and regions of Argentina*, by the National Water Institute, Under-Secretariat of Water Resources.

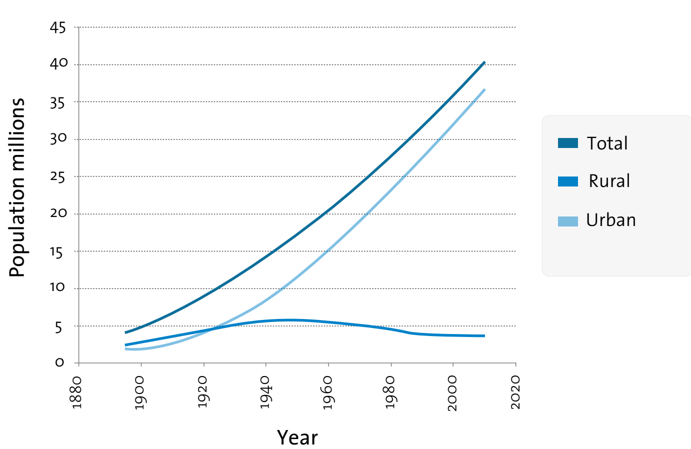
Wetlands occupy 24% of the area of the country, but are home to approximately 70% of the country's total inhabitants, whereas arid zones account for 61% of the territory, yet only contain 6% of its inhabitants. This water/population ratio is exactly the opposite of the majority of Latin American countries.

Though groundwater resources are of crucial importance in the arid and semiarid regions of the country, there is insufficient information regarding these resources nationwide. Available information refers to local aquifers, particularly in the areas of Cuyo, the North East and the Pampas region (Aquastat, 2000). The recently-created National Federal Plan for Groundwater at the Under-Secretariat for Water Resources (SSRH, 2012) will undoubtedly contribute to creating the information required for the integrated management of this key resource. Argentina possesses a broad distribution of aquifers with diverse characteristics throughout its territory, which enables water to be supplied for human consumption, particularly in most of the towns in the interior of the country. However, most of the water consumed is for irrigating agricultural production.

The Plan stipulates that sustainable underwater management is crucial to preventing a decrease in stored volumes or a reduction in wetlands areas, maintaining the useful life of boreholes, ensuring the quantity and temperature of thermal exploitations and preventing modifications in the surface of the land, among other undesirable effects of non-sustainable use. This National Plan is currently undergoing its first phase of implementation, which involves creating a hydrogeological database, continuing studies on the Guaraní Aquifer System in Argentina, and various forms of participation in actions involving trans-border aquifers and inter-jurisdictional basins.

The uncontrolled increase in the use of surface and groundwater, in both the industrial and productive sphere, with discharges of untreated effluent and the haphazard development of extensive marginal population settlements, meant that by the early 21st century, water resources had significantly deteriorated as a result of inadequate exploitation and the dumping and infiltration of polluting substances. This resulted in problems in the development of aquatic life, the emergence or increase in water-borne diseases, the deterioration of conditions for various leisure activities and an increase in water purification costs.

Figure 3. Evolution of Argentina's population



2. Some Notes on Urban Population

The population in Argentina's major urban centers grew far more rapidly than the country's total population. Figure 3 shows that in recent years, urban concentration has maintained a positive growth rate, with a marked decrease in the rural population.

According to information from the National Institute of Statistics and Censes, INDEC, (2011), Argentina's population data can be summarized as follows:

- Total population: 40,117,096 inhabitants (49% male)
- Annual population growth rate: 1.036%
- Birth rate: 18.6%
- Mortality rate: 7.6%
- Life expectancy: 76.8 years.

- Urban population in centers with over 2,000 inhabitants: 89.31% (48.27% male)
- Rural population in centers with fewer than 2,000 inhabitants: 3.40% (50.81% male)
- Scattered rural population: 7.28% (54.02% male)

The information from INDEC indicates that the total population estimated on July 1, 2014 was 42,669,500 inhabitants, 48.9% of whom were male, with an annual growth rate in the order of 1%.

According to the same source, Argentina's ten largest urban centers were home to a total of 21,050,797 inhabitants; that is, 52.47% (over half) of the country's total population.

As regards large urban agglomerations, there is debate surrounding the effective definition of "Greater Buenos Aires." Consequently, in 2003, INDEC proposed that the urban conglomerate be considered to comprise the city of Buenos Aires in addition to 24 surrounding districts belonging to the province of Buenos Aires.

However, the name "Greater Buenos Aires Agglomeration" has been given to a combination of the city and 30 districts in the province of Buenos Aires, which, whether totally or partially, comprise the "population belt" composing the agglomeration (INDEC, 2003). If one considers only Greater Buenos Aires and Greater La Plata, the Greater Buenos Aires "agglomeration" represents 35.85% of the total Argentinian population.

Though there is a lack of accurate information on this issue, it is clear that demographic growth in cities with the highest number of inhabitants – particularly Greater Buenos Aires – has taken place in suburban zones, generally as a result of internal migration or immigration from neighboring countries that form settlements, some of which experience severe problems of drinking water, sewerage and the risk of excess water. Figures 4 and 5 show a satellite image and a plan of the districts in the Buenos Aires agglomeration.

3. Types of Water Supply Sources

As a result of its extensive geographical distribution, seasonal and inter-annual stability and the high flexibility permitting its exploitation, groundwater is used extensively in all socio-economic sectors. Indeed, its use ranges from small household wells for the domestic requirements of families in the suburbs of Buenos Aires to the battery of 118 irrigation wells for the Valley of Tulum (Province of San Juan), capable of providing a flow of 24 m³/s, through the wells that capture the Paraná aquifer, with highly saline waters yet suitable for industrial use.

Figure 4. Buenos Aires agglomeration. Satellite Image

Figure 5. Buenos Aires agglomeration. Physical delimitation and districts. (INDEC, 2003)

Table 1 estimates the various consumptive uses of water extracted in Argentina between 1993 and 1997 (Calcagno et al., 2000).

The national average for the contribution of groundwater to the total demand coverage, of approximately 30%, does not reflect the importance of the role of these resources. Thus, in the irrigation sector, groundwater ensures multiannual regulation, which during periods of drought, such as the one that lasted from 1967 to 1972, offset the lack of surface resources.

The distribution and occurrence of the aquifer systems in Argentina's mainland territory is conditioned by the geological structure and climatic and hydrographic factors. Four broad hydrogeological regions can be distinguished (INCYTH, 1991): intermountain valleys, the Pampa Chaco plain, the Missionary tableland and Patagonian tablelands.

According to the specific bibliography (World Bank, 2000), the essential characteristic of the intermountain valley region, which includes the Andes mountain range and pre-mountain range region, is its extensive clastic sedimentary deposits that constitute aquifer systems with high permeability at the foothills and medium to low permeability in the center of valleys and at a depth. This region mainly encompasses the north east and Cuyo region (provinces of Jujuy, Salta, Tucumán, Catamarca, La Rioja, San Juan, San Luis and Mendoza), with an arid and semi-arid climate. The working of the aquifer systems is closely linked to the hydrology of the rivers, whose runoffs constitute the main natural recharge of these systems. There are aquifers that discharge into endorheic basins, such as those of Puna, the Tucuman alluvial fan and the valleys of Catamarca and Tunuyán and aquifer systems that discharge into the floodplain that tends to flow into the Atlantic Ocean, such as those in the valleys and alluvial fans of the Mendoza, Atuel, Diamante and San Juan rivers.

The La Pampa Chaco plain has aquifers in clastic sediments throughout the region. The predominant morphology is plains, ranging from undulating to depressed and high. One part is located in the coastal and Mesopotamian zone, which corresponds to the provinces of Formosa, Chaco, Corrientes, Santa Fe and Entre Ríos; the so-called central zone or Pampa Gringa comprising the provinces of Santiago del Estero, Córdoba and La Pampa, and the other contains the province of Buenos Aires and the Buenos Aires agglomeration. In a predominantly humid climate, aquifer systems, are mainly recharged by rainfall infiltration. The groundwater resources in the region are mainly derived from the extensive aquifer system called Puelches, which includes three overlapping, interlinked aquifers: Epipuelches or Pampean, Puelches and Hipopuelches or Paraná.

The Missionary Plateau Region includes the provinces of Misiones and part of that of Corrientes. The aquifers comprise low permeability basalts and the sandstones of the Misiones Formation. The latter belong to a mega-aquifer, known as the Guaraní Aquifer, with an area of 1,500,000 km², occupying part of Brazil, Paraguay, Uruguay and Argentina.

The Patagonian Tablelands Region features an arid climate, with little or no rainfall. This region stretches from Tierra del Fuego to the Colorado river, including the provinces of Neuquén, Río Negro, Chubut, Santa Cruz and Tierra del Fuego. The aquifer systems include the formation of Patagonian pebbles, basalt plateaus and above all the floodplains of the rivers that rise in the south of the Andes mountain range.

Table 1. Extraction of water, by use and source, between 1993 and 1997

Use	Surface water		Groundwater		Total	
	10^6 m³ / year	% of the total water used	10^6 m³ / year	% of the total water used	10^6 m³ / year	% of use in relation to total extracted
Irrigation	18,000	75	6,000	25	24,000	71
Livestock	1,000	34	2,000	66	3,000	9
Municipal	3,500	78	1,000	22	4,500	13
Industry	1,500	60	1,000	40	2,500	7
Total	24,000	---	10,000	---	34,000	100

Source: Calcagno *et al.*, 2000.

Figure 6. Physical and political map of the Province of Buenos Aires (INA, 2010)

In particular, the province of Buenos Aires is characterized by belonging to a vast plain occupying approximately 270,000 km² and is home to over a third of the country's population. The largest slopes are located in the Tandil and Ventana mountain ranges, which occupy around 10% of this area. Figure 6 shows a map of the province of Buenos Aires (INA, 2006).

The rest of the province mainly features very flat topography, with slopes in the order of one per thousand, just above sea level. This characteristic means that rain water has a limited ability to flow over the surface of the land, as a result of which most of this water returns to the atmosphere through evaporation and plant transpiration, while the remainder filters into the soil and recharges the aquifers. During the rainy season, the excess water feeds the aquifers, thus increasing the groundwater level. The water often rises to ground level, creating large surface lagoons characteristic of the heavy semi-permanent flooding that has affected this region on numerous occasions. The subsoil of the Province of Buenos Aires therefore contains an enormous amount of groundwater levels that can easily be exploited (Bonorino et al., 2009).

However, nowadays, the country's major urban centers are recharged by surface water resources. In particular, the large centers on the Paraná and La Plata rivers supply their riverside population through river water intakes with large-scale purification systems.

4. Drinking Water and Basic Sanitation in Argentina's Cities

80% of Argentina's population have a home connection to a drinking water network, and 53% have a home connection to a sewerage network, rising to 90% when improved sanitation systems are also included.

The 32 urban agglomerations, comprising over 70% of the national urban population, have an average drinking water coverage by network of 96% of inhabitants and sewerage coverage by network of 68% of inhabitants. The Buenos Aires agglomeration is below this average (83% and 58%, respectively).

In Argentina, the national average of water production per inhabitant served is estimated at 380 liters a day, with figures varying widely between the various provinces, from a maximum of 654 liters a day per inhabitant in the Province of San Juan to a minimum of 168 liters a day in the Province of La Pampa. Non-revenue water is one of the main efficiency problems encountered in drinking water services. It is calculated that losses in the network, sub-invoicing through clandestine connections and failure to update users' registries account for between 35% and 45% of the water produced, meaning that the average supply in Argentina is approximately 250 liters a day per inhabitant. This high level of consumption, compared to that recorded in numerous countries worldwide and in Latin America, can partly be explained by the low level of micro-measurement of consumption that prevails in Argentina's systems, particularly in the majority of services in large cities, where users are invoiced on the basis of "open faucet" tariff regimes. In this regard, based on international antecedents, the average consumption recorded by systems that operate using micro-measurement is in the order of 80 liters a day per inhabitant (PAHO, 1999).

Significant disparities across regions and provinces, and between urban and rural areas, can be observed in both drinking water and sewerage coverage. In the case of drinking water, coverage through house connections has increased by 10% in the past five years. This increase in coverage shows that other forms of supply have been replaced by house connections. In the case of sewerage service, coverage through a house connection has remained constant in recent years, suggesting that coverage has increased at the same rate as the population. On the other hand, the population without coverage has decreased in favor of types of provision other than house connections. In Argentina, the greatest environmental problem linked to water is due to the limited treatment of effluents and the heavy legacy of the lack of adequate urban planning. In the periphery of Buenos Aires, the occupation of the flood valleys of the Matanza-Riachuelo and Reconquista rivers, and of streams and tributaries, is closely linked to the pollution of the coastal strip of the Río de la Plata and part of the Paraná Delta. The factories installed in these valleys, which involve complex controls, do not usually have a history of treating these effluents. Moreover, irregular settlements (known as "villas" here) do not all have adequate services for water supply and sanitation, which contributes to pollution. The emblematic case of the Matanza-Riachuelo basin suffers from several water and environmental problems: flooding of residential and industrial areas, drains in settlements without sanitation services, garbage collection and processing with techniques that fail to comply wiht hygiene, safety and health standards, and a certain informality in industrial activities. The National Government, the Government of the City of Buenos Aires, the Province of Buenos Aires and various municipalities of the province share jurisdiction over the basin. The creation of the Matanza-Riachuelo Basin Authority (ACUMAR) has significantly facilitated the coordination of the actions of various organisms, in an attempt to reach a consensus on a single joint strategy, without which it would be impossible to reverse the urban and environmental degradation.

Another environmental water problem affecting urban zones in Argentina is groundwater pollution. In most of the country, groundwater management has been ineffective, meaning that only partial quantitative information is available to assess the current state of aquifers and the water quality trends in each of them. The responsibility for groundwater management lies with the provincial governments, which do not generally have the financial and human support to manage a resource that is much less visible than surface water.

According to INDEC, in the last trimester of 2006 (EPH–IV Trimester 2006, INDEC), coverage in the 32 urban agglomerations, whose urban population is equivalent to 70% of the national total, had average access to drinking water through a network of 96%, with sewerage coverage for 68% of its inhabitants.

Table 2 shows that the lowest coverage of drinking water service corresponds to Greater Buenos Aires (83%), since although the federal capital zone has almost total coverage, as mentioned before it includes suburban zones with a high population density and low income. Though Greater Buenos Aires has a lower figure for domestic sanitation service (58%), the lowest level is registered in the city of Córdoba (35%).

Sanitation supply in Argentina has historically been lower than drinking water coverage through a network. A comparison of the districts shows that this gap between drinking water and sanitation services has varied. It is measured using the quotient of water users per sanitation service user, whereby the highest number expresses the highest asymmetry.

Marginal urban areas experience difficulties linked to the expansion of drinking water and effluent collection and disposal services, and improving the intermittent supply and disinfection.

5. Organization of Service Provision

The current distribution of water and sewerage services in Argentina mirrors the structure of the country. Indeed, each province has the power to establish its own jurisdictional norms for the institutional organization of drinking water and sewerage. This implies that each province has its own regulatory framework, which is basically structured as a control agency and a private or state

Table 2. Urban drinking water coverage in Argentina.

Urban center	Drinking Water %	Sanitation %
Greater Buenos Aires	83	58
Córdoba	96	35
Rosario	99	61
Mendoza	96	80
La Plata	92	68

Source: INDEC-EPH IV Trimester 2006

operator responsible for the local urban services of the province. In many cases, small urban centers have small, generally public providers, and a rural structure managed by the state.

Drinking water supply installations appeared in Argentina as a preventive measure implemented by the State following the cholera epidemics that devastated the city of Buenos Aires in the late 19th century. Over the course of 75 years, from 1912 to 1980, the national government was responsible for investment and supply through the state company Obras Sanitarias de la Nación (OSN), the only body in charge of designing, constructing and operating these installations.

In 1964, a new body, SNAP (National Drinking Water Service) was created to finance and facilitate service expansion in rural areas. This marked the beginning of a series of programs financed by the Inter-American Development Bank and the economic support of the Nation and the Provinces. Moreover, the foundations was laid for the creation of 1,500 cooperatives that assumed responsibility for supplying water in small- and medium-sized villages. In 1980, the National Government decentralized the OSN's services, transferring them to their respective provinces. The assets were transferred free of debt or charges, but the new companies were obliged to find an economic formula that would enable them to finance the operating costs and investments to renovate and expand the service.

Between 1989 and 1990, the State Reform Program was characterized by a generalized transformation of the organization of public services, which involved incorporating private companies into the administration of these services, mainly in large cities, which had thitherto been operated by public companies and institutions. The organizational structure was completed by the creation of norms established in a regulatory framework, and of specialized and autonomous agencies for the regulation and control of service provision. Furthermore, at the government level, the National Body for Water Sanitation Works (ENHOSA) was created, with nationwide jurisdiction, designed to organize, manage and implement infrastructure programs derived from the national drinking water and sanitation services.

The most important concession to a private company was signed in 1993 for the metropolitan areas of Buenos Aires, with a consortium led by the French company Lyonnaise des Eaux-Suez, called Aguas Argentinas, S.A. During the period from 1991 to 2000, approximately 20 services were privatized in Argentina, including the largest cities, such as Santa Fe and Rosario (Aguas Provinciales de Santa Fe, S.A.), Córdoba (Aguas Cordobesas, S.A.), La Plata and Bahía Blanca (Azurix S.A.) and Tucumán (Aguas del Aconquija, S.A.). This model experienced its first crisis with a number of failed processes in 1997, when the contract concession in Tucumán was rescinded and subsequently in 2002, in the Province of Buenos Aires. In both cases, the state resumed responsibility for these services.

The macroeconomic crisis and the devaluation in 2002 was followed by a widespread process of renegotiating concession contracts for public services. Later on, contracts with the concessionary companies in Santa Fe (2006), the metropolitan

Table 3. Urban drinking water coverage in Argentina

Type of provider	National	Provincial	Municipal	Total
Public Company	1	8	0	9
State Company	0	3	2	5
Self-governing entity	0	1	10	11
Centralized body	0	4	377	381
Private company	0	7	10	17
Cooperative	0	0	639	639
Neighborhood association	0	0	768	768
Total	1	23	1,806	1,830

Source: ETOOS, 2003

areas of Buenos Aires (2006) and Catamarca (2008) were rescinded. As a result, the participation of private sanitation companies in Argentina fell from approximately 70% of users connected to a drinking water network in the mid-1990s to less than 30% at present. It is worth noting that this participation had only been 13% before privatization, largely due to the presence of cooperatives and neighborhood associations.

Melina Tobías (2012), having analyzed the results obtained following a decade of private service supply, observes a large disparity between the goals originally set and effectively achieved. The data available for 2001 show that Aguas Agentinas, S.A. barely contributed 19.2% of the investment agreed to (Azpiazu, 2010). The drinking water coverage goals, which were supposed to achieve 88%, only totalled 79%. As regards sanitation drainage, 63% coverage was achieved, though the objective established was 74%. The worst results linked to primary wastewater treatment as the concession contract set a goal of 74% but only attained 7% (ETOSS, 2003).

It is interesting to noate that nowadays, it is estimated that there are 1,830 drinking water service providers, of which 365 also provide basic sanitation services. Table 3 shows the classification by legal nature of the provider and the level of decision or jurisdiction.

6. Water and Sanitation Service in Greater Buenos Aires

For various reasons, there has been a delay in the implementation of important expansion and infrastructure works, and the achievement of coverage levels in the concession area. In response to this situation, the management of the state company AySA, with the support of the national government, proposed to design and implement a Master Plan to reduce the deficit and achieve the objective of universalizing services, thereby complying with Millennium Development Goals set by the United Nations (UN).

The main actions of the plan involve developing basic infrastructure, expanding existing installations and renovating and rehabilitating networks. The central works to supply drinking water are the construction of the "Paraná de las Palmas" water purification plant, with an investment of over 17 millions Argentinian pesos, to serve two million persons in the Tigre district and lasting until 2020; and the creation of the "Virrey del Pino" inverse osmosis plant in the La Matanza district, which has a high density of low-income inhabitants. As regards sewage systems, the AySA plan is considering creating a new effluent removal plant in the Berazategui district, to significantly improve the quality of the water supplied to the city of Buenos Aires and its conurbation.

To extend the sewage network, AySA plans to modify the current distribution of the network, by building a large underground collector that will run parallel to the left bank of the Riachuelo and intercept a large part of the effluents currently received by the Berazategui basin through the main sewers. This work is essential to increasing coverage levels in the southern metropolitan area of Buenos Aires, as the new collector will relieve the flows of the Berazategui basin, whose capacity is currently saturated, thus giving it a greater capacity to receive new effluents from the zones to be incorporated into the network (AySA, 2010, "User Report").

While the region with the highest income per capita and the greatest urban consolidation has full service coverage, the districts of Greater Buenos Aires have levels far below those of the capital city (Merlinsky et al., 2011).

These large infrastructure works promoted by AySA are designed to solve the problem of coverage in the medium and long term. However, the critical sanitary situation of certain regions in the Greater Buenos Aires area, compounded by the negative effects of poverty on inhabitants' living conditions, made it necessary for the company to undertake local actions to expand water and sewerage services in low-income neighborhoods.

To this end, AySA employed two strategies: the Participative Management Model and the so-called "Water+Work" plan and "Sewage+Work" plan, designed to increase the interaction of the company, as the main source of financing, with neighbors - who provided labor - and the municipality - responsible for providing certain material inputs and the technical management of the works. In the case of these plans, the following players are involved: the AySA company, responsible for designing the project and the financing and technical supervision of the works; neighborhood cooperatives, which provide the labor for undertaking the works; the municipalities, the players directing the projects and the entities implementing the works, other state organizations such as the Institute of Third-Sector Activities and Social Economy (INAES), which provides technical and legal assistance for the creation of the cooperatives and organizations such as the Greater Buenos Aires Union of Sanitation Worker (SGBATOS), which provides training for cooperative members (AySA, 2011).

Six years after the state began to manage service provision, drinking water coverage within the concession area has benefits 8,1 million inhabitants, while 5,7 million persons have sewerage service (AySA, 2010). According to data provided by the company, in late 2010 a total of 1,021,825 inhabitants were beneficiaries of the "Water+Work" and "Sewerage+Work" plans, with the former accounting for over 90%.

At the same time, during the first five-year revision of tariffs, in 2001, the concept of social tariff was introduced, with a fund of 4 million Argentinian pesos a year being established for its financing. This was made possible by a subsidy contributed by all the users of the concession, for the low-income residentail users who were not able to pay their bills (Lentini, 2007).

7. Wastewater and Reuse

A first approximation of the volume of municipal wastewater discharged into the sewerage networks can be made, given that according to the National Population, Household and Housing Census of 2010 Argentina had a population of 40,117,096 inhabitants, 48,8% of private homes had a sewage drain, there were 11,317,507 private homes, 12,171,675 households, an average of 3,3 inhabitants per household, and 12,2% of households shared housing (INDEC, 2012). Consequently, applying an average supply for the country of 0,3 m^3/(inhabitants.day) and a reduction factor of 0,8 (80% of the water supplied and used is discharged into the sewerage network), the volume of wastewater discharged into the sewerage network can be estimated at approximately 1.596 x 10^6 m^3/year.

Information from the early 21st century indicates that only 10% of the total volume of domestic effluent collected in the sewerage drain systems was treated by a purification system (Calcagno *et al*., 2000). The country's main obstacles to treating wastewater were the priorities established for the sector and the economic and financial resources available, particularly in view of the commitments made by Argentina when it signed the Millennium Development Goals (MDGs) in 2000.

Thus, the MDG regulation 8, "Ensure a sustainable environment" set the following global objectives, among others:

- Reduce the proportion of the population without access to drinking water between 1990 and 2015 by two thirds.
- Reduce the proportion of the population without access to sewerage drains between 1990 and 2015.

In this respect, between 2000 and 2009 Argentina almost tripled social investment in the area of "drinking water and sewerage", which rose from 0,9% of the total in 2000 to 2,3% in 2009 (MDG Argentina, 2010).

As for the destination of the wastewater, including agricultural reuse, the country still lacks regulations establishing the minimum budgets applicable in all jurisdictions. In this regard, the National Congress is studying several projects, but has yet to achieve the consensus required for their approval. One of these is the draft National Law for the Reuse of Wastewater (Sartor *et al*., 2012).

The province of Mendoza has specific regulations for agricultural reuse of treated waste liquids (DGI, 2003). Several municipalities are advancing in the regulation of the reuse of liquid waste treated for specific purposes, including Puerto Madryn, in the Patagonian province of Chubut, through Ordinance N° 6.301/2006, "Reuse of treated sewerage effluents" (municipality of Puerto Madryn, 2006a) and Appendix I of the Regulation (Municipality of Puerto Madryn, 2006b).

It is important to note that specific regulations are not yet in place for the quality control of the products irrigated with wastewater. The implementation of the Strategic Agro-Food Plan by the Under-Secretariat of Water Resources (PEA2 SsRH) will promote the adoption of tools to improve the use of water, including its reuse, for food production.

According to the 2002 National Agricultural Census (INDEC, 2002), the total are used for agricultural purposes in Argentina was 33,491,480 hectares (approximately 19% of the total are), of which only 1,355,601 hectares were effectively irrigated (approximately 4% of the total). Mendoza is the province with the largest irrigated area (267,889 hectares), which equivalent to approximately 19.8% of the total irrigated area in Argentina.

The main treatment plants in the province of Mendoza are those of Campo Espejo and El Paramillo. They process almost 80% of the domestic liquid waste treated in the province. Both use systems with stabilization ponds. The Campo Espejo purification plant treats approximately 140,000 m^3/day (1.7 m^3/s), which are used to irrigate approximately 2,000 hectares through direct reuse (Fasciolo *et al*., 1998), and which eventually indirectly irrigate over 10,000 hectares through the Jocoli canal (Barbeito Anzorena, 2001). The El Paramillo purification plant treats approximately 91,000 m^3/day (1 m^3/s), which are used to irrigate around 1,800 hectares in summer (Álvarez et al., 2008).

According to the information available (Fasciolo et al., 1998; Barbeito Anzorena, 2001; Álvarez et al., 2008) and the total surface irrigated in the province of Mendoza (INDEC, 2007), less than 2% of this surface is irrigated through the direct reuse of treated wastewater.

Chapter 12 of Resolution N° 400/2003 of the General Irrigation Department of the Province of Mendoza specifies the irrigation methods permitted by the Special Restricted Cultivation Area Regulations (ACRE): seedbeds without a slope, furrows without sewers at the base, subsurface irrigation and localized irrigation, and expressly prohibits irrigation by sprinkler, pivot or similar methods that project effluent into the atmosphere.

8. Urban Impact due to the Rise of Groundwater

Numerous towns in the metropolitan area of Buenos Aires have experienced the progressive rise of water tables, and have discussed the origins of the phenomenon, the individual relevance of its causes and emerging responsibilities. Moreover, the water that emerges has serious quality problems. In short, the uncontrolled rise of water has caused the following problems: the flooding of basements even in zones on high ground, foundation problems in various types of structure, upwelling of water in low zones with flooded land, slump of blind wells, polluted water in contact with the population, destruction of pavements, in short, a serious decline in the quality of life (Bianchi and Lopardo, 2003).

According to certain preliminary explanations, the phenomenon could result from an increase in rainfall and climate factors. Others say that it is caused by anthropic actions such as the lack of sewers in the affected zones, the importation of water through drinking water pipelines from sources outside the basin, the sharp decrease in water supply through domestic wells, the elimination of the provision of industrial water through local wells and the systematic retraction of the public supply of drinking water from underground sources.

A specific study has been carried out in a region in a “water emergency” state in the Lomas de Zamora district in the southern zone of Greater Buenos Aires, with an area of approximately 88 km² and a high population density, which rose from 574,330 in 1991 to 627,806 in 2003. Lomas de Zamora is located in a low region of the basin of the Matanza river, which is very inefficient in comparison with the natural drainage network into the Matanza-Riachuelo system, and makes the district more vulnerable than medium and large areas in regions in the Buenos Aires metropolitan area.

Since high population growth has not been accompanied by a rise in basic sanitation infrastructure, anthropic causes also interfere negatively with natural ones, such as the increase in rainfall. In 1991, the drinking water network served 69.9% of the population of the Lomas de Zamora district, while the sewerage network covered only 22.7%. The drinking water network currently supplies 90%, but uses surface water, imported through large-sized pipes from treatment plants in Río de la Plata. On the other hand, the sewerage network has been omitted from the concession's work plan, remaining in a service that only serves 33% of the district's population. Other anthropic factors specific to the district must be taken into consideration, such as deforestation, the dismantling of the industrial belt (which requires much less pumped water) and the aforementioned change in the drinking water supply source, which has a double impact. Indeed, when pumping from the aquifer ceases the pressures on it increase, and when water is incorporated into the region without associated sewage and rainwater drainage works, more water is absorbed into the ground.

Exploitation of the "Puelches" aquifer began in 1920. The expansion of its use for public and industrial supply caused an extraction rate far above its natural recharge, and produced cones of depression that reached apices of -35 m and -40 m in 1975 (Santa Cruz, 2000). The area with the highest exploitation of the aquifer was the one with the thickest aquifer. The most significant development of the cones of depression took place in the south east of the district, where the public supply wells were located, and in the south zone, the most industrially developed area. This overexploitation of the aquifer and the decline in quality (due to an increase in nitrate concentration), led to the progressive abandonment of the supply of groundwater for domestic use. When this supply service was abandoned, the number of active wells fell from 114 in 1990 to just 13 in 2001. Moreover, industries drastically reduced their extractions due to the economic crisis of that era, causing a recovery of the piezometric levels, and a change in the size and location of the cones.

The decrease or suspension of domestic primarily affected the north-east zone. In this zone, in the period from 1991 to 1995, pumping was 16.1 Hm^3 and in the period from 1996 to 2000, pumping had dropped to 7.5 Hm^3, equivalent to only 34% of the volumes obtained through anthropic means. This decrease in discharge capacity was a result of the change in supply source. In short, the variations in the phreatic level had different causes and degrees of affectation, according to their geographical location. Moreover, by associating the behavior of the phreatic level with these locations, various patterns of functioning were distinguished according to the topographic characteristics, degree of urbanization, deactivation of perforations (for both drinking water and industry), water imports, and the development and age of the drinking water, sewage and rainwater networks. These characteristics gave rise to a new concept, making it possible to manage the treatment of the problem, defined as "homogenous zones" (Bianchi et al., 2005). This determined the areas or zones in which the vertical movements (recharge or discharge) of the phreatic surface are produced from the predominance of a specific factor, whether natural or anthropic. It is thought that due to the low slopes of the metropolitan area, vertical movements prevailed over horizontal ones.

This experience demonstrated the need for in-depth studies on the natural and anthropic influence before making changes in the supply sources of drinking water in zones with incomplete sanitation.

9. Problems Associated with Surplus Water in Major Urban Centers

Undoubtedly, the main challenge faced by Argentina as regards water is to provide the entire population with integral drinking water and sanitation coverage, principally in the urban center of Buenos Aires and its conurbation. However, this urban conglomerate presents another equally significant obstacle linked to excess water management.

The numerous recent floods in various cities in the metropolitan area in particular, as well as the province of Buenos Aires have highlighted a challenge as significant as drinking water management and distribution. This challenge is linked to the capacity to conduct an integral analysis of the causes, effects and solutions associated with growing urban development, whereby the essence of the problem is the unplanned occupation of the flood valleys of rivers and streams.

Structural Vulnerability of Urban Centers

This progressive advance of the urban area provides the backdrop to a structural vulnerability that even the construction of large sanitation works has failed to eliminate.

Indeed, although for years the natural features of typical fluvial systems have coexisted with the uses and customs of the population, the pursuit of progress in the late 19th century and early 20th centuries fostered the rapid advance of urbanization on waterways, which resulted in the creation of piping or specific interventions on the original waterways, which attempted to conceal the natural traits of the system in order to develop neighborhoods, infrastructure and services. The dilemma of the occupation of land close to river courses (typically flood plains) has been a known fact since ancient times. The presence of a nearby waterway provides benefits for the development of a population, despite the damage floods are known to cause (Aradas and Bacchiega, 2012).

A clear example of this indiscriminate advance is given in Figure 7, which shows the gradual expansion of the metropolitan area of the city of Buenos Aires from 1750 to the present. It shows how waterways were progressively occupied by the urban infrastructure that invaded not only the flood valley, but also led to the occupation though piping of the courses themselves.

This uncontrolled growth has been identified in most of Argentina's riverside cities, where catastrophic floods have occurred at least once in the past 50 years. Example of this include Buenos Aires itself, La Plata, Villa Elisa, Luján, San Antonio de Areco, Arrecifes, Pergamino and Santa Fe, all of which have populations of between 30,000 and 3 million inhabitants.

The Influence of Climatic Variability

Beyond the structural vulnerability to flooding of many of Argentina's urban centers, complementary aspects exist that become parallel causes to the increase in recorded cases of urban flooding. Climatic variability and the main meteorological parameters' tendency to change are undoubtedly aspects to be considered.

Changes in average global temperatures can be a leading cause of the increasing rainfall observed in many regions of the world. In this context, records indicate that in the past 150 years the average temperature of the earth's surface has increased, and that the global temperature has risen by 0.74°C over the past 100 years and around 0.4°C in the past 25 years, the period with the most reliable observations (Camillón, AABA, 2010).

Figure 7. Evolution of the urban area of Buenos Aires

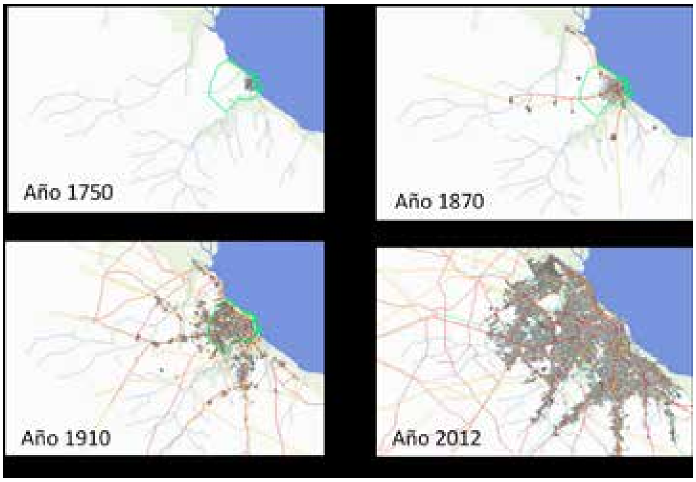
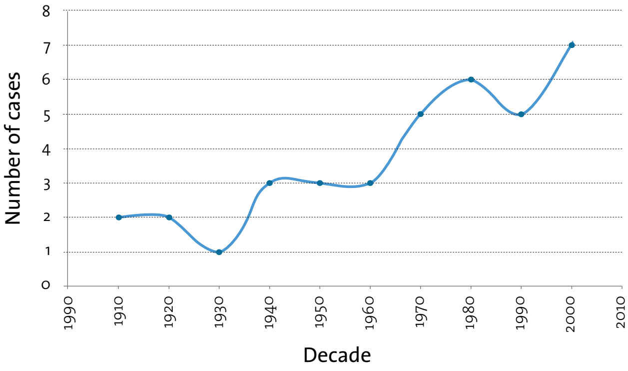


Figure 8. Number of cases per decade with rainfall of over 100 mm/day



Together with the variation in the temperature recorded globally, in Argentina in general and Greater Buenos Aires in particular, annual and daily rainfall have increased considerably. Figure 8 shows the increase in cases in various decades in which rainfall above 100 mm in a single day was recorded. This number has almost doubled in the past 50 years.

Likewise, changes in other variables linked to climatic variability have been recorded. Río de la Plata is experiencing an increase of its average level (Figure 9), driven mainly by the increase in the average sea level. The total increase was approximately 17 cm in the 20th century, of which approximately 50% took place in the past three decades (Barros and Menéndez, 2005).

In this context of climate change and vulnerability, floods have taken place in major Argentinian cities driven by varying amounts of rainfall. Table 4 and Figures 10a and 10b show some of the cities affected by severe flooding in recent years, within a radius of approximately 500 km around the city of Buenos Aires.

Each of the storms reported were analyzed separately, as extraordinary events with return periods of above 500 to 1,000 years. However, past records demonstrate that there has been at least one increase in the frequency of occurrence over the past 20 years. Some of the urban centers indicated have suffered more than one catastrophic flood during this period, while in others, such as the city of La Plata, several events have been recorded in a short period, such as those of Buenos Aires and the nearby town of Villa Elisa.

The aforementioned situation is a background to the concept of extreme and extraordinary events mentioned every time a catastrophic event takes place. Likewise, it is important to determine the level of vulnerability of each urban center in the face of rainfall events that, though considerable, are not beyond the probability of occurrence in each city.

Figure 9. Variation in the average level of Río de la Plata (Barros et al., 2005)

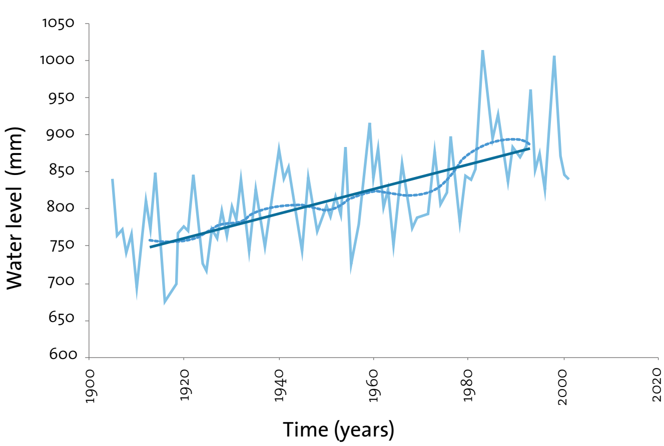


Table 4. Cities close to Buenos Aires with severe flooding

City	Precipitation (mm)	Year of Occurrence
Buenos Aires	100-200	1984-1995-2000 2001-2010-2013
Pergamino	200-436	1995-2009-2011
Santa Fe	400-500	2003-2007
S.A de Areco	250	2009-2011
Villa Elisa	240	2008
La Plata	390	2013

Source: ETOOS, 2003

Flooding in Major Urban Centers

The cities mentioned in which flooding was recorded have heterogeneous populations, which range between 30,000 and 3 million persons, and

Figure 10a. Cities affected by flooding

Figure 10b. Flooding in urban centers in the Pampa region (Bacchiega, 2012)

sizes. However, their common denominator is that they are located in flood valleys of natural channels, making them intrinsically vulnerable.

A common factor of all these centers, particularly the cities of Buenos Aires and La Plata, recently affected by catastrophic events, is their progressive development alongside various natural water ways. These urban development schemes are repeated in all the cases in which water logging processes have been recorded in recent years, meaning that images like those below are the inevitable consequence of the relative location of the cities, regardless of the amount of rainfall they may receive.

It can therefore be argued that in the majority of cases, the likelihood of floods reflects cities' basic vulnerability and the struggle between urban development and the natural geological courses of the natural sewage network. Buenos Aires is a clear example of this combination of effects, since over the decades it has grown in 11 basins that originally drained their surplus into natural riverbeds that are now piped and heavily urbanized. Figure 11 below shows the main hydrographic basins in the urban area of the city of Buenos Aires.

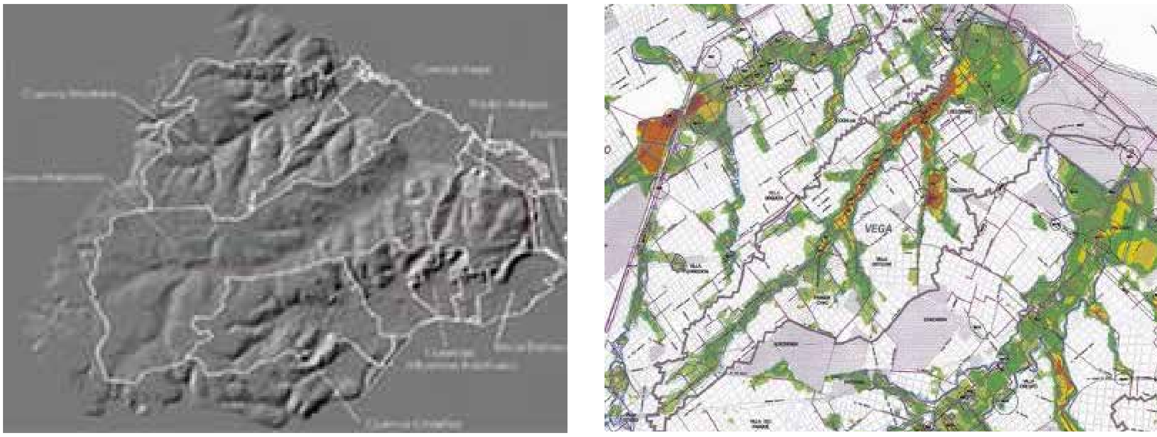
Of the basins indicated, those of Medrano, Vega and Maldonado streams are the most vulnerable as a result of the population density and urban infrastructure. The risk areas and the extent of the floods recorded reflect natural geomorphological characteristics.

The following figure shows the geomorphological formation of the city of Buenos Aires and the corresponding zones of greatest risk, based on the risk maps drawn in the Water Management Plan of the City of Buenos Aires (Consortium of Consultants, 2004).

These water logging and flooding processes have produced severe economic, social and environmental problems. Though these issues have been addressed for years by analyzing causes and solutions, the economic quantification of their effects has been limited.

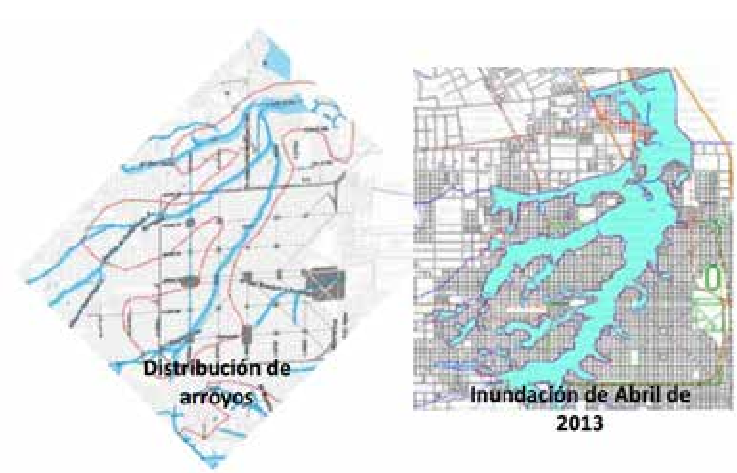
Figure 11. The city of Buenos Aires. Hydrographic Basins (GCBA, 2013)

Figure 12. The city of Buenos Aires: Geomorphological characteristics and risk areas Medrano, Vega and Maldonado Basins



In the indiscriminate occupation of land and the modification of the flow pattern in water basins and the absorption of water from rainfall, the rainfall, hydrology and topography (with land above sea level that varies between approximately 4 and 24 m) were not taken into account. Social and economic aspects are frequently exacerbated by the pollution of the water flowing in from the districts in the province of Buenos Aires, which comprises large industrial areas. This pollution mainly comprises the flow of agrochemicals used in agriculture and liquid effluents from industrial establishments, and the degradation of the coasts and the water of the Río de la Plata. The total negative impacts have not yet been studied in depth.

Figure 13. City of La Plata. Flooding in 2013



One issue common to other urban centers as well as Buenos Aires is that the areas with the highest frequency of flooding are generally those with the highest poverty levels. This increases the vulnerability of the lowest-income sectors.

The city of La Plata, the capital of the province of Buenos Aires, is very similar to Buenos Aires. Located 60 km to the south of the capital, it was planned before its founding in 1882. It was built directly on the flood valleys of three streams whose geomorphology was responsible for the severe flooding recorded in April 2013.

Figure 13 shows the location of the Gato stream and the extent of the flood recorded, following its geomorphological pattern (Aradas and Bacchiega, 2013).

This flood affected over 2,500 inhabitants, and principally struck the valleys of the natural waterways, regardless of the distribution of roads, avenues and rain pipes.

As in Buenos Aires, the most socially vulnerable zones of the city of La Plata are the most severely affected, as the streams' conduction capacity is significantly limited by the progressive occupation of their banks.

Figures 14 and 15 below show the discharge zone of the Gato Stream and the vulnerable zones of the Maldonado Stream.

3 million inhabitants live in the 60 km stretch that separates Buenos Aires, in floodable zones that have not been waterlogged.

Figure 14. Structural vulnerability in the discharge of the Gato Stream – La Plata

Figure 15. Structural vulnerability in the discharge of the Maldonado Stream – La Plata

Figure 16 shows the existing water basins between the cities of Buenos Aires and La Plata, where a dense urban structure has developed, with high levels of vulnerability. If any of these had been affected by events such as those that occurred in the cities of Buenos Aires or La Plata in 2013, there would have been even more catastrophic consequences. Studies undertaken by the National Water Institute (2014) established the maximum extent of the floods that would have taken place in these basins, had there been 390 mm of rainfall, similar to that observed in La Plata. The figure below displays the highest-risk zones in the basins of the Sarandí, Santo Domingo and Jiménez rivers.

In response to these issues affecting many of Argentina's cities, the traditional procedure of imposing conduction and retention works as the only solution should be replaced by new management and planning methods that include aspects linked to flood vulnerability, water risk and structural and non-structural action measures, to produce clear guidelines for an integrated management that understand that floods affect society as a whole (Aradas and Bacchiega, 2012).

Thus, the aforementioned intrinsic vulnerability of urban centers must be considered in the protection schemes implemented, risk analysis and therefore the rules for decision-making and defining integral analysis schemes that comprise an adequate combination of structural and non-structural measures. This aspect, which is difficult to implement in most cases, is the greatest obstacle to reducing risks associated with urban water surplus.

The Challenge of Integral Water Risk Management in Argentina's Urban Centers

The structural vulnerability faced by urban centers is the result of the relative position of the infrastructure with regard to the flood valleys of natural waterways that existed before the urbanization process. However, other environmental, socioeconomic and political circumstances combine with this natural condition to determine the population's flood vulnerability. These elements, in addition to the unpredictable rainfalls and high water levels that cause the problem, make it necessary to design the cities' protection levels though an integral risk analysis that links all the elements involved and determines the efficiency of various possible concrete actions.

Figure 16. Water Basins of the South Agglomeration of Buenos Aires

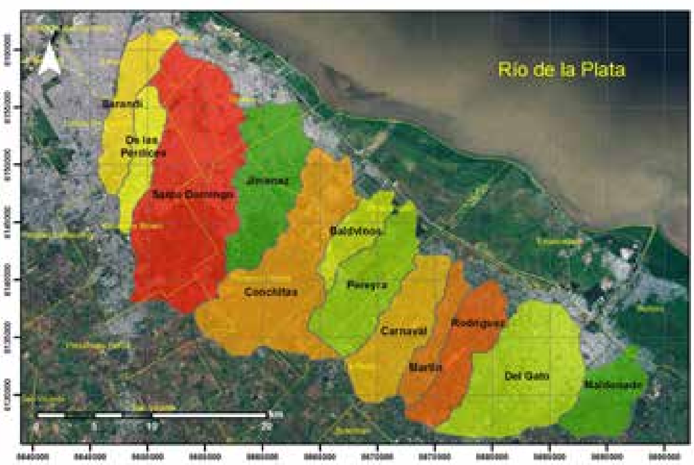
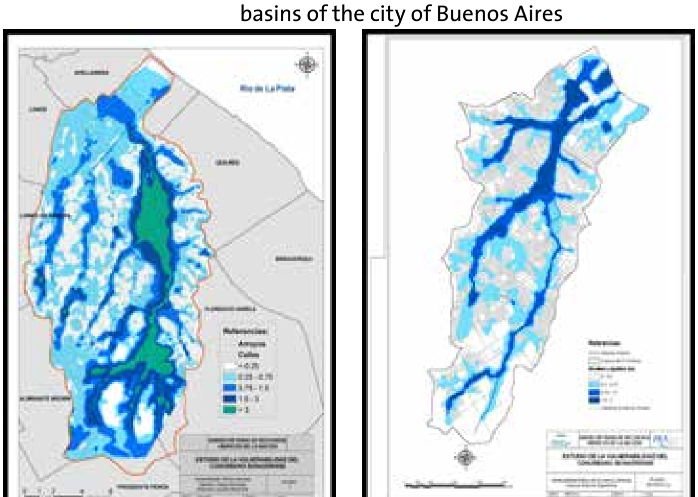


Figure 17. Extent of floods in the southern basins of the city of Buenos Aires



Basin of the Sarandí – Santo Domingo Streams Basin of the Jiménez Stream

The floods recorded in the majority of Argentina's riverside urban centers, and the resulting economic and human losses, highlight the need to address this problem comprehensively, giving water surpluses the same level of urgency as droughts.

Flood risk management proposes to mitigate flood risks to an acceptable or tolerable level, either by reducing the frequency of the flooding or its consequences, by decreasing exposure and/or vulnerability. In most cases, flood risk can be mitigated but rarely eliminated.

The aforementioned previous cases, particularly the city of Buenos Aires, have common factors in terms of protection levels before the flood and the measured reactions taken after the event.

- In all cases, the adaptation levels of water infrastructure were not completely implemented.
- Structural solutions that are projected and not always implemented with the planned degrees of protection, with rarely exceed five years of design recurrence, with the exception of the city of Buenos Aires, whose works were intended to be implemented within ten years.
- Low risk perception by the population living in the zones susceptible to flooding.
- Low or no implementation of non-structural measures.
- Low protection levels in actions during the emergency.
- Unplanned and non-contextualized structural actions after the emergency.

These characteristics of the solutions adopted until the present, with the exception of the Water Management Plan developed in the city of Buenos Aires, should help to design an integral approach to the problem of flooding that explicitly recognizes that human settlements and draining influence each other mutually, while acknowledging the fact that even works built with the highest protection level do not substantially change the structural vulnerability of urban centers liable to flooding.

Figure 18. Construction of relief tunnels in the city of Buenos Aires

One example is this is the basin of the Maldonado Stream in the city of Buenos Aires, where two relief tunnels were recently built, with a diameter of 6.90 m and a length of 5 km, under the existing piping. These tunnels were built over 20 m below the surface of the city, and interconnected with the current piping. The high investment cost of this work is justified, to minimize the consequences of flooding caused by storms that recur every ten years. In this context, though the work has been finished, the effects of normal floods have been mitigated, but the intrinsic social and urban vulnerability has not changed, and will continue to exist for more frequent storms.

Based on the previous example, it can be argued that for many years classic project assessment made it possible to strike a balance between the statistical models to estimate the recurrence of extreme events and the technical economic analysis of mitigation works (structural measures), often required to support the financing feasibility of the associated investment amounts. This resulted in works with a recurrence rarely above 20 years. Nonetheless, this analysis model became more complex in response to the more recurrent extreme events and the challenge of achieving a balance between a more economic model and a more social model that would drive an increase in protection standards.

The decision pattern must obviously prioritize non-structural measures over structural ones, without this minimizing their positive effects on the broad range of recurrence of intense events. It is therefore sensible to consider these recommendations in the future development of action plans in centers susceptible to flooding in Argentina (Aradas and Bacchiega, 2013).

- Develop integral plans at the basin level where they do not already exist and then follow up on their implementation.
- Consider risk areas, by integrating areas of natural supply that view the basin as a minimum unit and the integration of regions, beyond jurisdictional or political divisions. Consider the formation of basin committees such as technical comptroller, analysis and supervision bodies for integral problems.
- Encourage the authorities to increase awareness of the risk of flooding, principally among the population at risk, by establishing the concept of structural vulnerability as a guiding principle for structural and non-structural solutions.
- Plan land use, giving the appropriate importance to the "security" provided by the works
- Design and check intervention strategies for a broad spectrum of events, to explicitly recognize the uncertainty inherent in meteorological processes.
- Consider existing antecedents in homogenous regions as antecedents characteristic of each urban center, in order to plan mitigation actions jointly.
- Adopt a criteria of "zero" additional runoff for all new urban developments, to preserve the existing infrastructure standard. That is, each new development must absorb and internally manage the excess runoff it causes.
- Implement meteorological records that allow correct interpretation of the temporal and spatial characteristics of the storms.
- Regularly review the measures proposed in the master plans to adapt to the evolution of the problem and the situation of the basin.
- Attempt to make the geomorphological traits of the sewerage system more visible.

10. Conclusions

The main challenge faced by Argentina for drinking water and sanitation is the universalization of these services. It is essential to supply millions of inhabitants currently lacking drinking water and sewerage services. Moreover, it is crucial that works be implemented to increase the treatment of waste water and raise awareness within the government and among professionals, technicians and all sectors of the population regarding the rational use of water and the protection of its quality.

This raises the following challenges: a) Designing and implementing socially and economically sustainable investment plans that prioritize the universalization of services and, where necessary, ensuring their financing by assigning the necessary funds in public bodies' budgets; b) improving the economic sustainability of the supply and achieving an improved rationalization of the tariff regime; c) increasing the efficiency levels of the management of operators and the efficient coordination between sector and jurisdictions; d) perfecting the information system for management and results; and e) promoting the participation of civil society and local authorities. To this end, the following actions are proposed:

- Foster and prioritize investment in the sector, taking into account the benefits resulting from their impact on public health, the environment and the general economy, the reduction of destitution and poverty and social cohesion.
- Establish explicit incentive mechanisms for the efficient management of operating companies and the rational use of services. Tariff regimes should comprise incentives to rationalize water use and supply, which could be achieved by significantly increasing the micro-measurement of the amounts consumed by users, and through investment to reduce losses in water networks.
- Strengthen regulation and control functions for service provision, to ensure the technical capacity and independence of action of the organizations responsible for these actions.
- Improve the legal and institutional mechanisms relating to the participation of civil society and local authorities, and enhance the dissemination and communication of information on the performance of control operators and authorities, and, primarily in elementary and high schools, foster education actions on the issues associated with drinking water and sanitation and their importance in preserving public health and the environment.

In addition to the problems existing in the water and sanitation sector, Argentina faces significant challenges for the handling, control and management of surplus water in urban centers. The intense rainfall recorded in nearby areas, with periods of occurrence below 20 years proves that large floods are not uncommon problems. Moreover, the increasing urban progress towards rivers' and streams' flood valleys has increased vulnerability in the majority of riverside cities.

The city of Buenos Aires and other nearby cities experience severe problems in managing water surplus linked to urban growth. Numerous floods have been recorded in the past 30 years, with significant economic and human losses. As an example of the path to follow, the city of Buenos Aires has implemented a successful Water Management Plan, which made it possible to establish the principal causes and consequences of flooding processes, and set guidelines for conduction works that mitigate the effects of frequent flooding. However, these engineering works, with the application of advanced technologies, do not ensure total protection from future floods.

This is why the greatest challenge in surplus management is the integral analysis of the problem, with a proper balance of structural and non-structural measures. This is crucial in the agglomeration of Buenos Aires, home to over 10 million inhabitants, the majority of whom are unaware of the risk posed by future flooding.

In response to this problem, it is recommended that priority be given to structural and non-structural actions to mitigate the effects of excess water in densely populated urban ones, the rise in water tables and disasters caused by heavy rain.

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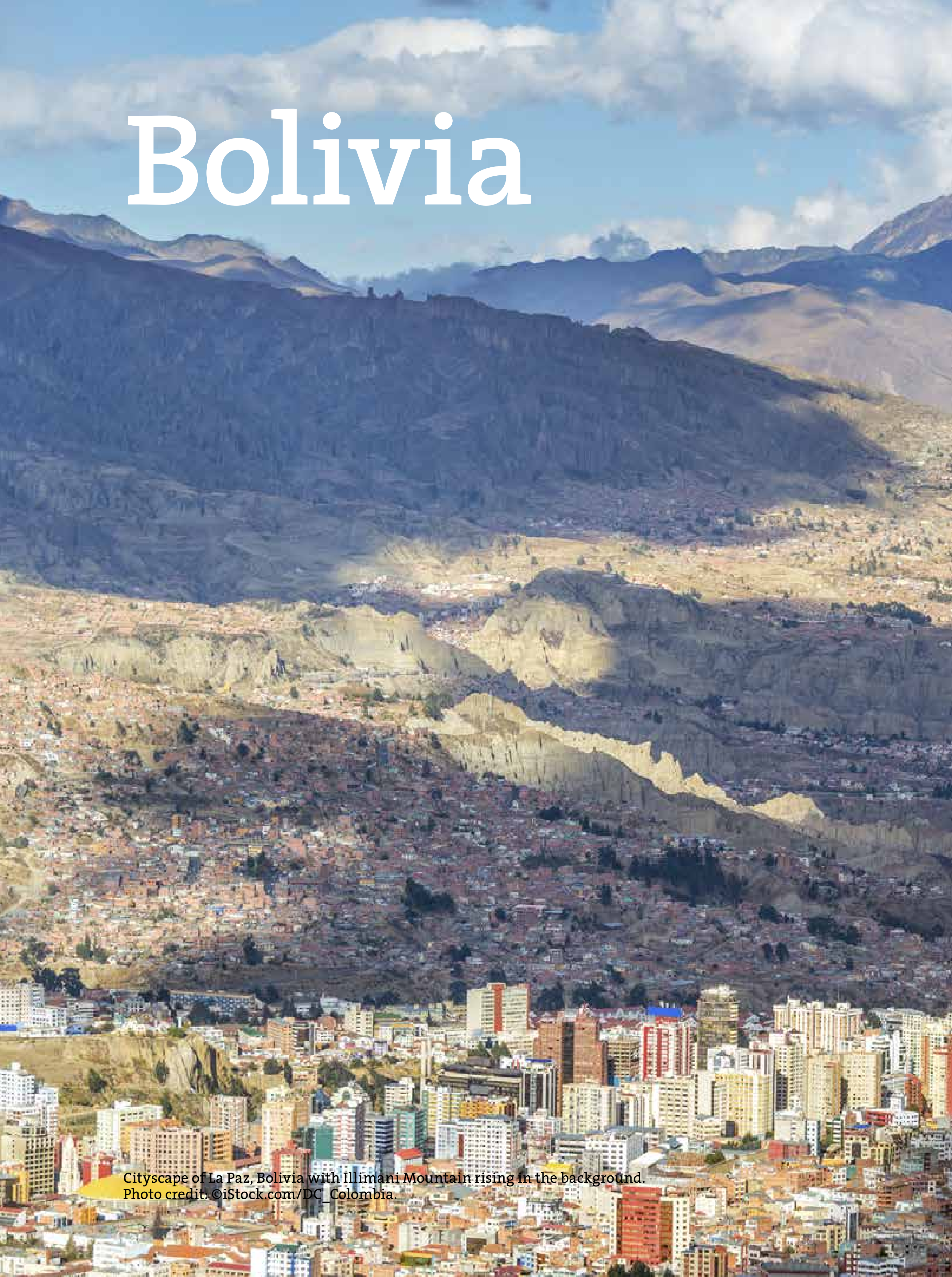
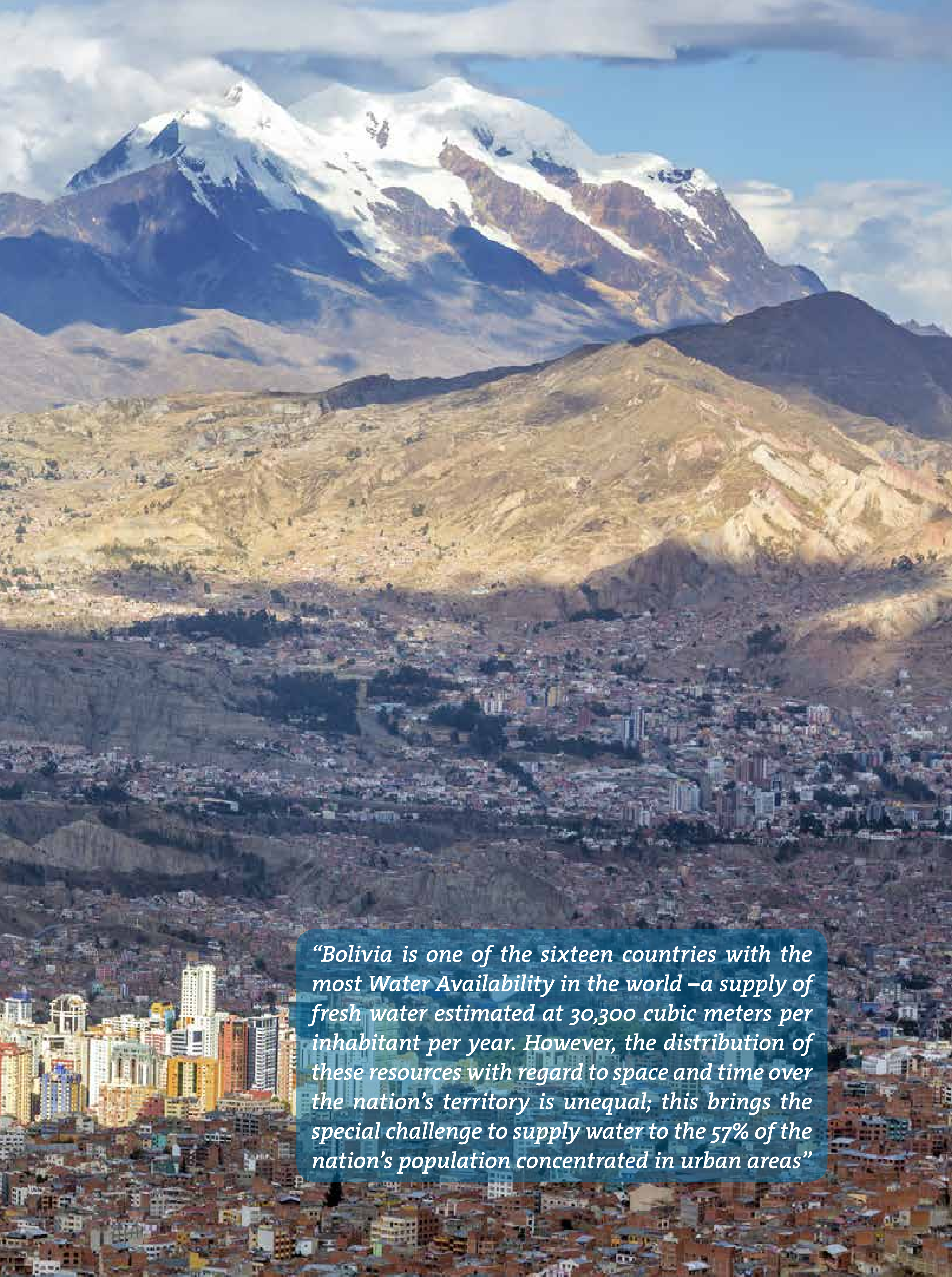
Bolivia



Cityscape of La Paz, Bolivia with Illimani Mountain rising in the background.
Photo credit: ©iStock.com/DC_Colombia.



“Bolivia is one of the sixteen countries with the most Water Availability in the world –a supply of fresh water estimated at 30,300 cubic meters per inhabitant per year. However, the distribution of these resources with regard to space and time over the nation’s territory is unequal; this brings the special challenge to supply water to the 57% of the nation’s population concentrated in urban areas”

Compendium of the Water Resources in the Capital Cities of the Departments of Bolivia

Fernando Urquidi-Barrau

Summary

This study presents a compendium of the current use of water resources in Bolivia, with emphasis on the administration of the water cycle in the capital cities of the country's nine departments. It has been prepared for the Water Program of the Interamerican Network of the Academy of Science (IANAS) and contains some conclusions and recommendations for the Bolivian governmental authorities who regulate and administer water in the country. Since the National Population and Housing Census for 2012 (CNPV, 2012), carried out by the National Institute of Statistics (INE) has not yet been completely published, a combination has been used with the data from the prior CNPV, for 2001.

1. Introduction

The Plurinational State of Bolivia is politically divided into nine departments, with their respective capitals (See Figure 1.1). They are La Paz, Oruro, Potosí, Cochabamba, Chuquisaca, Tarija, Pando, Beni and Santa Cruz. In these departments there are 112 provinces, with 339 autonomous municipal governments.

The 2012 CNPV shows the total population of Bolivia, 10,027,254 inhabitants and a relative growth, between the 2001 CNPV and the 2012 CNPV, of 21.18, with an average annual growth of 1.71%. It also demonstrates that 71.1% of the population is concentrated in the La Paz, Santa Cruz and Cochabamba.

The 2012 CNVP also indicated that 57% of the nation's population live in urban areas and 42.5% live in the rural part of the country. inhabitants, departments of .

The Urban Metropolitan area of La Paz, comprising the cities of La Paz and El Alto, together with the cities of Santa Cruz de la Sierra Cochabamba, contains 60.2% of the urban population.

Table 1.1 shows the nine capitals and the city of El Alto (the Metropolitan Area of La Paz), and the volumes of water distributed in them. The city of Santa Cruz de la Sierra (14.5% of the national population), the City of La Paz (7.8%) and the city of El Alto (8.5%) presently have no major water supply problems. The supply of water to the capital cities of Cochabamba (6.3% of the nation's population), Oruro (2.64%), Sucre (2.59%), Tarija (2.0) and Potosí (1.89%) still show certain deficiencies. The supply of water to the capital cities of Trinidad (1.06%) and Cobija (0.4%) suffer severe shortages and severe weather impacts on their sources and distribution networks since their ductwork is obsolete, compromising the quality and quantity of water distributed to the population, even evidencing a limited water supply and daily rationing. It must be mentioned that all the Bolivian department capitals have problems of different degrees with their drainage and sanitary sewage system(for both domestic wastewater and rainwater).

Figure 1.1 Map of the Plurinational State of Bolivia and its Capital Cities

The 2001 CNPV found that 37.7% of the inhabited dwellings in the country do not have piped-in water. The 2012 CNPV shows that this percentage dropped slightly, to 33.9%, thus persisting as a common national problem requiring solution.

Table 1.1 Department Capital Cities

City	Number of Inhabitants[2]	Urban Radius Area (Km²)	Number of Dwellings[3]	Volume of Water (liters/ day)
La Paz /El Alto[1]	1,613,457	592	370,574	187,129,000
Santa Cruz	1,453,549	567	252,136	172,800,000
Cochabamba	630,587	108	123,477	73,785,000
Oruro	264,638	28.5	49,436	27,000,000
Sucre	259,388	33.9	49,979	25,435,000
Tarija	205,349	42	36,126	35,037,000
Potosí	189,652	31	35,182	18,064,000
Trinidad	106,422	23.5	15,588	10,500,000
Cobija	46,267	19.5	4,923	2,130,000
Total for all Cities	4,769,309	1,445.4	937,421	551,880,000
Total Bolivia	**10,027,254**	**1,098,581**	**1,977,665**	----

Notes: 1 La Paz Metropolitan Area; Cities of La Paz (population 764,617.) and El Alto (population 848,840.)
Source: In-house study based on the 2012 and 2001 CNPVs.

1.1 Bolivian Water Legislation and Standards

Water is often the cause of social and political strife. In addition, in Bolivia there is a close relationship between access to water and the conditions of poverty among the population. The lack of clean, safe water directly influences the health of the residents of Bolivia and their economic activity.

Bolivia still does not have a policy and a National Water Resources Administration Plan that contemplates the management of the water cycle. The water policy and the institutional situation are weak, incomplete and outdated. Its obsolete regulatory framework has prevented the creation of a modern, adequate administrative system contemplating the multiple sustainable uses for water, and has substantially weakened the national and local water authorities.

At present, Bolivia is still governed by the Water Ownership and Use Law, based on Supreme Decree (D.S.) dated September 8, 1879, which was promoted to the category of Law on November 28, 1906. It establishes the relationship between the State and its water resources. Sections of this law have been repealed by subsequent norms. Some of its provisions are still in force but are not enforced since they are unknown. There are also sectorial norms, passed before 2009 (e.g., the Irrigation Law), the forestry Law, the Environmental Law, the Drinking Water and Sanitary Sewage Law, et al) and institutional standard (e.g., the creation of a Ministry of Water, today known as the Ministry of Environment and Water; the Municipalities Law, the Administrative Decentralization Law, et al). These sectorial laws and regulations establish different, sometimes contradictory norms and deal in a limited way with sectorial water management.

There is still no government action reflecting a firm, decisive policy regarding the country's water resources management, despite recent strides in the norms, and the fact that the new Constitution, proclaimed on February 7, 2009 contains fourteen specific articles setting forth the state's present political vision regarding water. The most important of these are the following:

Article 373. I. *Water is a most basic right for life within the framework of sovereignty of the people. The State will promote the use of and access to water based on the principles of solidarity, complementarity, reciprocity, equity, diversity and sustainability.*

Article 373. II. *The surface and groundwater resources in every state constitute limited, vulnerable and strategic resources, and fulfill a social, cultural and environmental function. These resources may not be subject to private appropriation and neither these nor their services may be given up in concession.*

Article 374. I. *The State will protect and ensure the priority of the use of water to sustain life. It is the responsibility of the State to manage, regulate, protect and plan the adequate and sustainable use of water resources, with the participation of society, thus ensuring that all of its inhabitants have access to water. The Law will establish the conditions and limitations of all of its users.*

Article 375. I. *It is the responsibility of the State to formulate plans for the use, conservation, management and sustainable use of the watersheds.*

In addition, the current scenario of political "change" has fostered a predisposition on the part of the Federal Government to address the demands of the social organizations or movements –principally those of tenant farmers and the indigenous population (the native population), in many cases under the threat of conflicts, opening more or less formal scenarios of consensus or participation.

1.2 The Availability of Water

Bolivia is one of the sixteen countries with the most Water Availability in the world –a supply of fresh water estimated at 30,300 cubic meters per inhabitant per year. However, its distribution with regard to space and time over the nation's territory is unequal. There are regions with high rainfall (over 4,500 mm. per year) but in nearly half of the nation's territory this resource is scarce and there is a water deficit.

Bolivia is a country of both upstream (91%) and downstream (9%) waters. Its renewable internal water resources are estimated at 303 million cubic meters per year –the equivalent of 9,608 m^3/sec (Marka, 2009). The estimated 650 million cubic meters annually (FAO, 2000) of fresh water in Bolivia flow and fill four large internal basins.

a. The Amazon Macrobasin: Covers 65.9% of Bolivia's territory. About 572 million cubic meters per year flow down the Madera River to Brazil. The capital cities of La Paz/El Alto, Cochabamba, Santa Cruz de la Sierra, Trinidad and Cobija are located in this river basin.

b. The Plata Macrobasin: Covers 20.9 percent of the nation's territory. Its rivers, Pilcomayo, Paraguay and Bermejowhich have a a flow of 47,474 millions of cubic meters of water annually to Paraguay and Argentina. The capital cities of the Potosí, Sucre and Tarija departments are in this watershed.
c. The Central or Lake Macrobasin: : Covers 11.4% of the nation's territory. 14,700 cubic meters of water annually drain from Lake Titicaca and Lake Poopó, the Desaguadero River (with its Bolivian and Peruvian tributaries) and the major salt flats of Uyuni and Coipasa.
d. Pacific Ocean Macrobasin: : Covers only 1.8% of the territory, with almost no surface flow (rainfall of less than 100 mm. annually) and a significantan aquifer flow, consisting mainly in ancient waters (10,000 years old), flowing toward the Pacific Ocean in Northern Chile (the Loa River). This limited macro-basin has no major population settlement.

In the first three of the four above-mentioned macro-basins, the water with a quality fit for drinking and irrigation has, as its main drawback, the contamination caused by urban, mining, agriculture and industrial activities, which in many cases surpasses the maximum allowable limits for hazardous substances, and creates environmental problems.

There is no nationwide inventory or databank for aquifers and groundwaters, nor for the storage or recharge volumes. There are only records of studies, prospecting programs and the evaluation of a few specific zones. (GEOBOL, 1985).

In general, the temperature and rainfall increase from west to east across Bolivia. Depending on the zone, the average annual rainfall range varies from 100 mm. (in southeastern and southwestern Bolivia) to more than 4,500 mm.(in eastern and northeastern Bolivia). The rainy season is in the summer from November to March when sixty to eighty percent of precipitation falls in these five monthsThe runoff appears in great volumes on the plains of the Amazon macrobasin, but is negative when it causes flooding due to flows that exceed the watersheds carryingcapacity. This produces a negative impact on productive activities and infrastructure. The available weather data show that the Amazon macrobasin receives twice as much rain as the de la Plata River and four times more than the Central or Lakes macrobasin (Bolivian Water Balance, 1990). The difference is even greater in comparison with the Pacific Ocean macrobasin.

1.3 Use and Consumption of Water

Water consumption in Bolivia is estimated between 1,24 and 2 billion cubic meters annually –that is, only 0.3% of the estimated availability. The greatest water demand (94%) is for agriculture, for irrigation with canals and for open irrigation ditches (Van Damme, 2002). In second place is the demand for human consumption, from 110 to 125 million cubic meters annually. In urban areas water is used mainly for household purposes. Only seven of the nine

Table 1.2 irrigation systems and irrigated water by categories

Department	Micro		Small		Medium		Large		Total	
	Systems	Area (ha)	Systems	Area (ha)	Systems	Area (ha)	Systems	Area (ha)	Systems	Area (ha)
CHUQUISACA	275	1,653	373	11,370	26	4,261	4	3,884	678	21,168
COCHABAMBA	303	1,938	577	22,225	128	27,403	27	35,968	1,035	87,534
LA PAZ	263	1,703	665	21,047	28	6,052	5	7,192	961	35,994
ORURO	172	940	134	3,638	3	440	3	9,021	312	14,039
POTOSÍ	549	3,240	392	10,146	14	2,254	1	600	956	16,240
SANTA CRUZ	42	269	144	5,456	44	8,434	2	1,080	232	15,239
TARIJA	129	785	331	12,755	83	17,101	7	5,710	550	36,351
Total	1,733	10,528	2,616	86,638	326	65,944	49	63,454	4,724	226,564

Source: In-house document based on 2001 and 2012 CNPV.

departmental capitals have permanent, twenty-four-hour-a-day water service.

Despite the significant increase in drinking water service coverage, around 33.9% of all dwellings –over 2.81 million dwellings according to the 2012 CNPV– still lack piped-in water.

The transfer of responsibility for providing drinking water and sewage services to the autonomous municipal governments has created many conflicts because human consumption has priority over other uses. The greatest intrasectorial and intersectorial conflicts are in the irrigation sector –especially where water is scarce.

1.4 Administration of the Water Cycle in Urban Areas

At present, the federal Bolivian authority which administers water supply in the urban and rural areas is the Taxation and Social Control Authority for Drinking Water and Basic Sanitation (A.A.P.S.) of the Ministry of the Environment and Water Resources. This body was created in 2009 by Supreme Decree ("D.S.") No. 0071 to tax, control, supervise and regulate drinking water and basic sanitation under the Drinking Water and Sanitation Sewerage Law No. 2066.

The A.A.P.S. comprises a Board presided over by the Minister of the Environment and Water. Its members are the Vice-Minister for Drinking Water and Basic Sanitation, the Vice-Minister for Water Resources and Irrigation and two social representatives from the Technical Committees for Registration and Licensing (CTRL). The Board receives, studies and grants the right to provide drinking water and/or sanitary sewerage services and to regulate licenses and registrations for water use. Table 1.3 shows the administrative structures which provide local water supply services in the departmental capitals.

For the drinking water and sanitation sector, the urban region comprises four types of cities, identified according to their population: metropolis, large cities, intermediate cities and small cities. According to the 2012 CNPV and estimates for 2005, there are three metropoli: La Paz/El Alto, Cochabamba and Santa Cruz (56.6% of the urban population and 26.9% of the total population); nine large cities (12.3 percent of the urban population), 25 intermediate cities (5.5%) and 65 small cities (3.2%), with decreasing population growth. There is no official distinction of periurban as a function of the size of the population. It is simply assumed that it comprises the areas surrounding these four types of cities.

1.5 Sources of Water in Urban Zones and the Impacts of Urbanization

In the metropolis and the departmental cities of Bolivia (including the city of El Alto), the supply of basic services such as piped-in drinking water has not kept pace with either the population growth or the demand, but has been characterized by low investments, poor maintenance and the poor quality of basic services. This has caused health problems and discontinuityin the water supply.

Most of the services are in public hands (mainly municipal governments) and their rates have always been subsidized. They do not meet the costs of operation and maintenance. These conditions have prevailed despite efforts for privatization in the cities of La Paz/El Alto (the waters of Illimani) and Cochabamba (the waters of the Tunari – the "Water War" of 2000). There is limited and insufficient coordination among the A.A.P.S., the municipal authorities and the departmental governments.

Briefly, in the departmental capitals, 44% of the drinking water and sanitary sewerage system have some type of state (municipal) administration; another 44% have a co-operative administration while the remaining 12%, have joint, undefined administration. For lack of funds, the water does not reach the entire population. Accordingly, local initiatives have emergedspontaneouly for the construction of small systems, or to seek alternate sources of water supply such as tank trucks or the unauthorized drilling of shallow wells.

The intermediate cities develop their own administration and management of drinking water and sanitary sewerage. They had such programs as CORPAGUAS (Water Corporation) which offered technical assistance for their organization. The National Regional Development Fund (FNDR) and the Social Investment Fund (FIS) also provide pre-investment funds. The incumbent Federal Government has in place an investment program, known as "My Water", now in its third stage, to improve water services in cities and in the rural villages.

With regard to environmental protection, the A.A.P.S. does not exercise effective control over the water cycles. The capital cities and other intermediate and small urban areas do not have specific plans or effective environmental control systems for the protection of surface or groundwater. Its sanitation programs are limited to the canalization and piping of rivers and streams. The largest cities have limited tree-planting programs in the periurban areas. The municipal authorities take a permissive attitude regarding environmental control, and if it is carried out at all, it is limited to such points of industrial contamination as breweries, sugar mills, tanneries and others. There is strict follow-up of contamination from large-scale private mining companies, with little attention being paid to the many mining co-operatives and small mining companies.

2. Drinking Water Service Coverage

The partially published 2012 CNPV provides data regarding the department-by-department coverage

Table 1.3 type of administration and flow offered in the departmental capital cities

City	Administration	Water supply	Flow (liters/second) (lt/seg)
La Paz / El Alto	EPSAS S.A. (A quasi-governmental company))	8 sources of water from melting: Tuni, Condoriri, Huayna Potosí, Milluni, Choqueyapu, Incachaca, Ajan Khota, Hampaturi Bajo. Tilala System (30 water wells)	Rango: 2,011 – 3,000
Santa Cruz	SAGUAPAC (Cooperative)	Groundwater	Range: 347 – 2,067
	9 small private cooperatives	Surface water sources	722
Cochabamba	SEMAPA (Municipally operated company))	Surface water sources: Escalerani, Wara Wara, Hierbabuenani and Chungara	Range: 191 – 404
		Groundwater: Quillacollo	462
Sucre	ELAPAS (Municipally operated company))	Surface water sources: The Cajamarca system, which includes the Cajamarca, Safiri, and Punilla rivers	80
		Surface water sources: The Ravelo system, including the Ravelo Ravelo, Peras Mayum Jalaqueri, Murillo and Fisculco rivers.	390
Oruro	Local Aqueduct and Sewerage Service and - SeLA ((Municipally operated company)	Surface water sources: The Sepulturas and Huayña Porto Rivers	34
		Groundwater: (Challa Pampa, Challa Pampita and Airport)	528
Potosí	AAPOS (Community-owned Company))	Surface water sources: San Juan river and 21 lakes (Khari Khari, Tarapaya, Irupampa, Illimani, Challuna)	220
Trinidad	COATRI (Cooperative)	Groundwater	118
Tarija	COSAALT (Cooperative))	Surface waters: Rincón, La Victoria, Guadalquivir and San Jacinto Rivers	574
		Groundwater	279
Cobija	COSAPCO (Cooperative)	Surface waters: Bahía Creek	24

Source: In-house document based on data furnished by the operators.

Table 2.1 Piped-in water distribution to dwellings

Department	% Total Coverage	% Total Coverage	% Total Coverage	% Total Urban Area Coverage %	Total Urban Area Coverage
Source of Information	BM (1999)	INE (2001)	INE (2012)	OPS (2001)	INE (2001)
Chuquisaca	52	53.9	39.1	86.6	86.0
Cochabamba	66	53.9	54.4	70.5	68.6
La paz	80	65.5	70.6	99.9	85.6
Oruro	74	57.5	63.6	90.3	85.6
Potosí	52	44.0	55.6	81.3	86.5
Tarija	73	75.5	81.5	90.3	90.8
Santa cruz	83	77.7	82.3	94.2	90.4
Beni	57	35.1	40.8	---	47.6
Pando	31	38.6	32.0	---	73.5

Source: In-house document using data from 2001 and 2012 CNPVs.

of water services, sanitation sewerage and other services. (See Table 2.1). There are no city-by-city data; accordingly, a complete analysis cannot be performed.

The data analyzed and presented in Tables 2.2 to 2.4 are based on the 2001 CNPV. There are major discrepancies between the distribution of water between the urban and rural areas, and in the distribution by ductwork systems. In rural areas, over 43% of water used in homes comes from wells, waterwheels and surface sources such as rivers and streams.

2.1 Contamination of urban water

Practically all of the nation's urban centers lack modern domestic and rainwater drainage. Improvements in street pavement and the canalizing of rivers and streams are the cause of major problems in surface rainwater runoff. They represent one of the main problems affecting the environment and public health. The degree of contamination of the rivers and streams that run through the main departmental capitals and other intermediate and small urban centers is high and alarming.

A . Domestic urban contamination

Due to the increasing number of residents in the different cities, domestic contamination affects the rivers with which they are in contact. The load of organic contaminants in these rivers is extremely high –being estimated at more than 100 mg. per liter.

Only 40% to 60% of garbage, or solid waste, is collected by municipal services and treated in adequate landfills (see Table 2.5). The remainder of urban waste is clandestinely dumped in rivers, ravines, streets and storm drains, which causes these collectors to be plugged.

Due to the permanent demand for urbanized land and new urban thoroughfares, the banks of the river have been occupied. These occupations are irregular and not according to norms. However, the weak municipal governments allow the occupation of these high geological risk areas. The inadequate urban control prevents these areas, which are indispensable to the maintenance and safety of the water infrastructure, from receiving adequate ecological handling, thus affecting the course of the rivers.

In 1993, JICA and HAM estimated that 403,000 persons discharged wastewater into the River Choqueyapu from La Paz. This is the equivalent of a discharge of three million cubic meters annually. In the cities of Santa Cruz and Cochabamba, discharges were of the same magnitude. Today, with urban growth, the discharges are surely even greater. .

The overworking of dry lands in the high and low parts of the rivers endangers the safety of their slopes. In addition, unauthorized earthworks and

Table 2.2 Distribution of water in dwellings

System	Urban Area		Rural Area	
	Total dwellings	%	Total	%
Piped-in Water.	%	82.93	766,703	26.63
Public Water Pools		5.33		10.78
Well or Waterwheel with Pump		1.93		5.99
Well or Waterwheel without Pump		3.45		22.00
River, Slope or Channel or Canal		0.93		27.65
Lake, Pond or Pool		0.10		2.07
Tank Truck (Water Cart)		3.15		0.34
Other		2.18		1.54

Fuente: Elaboración propia con base en datos del CNPV 2001.

Table 2.3 Distribution of piped-in water

System	Urban area %	Rural area %
Inside the Dwelling	44.78	4.86
Outside the Dwelling but on the Lot	46.89	47.19
Outside Dwelling Lot	2.03	6.35
No Piped-in Water	6.30	41.57

Table 2.4 Sanitation service for dwellings

Availability	% Urban area	Rural area
Has	88.36	42.32
Does not have	11.64	57.68
Type of use	**Urban %**	**Rural %**
Private	63.82	36.12
Shared	24.54	6.20
No Bathroom	11.64	57.68
Bathroom or latrine drain	**Área urbana %**	**Área rural %**
Sewer	55.25	2.07
Septic Tank	12.51	4.08
Cesspool	19.66	34.27
Surface (street/river)	0.94	1.90
No bathroom	11.64	57.68

Source: In-house document based on 2001 CNPV data

Table 2.5 Garbage collection in the cities according to source (in metric tons)

Source	2008	2009	2010	2011
Total	**873,728**	**954,628**	**995,519**	**1,010,192**
Household	712,998	954,629	995,519	782,339
Public Spaces	63,008	62,070	70,469	57,273
Markets	52,848	59,064	73,263	68,428
Hospitals	7,254	7,309	9,642	11,267
Other	37,620	90,627	84,158	90,885

Source: Statistical Report on the Environment in Bolivia. 2012 .

clandestine settlements cause erosion of the slopes and greater flows of surface runoff, provoking mudslides and geo-hydrotectonic disasters.

B. Industrial contamination

In Bolivia there are approximately 15,000 industries. About ninety percent of them are small (one to ten employees), such as artisan workshops. Eighty percent are in the cities of La Paz, El Alto, Oruro, Cochabamba and Santa Cruz. The main industrial sectors are metallurgy, metal finishing, industrial minerals, chemicals, shoemaking and tanneries, and the textile, paper and food industries. They produce large quantities of liquid effluents, mixed with solids which add to the organic contamination coming from sewers in the urban areas. Generally, industrial wastewater and urban wastewater are discharged into the rivers. This makes it difficult to calculate the degree of contamination caused by industry alone.

The use of water in industrial activities is, in large measure, linked with the consumption of drinking water in the cities, since a high percentage is found in the urban or suburban area (for example, 67% in Cochabampa.) Very often, the factories or industries have their own source of water (generally a shallow well) and a contract with the basic sanitation company to discharge wastewater. The lack of adequate control means that these discharges give rise to major contamination processes which are often later used downstream for human consumption and nonindustrial agricultural irrigation.

C. Contamination from mining activities

Historically, the most important base of the national economy has been mining activity. This activity is presently concentrated in the Andean highlands and is carried out by the state-operated C*orporation Minera de Bolivia* (COMIBOL), small and medium-sized private companies and the growing co-operative mining sector.

For its settlements and mills, access to water resources is part of the mining concession or contract. Wastewater must be restored to the original waterways in equal quantity and quality, but this rarely happens. Both in the Andean zone –with traditional mining– and in the Amazon regions –with their processing of mercury– major contamination problems have arisen in the surface runoff and surface and deepacuifers.

The rivers most severely affected by mining contamination are in the Pilcomayo watershed (the Tupiza, Cotagaita, Tumusla and Pilcomayo rivers), of the Caine-Grande River (the Chayanta river) and the lake of Poopó (the Huanuni and Santa Fe rivers, among others).

Mining activities produce the following environmental problems:

- The generation of acid rock drainage (DAR).
- Contamination of rivers with heavy metals, and the degradation of the water ecosystems Contamination of groundwater reservoirs.
- Contamination of the soil, and of crops irrigated with contaminated water.
- Accumulation of metals in closed lakes.

3.Wastewater Treatment Systems in Bolivia's Capital Cities

In Bolivia, many of the intermediate and large cities and towns have sanitary sewage systems with no type of wastewater treatment. In most cases, they dischargewastewaters directly into such natural bodies of water as rivers or lakes. However, around three thousand liters of wastewater per second are treated in the different capital cities (See Table 3.1).

The overall outlook for wastewater treatment in Bolivia may be summarized in three situations:

- No treatment –discharged directly into a river, or else there are latrines.
- With primary treatment (septic and Imhoff tanks)
- With treatment in secondary or tertiary stabilization ponds

Table 3.3 offers a summary of the types of treatment existing in the country's departmental capitals. Most of these treatment systems have limited capacities or operate poorly for the following reasons:

- Weather conditions (low temperatures throughout the highland region)
- Water and organic overloading due to poor design or unforeseen population growth
- Lack of maintenance and operation due to insufficient economic resources
- Lack of projects for the reuse of treated water.

The reuse of wastewater in agriculture offers the following advantages: multiple uses of a scarce resource, recycling of nutrients, the prevention of river contamination and the supply of municipal water at a low cost (Van der Hoek, 2002). It involves, however, the following risks: (a) contamination of the soil with chemicals and heavy metals, and (b) the threat of the presence of water from zones where household wastewater and industrial wastewater are not separated. It is very important to seek solutions to urban and industrial contamination which optimize the economic benefits to farmers and, at the same time, minimize the health risks.

Table 3.1 Volume of wastewater treated by capital city (In liters per second)

Capital City	2008	2009	2010
La Paz/El Alto	s.d.	s.d.	s.d.
Santa Cruz	1,009	1,053	1,116
Cochabamba	795	655	522
Oruro	245	750	750
Sucre	140	152	145
Potosí	13	125	132
Tarija	162	167	174
Trinidad	74	76	76
Cobija	s.d.	s.d.	s.d.
TOTAL	**2,478**	**3,022**	**2,966**

Source: Statistical Report on the Environment in Bolivia, 2012.

Table 3.2 Shows in detail the quantities of wastewater generated in the capital cities.

Quantities of wastewater generated in capital cities in 2001			
Capital City	Urban Population	Wastewater discharge in liters per second	Volume
La Paz/El Alto	1,549,759	1,291.50	40.70
Santa Cruz	1,543,429	1,286.20	40.60
Cochabamba	855,277	712.70	22.50
Oruro	237,286	197.70	6.20
Sucre	217,019	180.80	5.70
Potosí	237,576	198.00	6.20
Tarija	247,690	206.40	6.50
Trinidad	244,207	203.50	6.40
Cobija	20,987	17.50	0.60
Total	**5,133,230**	**4,294.40**	**135.40**

Source: Durán et. al., 2002.

Table 3.3 Water treatment systems in Bolivia's Capital Cities

Treatment system	Type of treatment	Treatment capacity (design) q (liters per second) uantity	Present treatment of tributary q (liters per second) uantity	Effluent
Alba Rancho, Cochabamba (1986)	12 stabilization ponds (8 for secondary treatment; 4 for tertiary treatment)	400	568	290.0
Industrial Park Ponds, , Santa Cruz (1980)	6 stabilization ponds (5 in service) in series with tertiary treatment	27.2	27.1	26.7
Lagunas Norte Viejas, Santa Cruz (1970)	4 stabilization ponds operating in a facultative anaerobic system	102.8	102.9	102.7
New Ponds o North, Santa Cruz (1989)	4 stabilization ponds operating in series as a facultative finishing system	251.7	254.9	247.0
La Tabladita, Tarija (1992)	2 stabilization tanks (primary anaerobic treatment), 2 tanks (1 for secondary and 1 for tertiary treatment)	63.4	133	108.1
Puchuckollo, El Alto	12 stabilization tanks in 2 series, each with 6 ponds	446	267	248

Source: In-house document, using data gathered from the treatment plants

3.1 Multiple Uses of Water in Urban and Suburban Zones

Most capital cities do not perform any type of water purification treatment before distribution. Accordingly, the quality of the water distributed depends exclusively on the quality of the source. .

The main users of water in the capital cities are the urban population (for home use), industry, and irrigators. The latter are generally in the periurban areas. There is an interdependence among these sectors: the irrigators produce vegetables and fruit to supply urban markets, and irrigate their land with a resource which, thanks to the increasing demand from populated areas, is increasingly scarce. This intensifies the pressure on both surface and groundwater resources.

One of the strategies adopted to maximize the use of water is the use of urban wastewater for agricultural irrigation. This application is not universal throughout the country but is applied only in the Andean regions, highlands and valleys. The use of wastewater in these regions may be classified as follows:

A. **Direct Use.** That is, when they are carried from the outlet (either from the sewer or the treatment plant) directly to the plots of land, or as the result of intentional breakage of the sewage pipe to use it for irrigation purposes. Wastewater, whether treated or not, is not diluted before use. This is common in Andean zones where water is scarce. Its use is formal when supported by a formal settlement or other type of agreement.

B. **Indirect Use.** This means the use of water from rivers where wastewaters are discharged, a minority of which is first treated;therefore diluted. This happens in most of Bolivia and in almost all the rural and periurban areas of Bolivia downstream from the departmental capital cities.

3.2 Contamination of groundwater

The degree of contamination of surface and groundwater is not fully documented. However, groundwater is the most sensitive to all manner of contamination, since groundwater flows at lower, almost nonexistent speeds. For the contamination of groundwater there are isolated data for the Cochabamba Valley (Renner and Velasco, 2000); Oruro (PPO, 1996); (Huaranca, Olivera Neumann-Redlin, 2000), and el the Northern Highlands (ZONISIG, 2000). Other data are contained in several scattered and unpublished reports .

In Bolivia, , a large part of the groundwater is unfit for either human consumption or irrigation due to high salinity factors. Studies on the use of the country's water show that when the supply is limited, as happens in the cities of Santa Cruz, Cochabamba and El Alto, the industries resort to the immediate alternative of drilling unauthorized wells. This causes the over-exploitation of the aquifer, damaging it for other uses. Generally, these are waters with low to medium salinity and water with low sodium content which may be used for most crops in almost all types of soil. (Renner and Velasco, 2000).

The groundwater in the urbanized areas (Santa Cruz, Oruro, El Alto, Trinidad) are threatened with industrial, agricultural and, above all, domestic contamination. In the urban areas of most of the capital cities, the infiltration of liquids leached from sanitary landfills presents a serious problem.

4. Drinking Water, Sanitation and Health in the Departmental Capital Cities

There is no undisputable system for the supply of sufficient fresh water or drinking water in the country. This term takes in its bacteriological safety. The existence of contaminated water in Bolivian cities is very common. This represents a permanent threat to the health of her inhabitants and means high rates of water-related diseases including dengue, malaria, typhoid fever, salmonellosis, diarrhea and parasitosis.

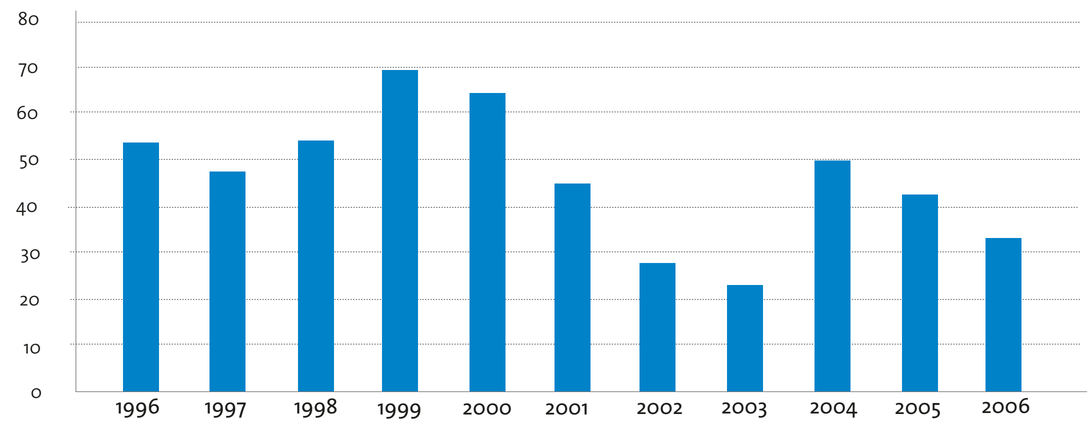
Drinking water and sanitation coverage in Bolivia has increased considerably since 1990, with heavy investments in this sector. However, the coverage is still the lowest in the continent and the quality of the service is mediocre. Political and

Table 3.4 Gives an idea of the general reuse characteristics of wastewater in the nation's different departmental capitals

Characteristics of the use of wastewater in the periurban areas of the departmental capitals and in the city of El Alto	
Capital City	Characteristics
Cochabamba	Direct use of the drainage from the treatment plant and indirect due to the use of the contaminated water from the Rocha River.
La Paz	Indirect use, through the drainage from the Río Choqueyapu river, where the sewage discharges, and from industry with no prior treatment.
El Alto (metropolitan area)	Indirect use from the Seco Seco River where wastewater from the Puchuckollo wastewater treatment is discharged.
Oruro	No reuse. The treatment plant discharges onto salt plains unfit for agriculture.
Trinidad, Cobija, Santa Cruz	No reuse. These are areas with heavy rainfall, where there is no irrigation.
Tarija, Sucre, Potosí	No data available

Source: Villarroel, 2001.

Chart 4.1 Shows the public investments made in the drinking water and sewer system sector between 1996 and 2006. They totaled 511 million dollars. However, this amount was insufficient to meet urgent needs.



institutional instability have served to weaken both federal institutions and many local institutions. The lowest degrees of coverage are found in the departmental capitals of Pando, Potosí and Oruro.

According to the WHO, in 2000 only 26% of urban systems offered disinfection, and 25% of the sewage was treated. According to the German Gtz study, in 2011 only 30% of the sewage collected was treated while 70% of the waters treated were inadequately treated because the sewage treatment plants did not operate properly.

The last three decades have revealed the fragility of the institutional framework of the sector, since it has undergone repeated restructuring as the result of the continuous turnover of the Federal Government. During the second administration of Hugo Banzer (1997-2001), the institutional framework of the sector was restored by Public Law 2029 issued in 1999, which established the legal framework for private sector participation and formalized the existence of a regulating body, the SISAB. The private sector received a concession for drinking water and sanitation services in La Paz/El Alto, granted to the company Aguas de Illimani, S.A. (AISA), a subsidiary of the French company SUEZ (which at that time was Lyonnaise de Eaux), in 1997, while in 1999 the system for Cochabamba was granted to Aguas de Tuman, a subsidiary of the multinational companies Biwater and Bechtel.

Due to two popular uprisings protesting the privatization of water –the first in Cochabamba in April 2000 (the Water War) and the second in El Alto in January 2005– these two concessions were cancelled.

The political platform of President Evo Morales for the 2006 elections proclaimed that "Water cannot be a privately run business because (if it turns into a commodity) it will be violating human rights. Water resources must be a public service." Accordingly, he created the Ministry of Water (now the Ministry of the Environment) in the institutional framework established in Public Law 2029 for Drinking Water and Sewerage Services, passed in 1999, revised and complemented in 2000 and with Public Law No. 2066. Morales' government is contemplating a new drinking water and sanitary sewerage service to be known as "Water for Life," which has not yet been approved.

The National Service in Support of Basic Sanitation Sustainability (SENASBA) is responsible for the planning and, in part, the implementation of community development, the promotion of hygiene and technical assistance to the service providers. In the cities, the municipal governments, either directly or through municipal service companies, are responsible for the administration and operation of these services. They are also responsible for formulating plans and programs for the expansion of the services in their area of jurisdiction in coordination with the Departmental Governments.

5. Description of the Sources of Water in the Departmental Capital Cities

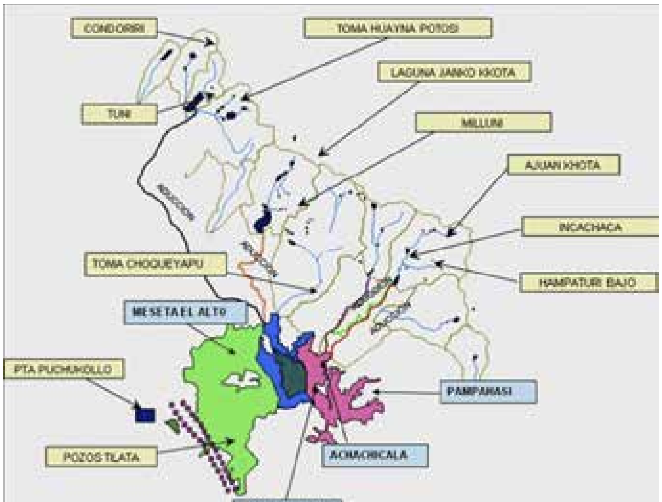
5.1 The LaPaz/El Alto Metropolitan Area

This treatise considers both cities La Paz/El Alto as the Metropolitan Area. The criteria used in defining the name "metropolitan area" are the following: continuing urban sprawl, and the relationship flow between both cities, including the public transportation system, the provision of basic drinking water, electric energy, public transportation and communications services. This creates a highly dynamic scenario, which consolidates the relationship between the two cities. However, they do not have the same quality and coverage of public services, especially with the supply and use of water.

5.1.1 Hydrology and Hydrogeology

The configuration and physical structure of the urban sprawl of the city of La Paz are influenced by the water network, comprising five water basins, which make up the La Paz River basin. It also has some 350 tributary ravines which open into rivers, streams and creeks which cause landslides and highly dangerous flash floods during the rainy reason. This water serves as a clandestine dump for approximately 100 metric tons of waste and rubble daily.

Figure 5.1 Layout of Water Sources and Systems for the Metropolitan Area



Source: EPSAS, La Paz.

A. The Rio de la Paz Basin . The formation of the Río de la Paz drainage network is parallel, due to the presence of uniformly spaced and relatively parallel rivers running from North to South. Its headwaters are in the snows of Chacaltaya, with the name Rio Kaluyo, which would later be changed to the Choqueyapu River, which runs all the way across the city of La Paz. It joins the secondary Orkojahuira River (known upstream as the Chuquiaguillo), the Irpavi and Hampaturi Rivers (known upstream as Khallapa and Mikhaya), and the Achumani and Huañajahuira Rivers to form the Río de la Paz, or La Paz River in the southern part of the Municipality, emptying its waters into the Amazon Basin. This basin has an area of 535 square kilometers and covers the entire urban area. (Núñez, 2004).

B. The City of El Alto , in the middle of the Bolivian highlands, at an elevation of 4,035 meters above sea level, has shallow ravines that cut through the fluvial-glacial quaternaries which, during the rainy season fill with water and tend to flood the lower parts of the city. The major ravines run North to South and are nearly parallel:
   a. The one known as Rio Seco (dry river) crosses the highway in route to Lake Titicaca and Peru.
   b. The Sake River ravine, which originates in the Milluni dam.

5.1.2 The Drinking Water Supply

The La Paz/El Alto Metropolitan area has a population of 1,613,457 inhabitants (CNPV, 2012) and a total of 370,574 dwellings. Of these, 86.35% receive piped-in water furnished by the Public Social Water and Sanitation Company (EPSAS), The population with drinking water service in the city of La Paz numbers 764,060 inhabitants, establishing a coverage of 91% according to EPSAS. This does not include around 30,000 inhabitants (4,763 water connections) served by 38 co-operatives from the slopes (the source of water from natural springs), who experience problems with the quality of their service. This increasesthe degree of coverage to 94.5%

For El Alto, the population with drinking water service numbers 981,812 inhabitants, with a coverage of 99%. (See Table 5.1 and Figure 5.2). In the city of La Paz there are three distribution systems which receive flows of water generated by the ice covering the mountain peaks of over 5,000 meters above sea level. The plateau system in the city of El Alto is also fed by glacial waters, while the Tilata system depends on 30 groundwater wells.

According to the EPSAS plans for 2011, the area covered by the drinking water piping network is 7,583 hectares (La Paz) and 13,455 hectares (El Alto), for a total of 21,028 hectares. This represents 80% of the potential service area. EDPSAS has records to show that the population with drinking water in both cities –La Paz and El Alto and their adjacent areas (Acholaca and Viacha)– reach 1,745,872 inhabitants. (See Table 5.1). This is an overall service coverage of 95%, and there are 312,117 active connections.

5.1.3 Sewerage Services

According to EPSAS (2011), a total of 1,376,562 inhabitants of the La Paz Metropolitan Area have sewerage service, out of a projected total of 1,836,737 inhabitants. (See Table 5.2). The overall coverage is 75%, with 216,866 active sanitary sewer connections. The present sewage service covers 6,372 hectares (La Paz) and 8,653 hectares (El Alto), for a total of 15,025 hectares. This means that the sanitary sewerage system covers only 57.2% of the potential service area.

Table 5.1 System-by-system drinking water service and connection area

System	Population in 2011	Area ((hectares)	Number of connections
Achacachi	215,028	1,256	
Pampahasi	256,048	3,937	
El Alto (La Paz Slope)	292,984	2,391	
La Paz – Population Served/Area with Piped-in Water	764,060	7,583	119,044
La Paz – Projection/ /Total Area	840,593	11,516	
La Paz Coverage	90.9%	65.8%	
El Alto (Plateau)	805,688	9,133	
El Alto (Tilata)	176,124	4,311	
El Alto – Population Served/Area with Piped-in Water	981,812	13,445	193,073
El Alto – Projection//Total Area	995,144	14,748	
El Alto Coverage	98.7%	91.0%	
Total – Population Served/Area with Piped-in Water	1,745,872	21,028	
Total – Projected Population/./Total Area	1,835,737	26,264	
La Paz/El Alto Coverage / TOTAL CONNECTIONS	**95.0%**	**80.0%**	**312,117**

Source: In-house document based on data from EPSAS in La Paz.

Table 5.2 Current sanitary sewer service and connections by systems

System	Population 2011	Area	Number of EPSA Connections
La Paz Serviced/Area with Piped-in Water	792,290	6,372	100,938
La Paz – Projection /Total Area	840,593	11,516	
La Paz Coverage	94.3%	55.3%	
El Alto – Serviced/Piped-in Water	584,272	8,653	115,928
El Alto – Projection /Total Area	995,144	14,748	
El Alto. Coverage	58.7%	58.7%	
Total – Serviced/Area with Piped-in Water	1,376,562	15,025	
Total – Projection /Total Area	1,836,737	26,264	
La Paz – El Alto Total Coverage	**75.0%**	**57.2%**	**216,866**

Source: EPSAS, 2011.

5.2 Santa Cruz de la Sierra - Capital city of the Department of Santa Cruz

Santa Cruz de la Sierra is the city which has undergone major transformations as the result of high growth and migration, thus requiring a continuous search for infrastructure and service solutions. It has a population of 1,114,095 (CNPV, 2011) and 252,136 dwellings. Of these, 91.74% have piped-in water. It is located on the right bank of the Pirai River. The city occupies an area of 567 square kilometers and has a perimeter of 110.2 km. The climate in Santa Cruz de la Sierra is warm and subtropical, with an average annual rainfall of 1,300 mm, and the heaviest rains in January and February.

5.2.1 Hydrology and Hydrogeology

The Pirai river, to the west of the city, with a flow of approximately 5,000 m^3/sec, crosses the city from north to south. It is also located between two major basins –that of the Grande (or Guapay) and Yapacani Rivers– all in the Amazon macrobasin. During 1990 and 1991, for the protection of the city, protection projects were carried out, covering a stretch of 15 kilometers running the length of the river. Practically one-hundred percent of the aggregates used to build the city of Santa Cruz de la Sierra and its environs come from the bed of the Pirai River.

At the end of the high Piraí River basin there is an enormous alluvial cone, which is confused with the alluvial cone of the Grande River and serves as the aquifer which is the source of drinking water for the city of Santa Cruz de la Sierra and the villages downstream from that city. The groundwater is of excellent quality for human and industrial consumption, and cooperatives of public and industrial services; it need only be chlorinated to be usable. The aquifer's recharge area are composed of the clastic deposits of the vast alluvial plain formed by layers of varying thickness of silty sand (SM), interspersed with low-compressble clay (CL). In addition, the aquifer receives rainwater and, to a lesser extent, infiltrations from the Piraí River and its tributaries.

In the city of Santa Cruz de la Sierra, where a substantial part of the demand for water is located, the absence for years of sanitary sewage has caused the contamination of the aquifers nearest the surface, due to the infiltration of untreated household wastewater. This has made it necessary to capture water from greater depths. At present, there are borings from depths of over three hundred meters.

5.2.2 The Drinking Water Supply

The drinking water supply system in the city of Santa Cruz de la Sierra depends exclusively on groundwater. Since 1979, this service has been furnished by the Drinking Water and Sanitary Sewerage Services Co-operative (SAGUAPAC). There are some other independent co-operatives which furnish only drinking water supply services.

SAGUAPAC is a co-operative and each owner of a water connection becomes a partner and co-owner, with the right to voice and vote. The co-operative seeks the well-being of its members, not monetary reward. SAGUAPAC has a rate structure with different social with different price levels according to characteristics of use: residential use, business use, industrial use and special use (hospitals, public schools, Government offices etc.)

SAGUAPAC operates the aquifers located in cretaceous and tertiary sediment more than five-hundred meters deep below the city of Santa Cruz de la Sierra, using for this purpose a group of sixty-one wells located in four fields (south, southwest, north and northeast), with four pumping stations, six storage tanks with a capacity of 29,000 cubic meters, a distribution net of 2907 km which hasan annual production (in 2003) of fifty-one million cubic meters. Taking into account the operation and recharge projections, some studies, , claim that by 2017 it will be necessary to incorporate an additional water source. SAGUAPAC has hydrogeological data about the aquifer's area of influence and has future, sustainable operation projects –that is, controlled extraction and supervision and follow-up on the aquifer's recharge.

The administrative structure of SAGUAPAC is complicated, but has been imitated in other South American cities. It has available a concession covering a specific area divided into nine districts. Each of these has a District Council, whose purpose is to gather the concerns of its members and seek to satisfy their requirements. The term served by the district council members is six years and there are three delegates who, together, comprise the Assembly of Delegates (twenty-seven members), whose main purpose is to approve all the important decisions of the co-operative. This Assembly of Delegates also elects the nine members of the Board of Directors and the six members of the Oversight Committee.

The following are some of SAGUAPAC's indicators for 2003:

- Drinking water coverage for 96% of the population
- Sanitary sewage coverage for 50% of the population
- A total of 123,597 drinking water connections
- A total of 64,096 sanitary sewage connections
- An average water tariff of 0.31 U.S. dollars per cubic meter
- An average sanitary sewage tariff of 0.29 U.S. dollars per cubic meter
- A water loss of 26%
- Annual invoicing of 19,500,000 U.S. dollars
- A 94% collection efficiency

5.3 Cochabamba, the Capital City of the Department of Cochabamba

The capital city of the department of Cochabamba (in Cercado province) is 2,535 meters above sea level and has a surface area of 10,605 hectares, a population of 778,442 inhabitants (CNPV for 2001) and 123,477 dwellings, of which 69.5% have piped-in water from the distribution network. It has an average annual temperature of 17.5°C. Rainfall varies between 400 and 500 mm. per year.

The Cochabamba Metropolitan Area is defined as the territorial, geographic and human area comprising the city of Cochabamba and the suburbs in its area of influence, including the districts of Sacaba, Cercado (Cochabamba), Tiquipaya, Colcapirhua, Quillacollo, Vinto and Sipe, all within the Rocha River subwatershed.

The urban expansion process of the Cochabamba Metropolitan Area has been horizontal, of low density, unordered and unplanned. The use of land suitable for agricultural production has created urban planning problems of different kinds, including conflicts arising from the occupation of public property, green areas and ecological and forest preserves. There are settlements ecologically classified as high risk, and as a natural catastrophe due to their location in gullies (the beds of tributary ravines of the Rocha River which carry torrents of mud). There has also been a proliferation of settlements on apparently vacant or abandoned lots, since their owners do not live on them.

An average of fifty percent of the population do not have access to piped-in water or public sanitation sewage.The contamination of shallow aquifers is alarming. The analyses carried out reveal vestiges of fecal matter and a wide range of bacteria, which represent a health hazard to the population.

Another environmental hazard is that only 64.7% of the total dwellings in the city have garbage collection and disposal service. The remainder of the population dumps its garbage in open fields, rivers or dumping grounds, forming focal points for contamination of the shallow groundwater.

The increase in the use of traditional organic fertilizers, industrial fertilizers and untreated wastewater in agriculture is also producing excessive nitrates, leading to a reduction of the soil's capacity for self-purification and nitrification.

5.3.1 Water Resources in the Cochabamba Urban Area

The city and valley are traversed, east to west, by the Rocha River, whose headwaters are in the Tuti sierra (in Chapare province) and the Tamborada river, its main tributary. Both rivers are highly contaminated and their flow is intermittent. They only carry continuously flowing water during the peak rainy season (December to February). Several intermittent rivers originating in the Northern Mountain Range of the valley (Tunari) empty their waters into the Rocha River during the rainy season. The Rocha River is 83 km. long from its headwaters to the point where it empties into the Caine River, southeast of the valley. Its flow of water spills into the Amazon macrobasin which flows across the watershed of the Mamorée River (Hydrography of Bolivia, 2007).

One of the main problems in the Cochabamba Metropolitan Area is the scarcity of water, caused by the low rainfall in their zone. The surface water reserve in some cases dries up completely. For this reason, it is necessary to prospect for and develop groundwater resources in the surrounding cities of Quillacollo, Sacaba and Tarata. The extraction of groundwater implies a substantial investment of funds which are difficult to raise. This leads to a deficient, inadequate development of the projects

Table 5.3 Average annual availability in potential surface and groundwater sources

District	Existing Sources		Potential Sources				
	Wells	Area Km²	Kewina Khocha Corani (lts.sec)	Palca Transfer	Misicuni Project Phases 1 & 2 (lts.sec)	San Miguel (lts.sec)	New wells
Cercado	600	254					50
Sacaba	149	31	1,046	160			20
Quillacollo	110					335	90
Tiquipaya	66	26			4,000		50
Colcapirhua	82						30
Vinto	52						40
Sipe Sipe	11	10					70
Totales	**1,070**	**321**	**1,046**	**160**	**4,000**	**335**	**350**

Source: SERGEOMIN, 2004.

which have been designed. However, the Municipal Drinking Water and Sanitary Sewer Service (SEMAPA) –the municipal company responsible for the administration of water in Cochabamba– owns a large number of wells, from which a significant flow is obtained.

The currents of water originating in the Cochabamba mountain range are calcium, magnesium and bicarbonate bearing (fresh water). These flows originate in sedimentary rocks such as volcanic rock. The concentration of the total dissolved salts generally does not exceed 300 mg. per liter. Important factors in their purity may be the steep topography of the terrain, which does not favor the retention of water in aquifers for long periods, and the acid composition of the rocks. The wells are not springs; therefore, the cost of pumping them must be added to make possible their exploitation.

The contamination of the groundwater in the mountain range is generally limited to the flows originating in the most shallow aquifers. The alluvial rivers are exposed to contamination through direct infiltration. These aquifers are in grave danger of being contaminated by such human activities as agriculture.

Thousands of dug or bored wells are found in the Central Valley. Their depth and flow vary, depending on their location. In general, their flows in the central region may be as high as 30 liters per second at depths of 125 meters. Toward the south, these values are lower. In the valley, SEMAPA drilled three wells in 1997, to depths greater than 200 meters. During Stage I, a well was dug down to 550 meters. The yields from these very deep wells do not exceed significantly the flow of the wells operating in more shallow aquifers. Permeability is reduced according to depth, due to the increased presence of clay between the productive layers, which prevents an adequate recharge of the aquifers. The age determined for the water from this deep well is eighteen thousand years BP.

5.3.2 Water Treatment Plants and Recycling in the City of Cochabamba

The main water treatment plants for reuse of water in Cochabamba are the following:

A. The Cala Cala plant, with a treatment capacity of 400 liters per second, treats waters coming from the Escalerani system and the Aranjuez plant, with a design capacity of 100 liters per second for treating the waters coming from the Wara Wara system.

B. Wastewaters are transported by the sanitary sewerage system, and are treated at the Alba Rancho treatment plant, which has a stabilization pond system to treat up to 400 liters per second. It has eight secondary ponds with an area of 21.9 hectares, and four primary ponds with an area of 13.7 hectares. It also has a complete distribution canal network as well as collecting canals, with their flow measurement systems. In addition, it also has a mechanism for controlling and recording the weather conditions and their impact on the behavior and efficiency of the plant. An uncontrolled increase in new input may cause a highly damaging overload.

5.3.3 The Sanitary Sewerage System

A part of the sanitary sewage system of the city of Cochabamba dates from 1928. Minor improvements were made in 1945 before the Sanitary Sewerage project was implemented. Its coverage reached 42%, taking in principally the central neighborhoods (Las Cuadras, Muyurina and Cala Cala), covering an area of 1300 hectares. The 1945 Sanitary Sewerage Project for the city of Cochabamba was planned to completely replace the network. However, the lack of financing made it necessary to realize only part of the project, retaining 131 km. from the old network. The sanitary sewage network attaining a length of 425.98 km., with 33,229 household connections and 320 industrial connections, for a total coverage of 53% at the end of the project. At present, there are 729.91 km. of sanitary sewerage network, for a total coverage of 75.7%.

5.4 Oruro, Capital City of the Department of Oruro

The city of Oruro is located 3,736 meters above sea level in the Central Highlands. It is the capital of Cercado Province in the Department of Oruro, with a territory of 285.08 square kilometers.

It has a population of 202,010 inhabitants (CNPV, 2001) and a total of 49,436 dwellings, of which 87.99% have a piped-in water supply. It is divided into five districts, comprising two areas:

- The urban area (district 1), or the intensive area, with an area of 103.58 square kilometers.
- The extensive area, covering Districts 2, 3, 4 and 5, with an area of 180.66 square kilometers.

In the ecoregion on the semiarid and arid Andean floor is uncultivated, surrounded by a small mountain range. Prominent in this are a series of porfidic domes associated with lava infiltration, as well as dikes and subvolcanic chimneys. These domes are part of the San Felipe, Pie de Gallo, San Cristóbal, San José, San Pedro, Colorada, Rubiales, Argentillo, La Tetilla, Santa Bárbara, Cerro Calvario and Cerro Alamasi hills. The mountain range is home to the E.M. San José mine and the drainage that flows from this range is radial and centrifugal, causing problems of rain runoff in the urban sprawl during the rainy season and brings in contamination of the acid water discharged by the mine.

Its climate ranges from 12.4°C to an average temperature of 2.6°C. During the winter the low temperatures are bearable thanks to the extreme dryness. An analysis of average temperature variations shows an upward trend, at the rate of 0.0045 degrees Celsius annually. The records of monthly rainfall show minimal variations, between 10 and 20 mm. during the months from July to August, and 190 to 220 mm. from November to February.

5.4.1 Surface Water Resources in the Municipality of Oruro

The city of Oruro is surrounded by bodies of surface water. The Tagarete River borders the eastern side of the city (Districts 3 and 4). To the southwest there is the Thajarita River and the Desaguadero River to the west (Districts 3 and 4). To the south there is Lake Uru Uru (District 4) formed by a natural reservoir of the Desaguadero River and Lake Poopó. The surface water sources supplywter to the Municipality of Oruro via a flow of 34 liters per second, and come from the Sepulturas and Huayña Porto rivers, and form part of the Endorreica macrobasin in the Bolivian highlands.

The Desaguadero River is the basin's main collector, draining the zone until it empties into the Lake Poopó to the south. The Desaguadero River carries an average of twenty m^3/sec of water from Lake Titicaca to Lake Poopó, forming several subbasins as it crosses the northern highlands, and a part of the inter-highland mountains. The flood plains of the Desaguadero are important in the framework of evaluating water resources both in the Department and in the city of Oruro.

Lake Uru Uru is triangular in shape, with a southward vertex. During the rainy season 10% of the surface of water is within the limits of the Municipality of Oruro. However, the water in this section tends to flow down due to the effect of sediment deposits carried by the Desaguadero River. Between Lake Uru Uru and Lake Poopó, the Desaguadero River runs for thirty kilometers, with an average slope of 0.03%. It spills over in this region, also forming the so-called Soledad Lake, adjacent to Lake Uru Uru, according to recent data.

5.4.2 Groundwater resources in the Oruro district

These resources are managed by the city-owned company known as "Local Aqueducts and Sewage

Service", or SeLA. The Challa Pampa aquifer, located to the northeast of the city of Oruro, is exploited in the zones of Challa Pampa, Challa Pampita, Challapampa Grande and Airport and furnishes 94% of the 564 liters per second of drinking water distributed by SeLA. The Challa Pampa aquifer is a tectonic depression filled with recent lake sediment (from Lake Minchin), glacial-fluvial sediment and with fluvial-colluvial sedimentation. The different sediments have caused changes of facies, according to the variations in the salinity of the water. SeLA operates a battery of 23 tubular wells, from 50 to 120 meters deep, and has systems to transport the water to the JKW tank plant in SeLA's building. From there it is distributed for urban supply.

5.4.3 Drinking Water Supply

The water resources used to supply water to the city of Oruro originate in surface and groundwater sources. Tables 5.43 and 5.5 show the use of drinking water and the number of connections according to the type of user.

5.4.4 The Oruro City Water Treatment Plant

The city of Oruro has a Special Wastewater Treatment Plant (PETAS) located 2.5 kilometers to the southeast of the city. It is operated by the Department's Government. The plant is in the process of being transferred to the Oruro Autonomous Municipal Government (G.A.M.O.) This plant has been shut down for some time; accordingly, the wastewater is discharged directly, and untreated, into Lakes Uru Uru and Poopó. Only 1.5 Km to the north of the plant there is an open canal which is used to redirect the wastewaters directly to Lago Poopó The wastewater flows at a rate of 400 liters per second, even though SeLA produces 300 liters per second of drinking water. This leads one to believe that this is the mixture of rainwater and sewage system water.

5.5 Sucre, capital city of the department of Chuquisca

Sucre is the constitutional and official capital of Bolivia and the capital of the Department of Chuquisca. Geographically, Sucre is located 2,750 meters above sea level. It is located in the medium high lands between the highlands of the Andean plateau and the Gran Chaco lowlands of the southeastern plains. It has a population of 194,888 in habitants (CNPV for 2001) and 49,979 dwellings. Of these, 78.73% have piped-in water.

The city of Sucre has the weather conditions typical to valley areas, with dry, moderate climate and temperatures which range from a high of 22°C in the summer and a low of 8°C in the winter. The average ambient temperature is 15.2°C, and the average rainfall is 650 mm. per year.

5.5.1 Water Resources for the City of Sucre

The geographical location of the city of Sucre coincides with the hydrographic divide of the Amazonas macrobasin (Chico and Grande rivers), and the Río de la Plata macrobasin the Cachimayu and Pilcomayo rivers). Hence, the city becomes an area with two drainage directions, since some of its waters run toward the Amazon (in Brazil) while others run toward the Río de la Plata (in Argentina).

5.5.2 The Drinking Water Supply

The Sucre Local Drinking Water and Sewage Company (ELAPAS) furnishes and manages drinking water and sewage services for the city of Sucre. ELAPAS comprises a decentralized Public Service

Table 5.4 Use of drinking water according to types of user january to november 2009 and 2010 (in cubic meters)

Type of user	January to November 2009		January to November 2010		Percentage Variation
	Consumption	Percentage Variation	Consumption	Percentage Variation	
Total	**5,221,773**	**100.00**	**5,415,500**	**100.00**	**3.71**
House-hold	3,565,204	68.28	3,736,765	69.00	4.81
Commercial	758,128	14.52	792,575	14.64	4.54
Industrial	255,293	4.89	262,362	4.84	2.77
State	643,148	12.32	623,798	11.52	(3.01)

Source: Local Aqueduct and Sewerage System Service (SeLA), Oruru and and and National Statistics Institute (INE), 2011

Company of the Sucre Municipal Government, with its own status as a legal entity, and administrative, financial, and management autonomy, an infinite corporate life, its own legal status and independence from the Municipal Government. It was created by Supreme Decree No. 07309 in 1965.

ELAPAS furnishes 25,435,587 liters of drinking water per day to 49,900 dwellings (CNPV for 2012). It has two systems, fed by surface water.

A. The Cajamarca System, which includes the Cajamarca, Safiri and Punilla rivers, with a flow of 80 liters per second.
B. The Ravelo System, which includes the Ravelo, Peras, Mayum, Jalaqueri, Murillo and Físculco Rivers and contributes with a total flow of 389 liters per second.

There are also transition and storage tanks made of stone masonry in Silvico and Guerraloma, respectively.

Among ELAPAS' medium-term projects intended to improve its service are the following:

1. The conclusion of the work for Phase I of the Lajastambo project. This is the main source of supply for the recently rehabilitated Cajamarca Transportation Water System.
2. The realization of Phase II of the Lajastambo project financed by the Federal Government.
3. A joint call for bids and for expressions of interest by the Ministry of the Environment and Water, the German company KfW and ELAPAS to study the final design of the project to increase the Sasanta-Yurubama flow/SUCRE III.

ELAPAS implemented its own rate structure, which contains a solidarity rate for consumption of less than 10 cubic meters, the purpose of this being to subsidize the families with the lowest income.

5.5.3 The City of Sucre Water Treatment Plant

Given the need for a water treatment plant, in 1970 the French company Francesca Degremont built the El Rollo Plant, with a capacity of 125 liters per second. In 1991, due to the accelerated population growth, the plant was expanded to a capacity of 250 liters per second. At present, due to the increase in the number of users, it covers only 85% of the flow required by the city. ELAPAS guarantees the purity of the water treated.

5.5.4 The Sewage System

The Sucre city sewerage system is used for wastewater and does not have a rainwater collection system. This system offers a coverage of 85.7%. However, its projection for 2015 is only 82.0%. Even so, ELAPAS ensures the collection of wastewater and their transportation from the system to the treatment plant. In 2009, the sewerage network was expanded by 6,350 linear meters of pipe in Lajastambo.

5.6 Potosí - the Capital of the Department of Potosí

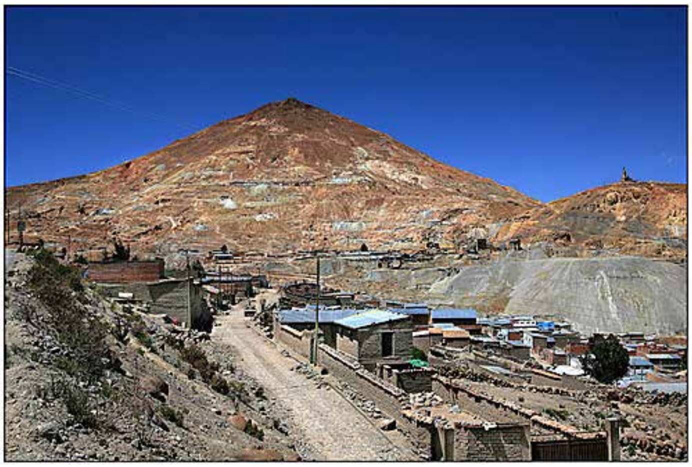
The District of Potosi is in the southern geographical section of the Eastern Range of the Andes. It covers a territory of 1,255 square kilometers, while the city of Potosí occupies 19.8 square kilometers as urban area. This urban area includes twelve districts, while the rural area includes four districts. In terms of physical geography, the territory comprising the District of Potosí has scarce planes and plateaus and some intermediate planes between mountain ranges where the city of Potosí is located. Geologically, volcanic and sedimentary rock are predominant, conforming an interesting complex.

Table 5.5 Number of connections and percentage-wise participation according to type of user according to type of user january-november 2009 and 2010 (in number of connections)

Type of user	January to November 2009		January to November 2010		Percentage Variation
	Consumption	Percentage Variation	Consumption	Percentage Variation	
Total	**46,796**	**100.00**	**49,383**	**100.00**	**5.53**
Domestic	43,965	93.95	46,440	94.04	5.63
Commercial	1,969	4.21	2,061	4.17	4.67
Industrial	113	0.74	115	1.23	1.77
State	749	1.60	767	1.55	(2.40)

Source: Local Aqueduct and Sewerage System Service (SeLA), (SeLA), Oruro and National Statistics Institute (INE), 2011

Figure 5.2 Mining contamination in the city of Potosí.



It has a population of 133,268 inhabitants (CNPV for 2001) and 59,734 dwellings. Of these, 86.55% have piped-in water. It has an annual rainfall of 360 mm. and an average monthly temperature between 5.2° and 13.7°C.

5.6.1 Hydrography

In terms of hydrography, the rivers in the district of Potosí belong to the Pilcomayo subbasin, which is part of the Río de la Plata macrobasin. Along its trajectory the Pilcomayo River receives as tributaries the rivers known as the Mayus, which crosses the district, and the Tarapaya.

5.6.2 Drinking Water Resources

The administration of the facilities offering drinking water and sewage coverage to the city of Potosí is the responsibility of the Autonomous Administration for Sanitary Prospects (UAAPOS). During the five-year period from 1998 to 2002, the drinking water network has been expanded, taking in an overall total of 14,538 meters, corrective maintenance on the network (change of intake), preventive maintenance and changes in the main network running 3,250 meters, and changes in connections to 330 dwellings. Until 2002, the drinking water distribution network operated as a single circuit. In order to ensure that the water supply is continuous and at a pressure in accordance with national and international standards, it is now divided into two circuits: (a) the Chapini Circuit 1 and b) The Chapini Circuit 2.

The city of Potosí receives its supply of drinking water from surface water sources, collected and stored in 22 ponds, which allow for the impounding of 8,114,000 cubic meters, with a transportation network, or aqueducts, from six different subbasins, transported to the city, by six systems, to the Millner Treatment Plants built in 1974, where they enter a main tank with a capacity of 2,500 cubic meters and are gravity-fed to the distribution network.

a. The Kari Kari Ponds Source. The water from the Kari Kari Lagoons is used for human consumption. This system is vulnerable due to such natural phenomena as El Niño, characterized by an increase in temperature and a reduction of rainfall, causing a decrease in the water stored.

   The water stored in the Kari Kari ponds reaches a total of 8,114,000 cubic meters. However, during the dry season it drops to 2,143,489 cubic meters, presenting problems in its quality, since the sludge it carries aggravates the problems in the treatment plant due to the plugging of filters. This system has 32 artificial ponds which feed six treatment systems.

   There is also the possibility of incorporating the Laka Chaka water basin to complement the sources of supply that exist at Kari Kari. The waters from the Laka Chaka system are being transported by an intake system to mining plants. The water potential of this system is very high, and there is a junction of connections between the intake at mining plants and the Chalvir Millner intake.

b. The San Juan River Source This surface water source has been in use since the end of 1999, and has such modules as intake works, an intake line, a storage tank and chlorination station. The storage tank is in Cerro Chico. From here water is sent to the Chapini tank and to the network. This network supplies 97.21 liters per second –the equivalent of 3,065,709 cubic meters annually for a consumption of 64 liters per inhabitant per day. This is the equivalent of a deficiency in the system, which must operate at a total capacity of 150 liters per second.

c. The La Palca Pumping Source. This source of surface water is below the level where Potosí is located. Accordingly, it must use a pumping system. Due to its high operating cost, this system is not used and is held in reserve in case of severe drought.

5.6.2 The Treatment Plant

Until 2011, the district of Potosí had only a system of filters where the flow entered each storage tank. This did not guarantee a supply of water in accordance with the Bolivian quality standards.

The Government of Japan donated 14.6 million dollars for the construction of a water treatment plant and the rehabilitation of the intake ductwork. The plant furnishes drinking water to up to 95% of the population of Potosí, benefitting more than 73,586 persons. The drinking water treatment plant includes decanting, filtration and reagent treatment systems. It treats a flow of 510 cubic meters per hour.

5.7 Tarija, the Capital City of the Department of Tarija

The city of Tarija is the capital of the department and is administered by the Autonomous Municipal Government of the City of Tarija in Cercado Province. In 2007, the urban population in the district of Tarija was 79.8% and the rural population, 21.2% of the total population of 279,274 inhabitants, with an annual population growth of 3.1% and an annual migration rate of 3.9%. The City Government of Tarija administers twenty districts –thirteen urban and seven rural.

The urbanized area of the city covers 42 square kilometers and has developed in parallel to both banks of the Guadalquivir River –a river with a flow of 4.5 m^3/sec, which crosses the city of Tarija from northwest to southeast. It has 135,651 inhabitants (CNPV for 2001) and a total of 36,126 dwellings, of which 88.14% have piped-in drinking water.

5.7.1 Hydrography

The surface water sources in the Tarija district and Cercado Province are distributed in two subbasins_: (a) the Santa Ana River and (b) that of the Tolomosa and Sella Rivers, both of which are tributaries of the Guadalquivir River. Both subbasins belong to the Grande river of Tarija, the Bermejo River basin and, in turn, to the Río de la Plata macrobasin.

In 2007, the Prefecture of Tarija undertook the Huacata Project to relieve the water shortage in the Central Valley –especially during the dry season. The project built a reservoir to hold water in the Huataca River basin in the north and to transfer it to the Guadalquivir River basin. With the water from the Huacata, several communities in the highest part of the Guadalquivir River basin receive both drinking water and water for irrigation. With the water from the Huacata and the water from other sources, the Tarija Water and Sewerage Services Co-operative (COSAALT, Ltd.) can expand the volume of the drinking water networks.

The Prefecture of the Department and COSAALT worked on the Guadalquivir River Sanitation Project as an overall environmental recovery project for the river, with several complementary components. The sanitation of the Guadalquivir River benefits the entire Central Valley, which covers 3,060 square kilometers, taking in a large part of the districts of Cercado, Avilés and Méndez and covering a population estimated at 250,000 inhabitants (in 2007) –175,000 urban inhabitants and 75,000 rural inhabitants.

5.7.2 Drinking Water Resources

a. Surface Water Sources

In 1986, the Tarija Drinking Water and Sanitary Sewerage Services Co-operative (COSAALT, Ltd.) was established. It holds the concession for water use and sewerage services, with a life of forty years. It has shown an average increase of 92 new connections monthly. Accordingly, in 2007 there were 26,018 users while in 2012 there were 31,702 users. The incumbent Government of the Plurinational State of Bolivia granted a license to continue the operation of the co-operative service by issuing, in 2010, Regulatory Administrative Resolution AAPS No. 251/2010.

In the Municipal Government of the City of Tarja and Cercado Province there are several possible sources of surface water supply. None of them, however, can completely cover the present and future demand by itself (see Table 5.6). The La Victoria River efficiently covers the demand only during the rainy season. Neither could other surface water sources, regulated by reservoirs, meet the demand, since there is a limited flow for human supply, with the greatest part of the flow being used for agricultural irrigation. Among this group of sources, are the projects for the Huacata, Calderillas and Tolomosa River reservoirs. .

In order to adequately meet the hourly variations in consumption it is necessary to increase the storage both in the zones now in use and those contemplated for future urban extension growth areas. To do this, an increase of 12,600 additional cubic meters is being contemplated.

Table 5.6 Average annual flow from surface water sources

Province	Source	Type of Intake	Area (km²)	Average Annual Flow (liters/second))
Cercado	La Victoria Galería	Subsurface	34.36	924
	Victoria 1	Surface	32.05	
	Victoria 2	Surface	28.14	
	Erquis	Subsurface	104.95	907
	Las Tirpas	Surface	913.31	5,939

Source: COSSALT, 2011.

The production reported by COSAALT for 2011 was 15,792,026 cubic meters, or the equivalent of 501 liters per second –an amount insufficient to meet the maximum daily demand. Table 5.6 shows the average annual flow of the present surface water sources for 2011.

In Cercado province, the present water coverage is 97% (44,599 families). The projects currently planned will permit a coverage of 99% (45,750 families), leaving only 359 families with no water coverage.

In sum, the surface water sources for the supply of water to the city of Tarija are as follows:

- The el Rincón de La Victoria River
- The Erquis River, (which supplies the users in Tomatitas)
- The Guadalquivir River (Las Tipas)
- Lake San Jacinto

b. Groundwater Sources

COSSALT controls 15 groundwater wells, but only six of them operate during the dry season. In addition, a preliminary hydrogeological study was performed in the Guadalquivir River basin, taking in the Cercado, Méndez and Avliés provinces. It identified the presence of two types of aquifers located in the zones mentioned below:

A. A multi-layer aquifer in fluvio-lacustrine sediment where water circulates at a lesser depth, with the ability to be transported at rates between 10 and 300 square meters [sic] per day.

B. An aquifer of hard, fractured rock (with secondary permeability) where water flows at greater depths.

The potential zones identified are as follows:

1. The Northeastern strip of the city
2. The San Luis-San Blas zone
3. The alluvial plain at the foothills of the Tolomosa-San Andrés-Tablada subbasin

5.7.3 The Treatment Plant

Since the nineties, a part of the wastewater from the city of Tarija has been treated in the oxidation ponds located in the San Luis zone. In the urban parts of the city, with no sewage system, wastewater is treated in septic tanks, generally poorly managed or are thrown untreated into the numerous ravines. It is estimated that about thirty-five percent of all wastewaters is discarded untreated.

The oxidation ponds discharge effluents into the Guadalquivir River. However, the ponds are wholly inadequate and insufficient to treat the total volume of the city's wastewater. The overloading of the ponds causes foul odors which become worse during periods of brusque changes in barometric pressure and daily temperatures. In addition, due to spontaneous urban expansion, the ponds are now within the city's urban boundaries.

5.7.4 The Sewage System

COSAALT is in the process of expanding the urban drinking water and sewage networks, and intends to raise the current coverage from 65% to 90% by 2030. In 2007, as a first stage, COSAALT undertook a program to expand the sewage network to 46 outlying neighborhoods and the construction of 40 kilometers of wastewater collectors.

In 2011, COSSALT had 27,382 household sanitary sewerage connections, offering a coverage of 82% of the total dwellings registered in the district.

5.7.5 Environmental Contamination

COSAALT, as a concessionaire, controls the discharges of fifteen industries in Tarija. These industries have permits which regulate the allowable discharges. Only one industrial plant has wastewater pretreatment facilities, and a great part of the industrial wastewaters produced do not enter the sewage system, thus contaminating the subsoil. An evaluation of the available data indicates that about 35% of all urban wastewater is industrial. Howsoever, these waters contribute approximately 50% of the total wastewater load. The data from COSAALT indicates that only 14% of the total load is regulated.

Certain industries in Tarija do not discharge their wastewater at the San Luis plant. These include the municipal slaughterhouse and a number of tanners –major producers of wastewaters with high BOD and COD concentrations. The impression is that the industries regulated represent only a small part of all industrial wastewaters. The connection of these industries to the PTAR (wastewater treatment plant) not only produces a greater volume of wastewater but also possibly cause greater treatment problems.

Untreated wastewater in the city and the rural centers severely contaminates the Guadalquivir River. Downstream of the city are several communities of small producers, who use untreated, raw water to irrigate vegetables destined to the city's markets.

The following three components have been designed for the treatment of household and industrial wastewaters: (i) the construction of a new Wastewater Treatment Plant (PTAR); (ii) decentralized pre-treatment of Tarija's industrial waters, and (iii) the reuse of treated water as irrigation water for grapes and fruit agriculture in the driest regions of the Central Valley.

This plant will replace the oxidation ponds at San Luis, which are wholly inadequate to treat the household and industrial wastewaters and are sources of increasingly serious environmental deterioration. This plant, with anaerobic technology in combination with biological filters, will be located at La Pintada, and have the capacity to meet all requirements until 2030, and a population estimated at 480,000 inhabitants.

5.8 Trinidad, the Capital City of the Department of Beni

Trinidad, the section capitalof Cercado province is located in the southeastern section of the Department of Beni. It is the capital of the Department of Beni. The urban radius is bounded on the west by the Ibare River, on the north by the Mocoví River; on the east and south there is a radius of eleven kilometers from the center of the main plaza. Within the urban perimeter a radius of intensive use has been defined, reaching five miles in any direction, outside of which use is more extensive. There is neither planning nor regulation of the use of the soil outside the urban perimeter.

The climate is warm and humid, with an average annual temperature of 26° Celsius, fluctuating from 8°C to 38°C. The cold season, from May to June, is characterized by cold southern winds, known as *"surazos"*. The months with higher precipitation are from November to March. The average annual rainfall is 1,900 mm. The heaviest rainfall recorded on a single day was 319 mm.

In 2002, the "Case Study: Use of Land in the Trinidad District" was commissioned, introducing an environmental approach to urban planning. This study identified four environmentally sensitive zones, five buffer zones and several zones subject to flooding and hazards.

A basic environmental change occurred in 1997, with the shift of the Mamoré River bed five kilometers to the west. As a result, the area surrounding Trinidad no longer receives floodwaters from the overflow of the main river. Since that time, urban developments have proliferated in the southern and western part of the city, in a zone defined as a protection and forestry zone. Apart from lacking the basic necessary services, natural disaster situations have arisen, with hundreds of families left homeless by the heavy rains and flooding. There is a project profile of a far-reaching programm prepared to build an "Ecological Belt", with a pumping station which would make these lands habitable.-

In addition, the change of course of the Mamoré River has decreased the lateral recharge of the aquifer as a source of drinking water, to the extent that it cannot maintain the flow expected for a system of high quality water for the city. A definitive solution to the quantity and quality problem would be to bring the water from the Mamoré River twelve kilometers away.

The lack of employment opportunities in the Beni Department has increased the influx of population to the capital, causing a rapid spread of the unplanned urban sprawl. There has been an increase in the percentage of population without basic services (drinking water, electric energy, sewage etc.) This has produced a consequent increase in the contamination of the sources of water, the soil, with foul odors, the proliferation of disease carriers and public health problems.

The city of Trinidad has 75,285 inhabitants (CNPV for 2001) and a total of 16,145 dwellings. Of these, 47.15% have piped-in water.)

5.8.1 Hydrography

The city of Trinidad, founded on the right bank of the Mamorée River, is surrounded by several waterways and a series of drainage canals which tend to flood the city. The Mamorée River is one of the main bodies running through the Amazon River macrobasin in Bolivia. It has a flow of 1,690 cubic meters per second as it passes near Trinidad.

5.8.2 Drinking Water Resources

The supply of drinking water in the city of Trinidad is the responsibility of the Trinidad Drinking Water Service Co-operative (COATRI), founded in 1988 with the past assets and liabilities of the Beni Regional Sanitation Works Administration.

The source of the water supply is a system of groundwater, with a battery of eighteen wells drilled to depths from 44 to 144 meters. The diameter of the wells is six to ten inches. Overall, they offer a flow of 112 liters per second and a daily production of 10,500 cubic meters. Annually, a total of 1,295,208 cubic meters of water are distributed. Since 2003, water has been available twenty-four hours a day.

The basic household water tariff in Trinidad is one of the highest in the country after Camiri and Asunción de Guarayos. It is higher than the tariff recommended by the Pan-American Health Organization for developing countries, of between one and two working days' pay monthly.

Until 2005, the COATRI had a total of 7,875 household and industrial connections. Taking as an average 6.5 inhabitants per connection as its basis, the COATRI estimates that the population served was between 51,000 inhabitants, or 60% of the population.

In the city, the co-operative holds a concession contract covering an area of 1,780 hectares. The concession confers on COATRI the exclusive right to the use and the obligation to distribute water within the geographical limits defined. The geographical extension of the concession does not cover the entire urbanized area of the city.

Apart from COATRI's scant coverage of access to water services, not only in Trinidad but also throughout the municipality, the water from natural water wells is of poor quality, with excesses of magnesium and iron. This gives it a salty taste and, sometimes, a brown color and disagreeable smell. The presence of fine-grained soils, iron and other minerals means that the wells drilled require constant maintenance and cleaning to maintain their flow. If timely maintenance is not performed, the well could be unusable in barely more than a year.

A project has been designed to draw water from an old branch of the Mamoré River in the village of Puerto Varador. This water comes from filtration activities and, while untreated, is of high quality, with a flow sufficient to supply the city.

Another problem foreseen in implementing the new water system is the insufficient capacity of the piping system to withstand the increased water pressure. This could cause underground leaks, since many of the pipes are either obsolete or were designed for the old system, which did not generate much pressure.

The construction of the drinking water treatment plant was concluded and offers a treatment capacity of 600 cubic meters per hour. This made it possible to cancel nine active wells. The system operates with seven wells of greater diameter.

5.8.3 Sanitary Sewerage

As a component of the Drinking Water and Sanitary Sewage Project, a sanitary sewage system is being implemented in Trinidad, with financing from KfW in Germany. COATRI estimates that it will offer services to 60% of the population. The system has 38,217 meters of underground pipe and three pumping stations.

The sewage system was finished and put into operation in 2004. In all, 4,644 subscribers enrolled in the system with long-term financing. Approximately 400 members connect to the system every year.

In 2005, 401 new connections were formed, thanks to a joint venture between the Prefecture of Beni, the Office of the Mayor of Trinidad and COATRI, subsidizing the cost of household connections. During this same project clandestine connections were detected but they have not been quantified. At present there are a total of 1,476 official connections.

Due to the city's flat topography, the system operates with four pumping stations. Should a power failure coincide with heavy rains, the system could spill over, causing generalized contamination in a large part of the city. For this reason, installation of an emergency power supply is necessary, to include three electric generators. This was not contemplated in the project. It has also been found that in the central part of the city, rainwater enters the wastewater system. This causes the pumping system to overload, with wastewater spilling over into some dwellings.

With regard to industry, not all industries are in the sewer system's area of coverage. Accordingly, they continue emptying their effluents into nearby waterways (Caso Nudelpa, the Marbán slaughterhouse and some tanners). This situation has caused canals, drains and ditches of water are being used as a reservoir for wastewater. This causes foul odors, visual contamination and the proliferation of the carriers of diseases. Therefore, such waterways as the San Juan creek have been contaminated with wastewater. In addition, there exists the possibility of these wastes infiltrating directly from latrines and contaminating the groundwater sources that serve to supply drinking water to the city.

5.8.4 Rainwater Drainage

Rainwater drainage is one of the most basic problems of the city of Trinidad. The Trinidad district is in a zone with a slope of 0%, a high average rainfall, on preponderantly clay soil, which complicates natural water runoff. In addition, the natural system which used to exist in Trinidad, which allowed the water from the northern part of the city to drain into the Mocoví creek, has been slowly interrupted as thoroughfares are paved, informal neighborhoods are established on the river bed, and blocking it with bridges and sediment. In the case of District 8, the existence of rice paddies on the wetlands has interrupted the natural flow that drained into the Mocoví channel, This has caused the water to stagnate and streets to flood. In addition, Trinidad has no drainage system which could efficiently evacuate the large volume of rainwater. The provisional water evacuation system comprises a series of ditches or canals built without adequate planning, which are constantly plugged due to lack of timely maintenance.

Based on a topographical survey, the Master Plan defines a series of eight drainage basins for the urban area. It also identifies a series of reservoirs which would absorb the torrential rains until the pumping equipment could empty them within a prudent period. Of the existing reservoirs, the San Juan Creek is the most important –the only internal rainwater reservoir, clogged with sediment and residue, and with an uninterrupted flow for many years. This situation means that rain causes prolonged flooding in the low-lying parts of the city, with consequent overflowing of latrines and canals. There is a Master Rainwater Drainage Plan, drafted between 1999 and 2001 which set forth a definitive solution to the problem. However, it has not been implemented.

5.8.5 Environmental Contamination

The water treatment system has a capacity of 10,500 cubic meters per day. This system contemplates three treatment stages: sedimentation, oxidation and maturation. Properly treated water is expelled to the southwest of the city through a creek known as El Estribo.

The growth and development of the Municipality of Trinidad has given rise to activities which release contaminants and have negative impacts on the air, water and soil, as well as on natural resources and biological diversity. These impacts affect the environment, health and quality of human life. Worldwide, the main causes or situations identified as causing negative environmental impacts on the Municipality of Trinidad are the following:

- Deficient handling of garbage
- Deficient handling of liquid urban and industrial waste
- Deficient rainwater drainage
- The rapid growth of informal urban settlements
- Deficient drinking water service
- The disorganization and rapid growth of the vehicle fleet
- Improper use and occupation of the soil and space
- The unsustainable exploitation of natural resources

5.9 Cobija, the Capital City of the Department of Pando

Cobija is an Autonomous District and the capital city of the Department of Pando. It is the only urban agglomeration to the north of the Bolivian Amazon. It is located on the bank of the Acre River, the natural border with Brazil, at an altitude of 235 meters above sea level. However, it is the least populated departmental capital in the country. It has a population of 20,987 (CNPV for 2001), and a total of 4,923 dwellings, of which 69.31% have piped-in water.

Cobija, together with the Brazilian cities of Epitaciolandia and Brasileia, comprise a single metropolitan area. The three cities are located on the bank of the Acre River, with which they have established a number of relationships, among them being the use of water resources, which also have a negative impact on the environment.

5.9.2 Hydrography

The entire Cobija District is in the hydrographic basin of the Acre River. This basin occupies an area of approximately 30,000 square kilometers and covers territory in Bolivia, Brazil and Peru. The Acre River is the receptor body of all of Cobija's surface water and is a tributary on the left bank of the Purús River, whose headwaters are in Peru, and discharges on the right bank of the Amazon River in Brazilian territory.

The Acre River establishes the northern boundary of the Municipality. At the same time, it is the border between Bolivia and Brazil. It crosses Bolivia West to East, from Bolpebra to Cobija, along a course 125 kilometers long, receiving water from the subbasins of the Bahía, Virtudes, Noaya, Buenos Aires, Madre de Dios, San Miguel and Píapi creeks. It changes course from north to south in the city of Cobija, entering Brazilian territory and discharging into the Purús River.

5.9.3 Drinking Water Resources

The supply, distribution and treatment of water in the city of Cobija are carried out by the Cobija Drinking Water Supply Co-operative (COSAPCO). The supply of drinking water comes from the Bahía creek, on the border with Brazil. Bahía creek has a continuous flow with low flow periods of 0.7 cubic meters per second. However, for lack of dilution, its waters during this period are highly contaminated and murky. The level of the water depends to a great deal on the rainfall in the tributary basin, and on the calming effect produced by the Acre River. The variations in its level are around 10 meters, reaching very low levels, of a 1 to 1.5 metersduring dry periods.

The water capture works are installed in a floating structure, with one pumping unit and a deficiently installed suction pipe. Due to urban growth, this water capture work is located downstream of both Bolivian and Brazilian urban areas, which spill their wastewaters into the creek.

The lack of urban planning to regulate human settlements in harmony with the overall population growth, the limited economic capacity of the municipal government to provide a sanitary sewerage network to these new settlements, added to the lack of a garbage and liquid waste handling system to improve or expand the discharge collection and control systems, have created a complicated environmental and social problem in the middle and upper watershed of the Bahía Creek. .

The water supply service is deficient in the high parts of the city and the capacity of the system is limited by the treatment plant, which can operate at a flow of 33 liters per second. The system operates eighteen hours a day. Cobija has, as its main future source of public water supply, the Acre River, which is the river with the greatest flow, and the Bahía and Virtudes creeks, which are its tributaries.

In relation to the use of groundwater in the future, preliminary studies reveal the difficulty of finding water available and of physical and chemical qualities fit for human consumption.

With regard to the coverage of the sanitary sewerage system, it is minimal in Cobija. This service operates –and there with considerable difficulties– only in the neighborhoods which have implemented the "Neighborhood Improvement" program implemented by the City Government by a loan agreement from the National Regional Development Fund. This has been implemented in nine neighborhoods.

A rainwater sewage system exists only in the old part of the city, and has collapsed completely, engendering problems in the pavement in this area. In addition, there is no project to solve this problem.

6. Conclusions

In Bolivia, for many years, in both its urban and rural areas, most of the plans or projects for the supply and the proper and sustainable use of water have not been implemented, for multiple reasons both political and economic. These include the failure to pass a new Water Law (of which more than thirty-five drafts have been submitted to the legislature for consideration) to supersede the obsolete law passed in 1906. This has given rise to a lack of integration and coordination of plans and/or projects of the many organisms and organizations both national and local, which act almost autonomously. This integration and coordination is absolutely indispensable to the joint and concerted search for viable solutions to the water cycle.

6.1 The Main Actions Aimed at Containing the Harmful Trends

The following urgent measures are suggested, in order to control the processes which now affect or threaten the achievement of the objectives of water resource management:

- The passage of a new Water Law –concerted, flexible and easily enforced, based on the articles of the Federal Constitution of 2009.
- The passage of clear, precise regulations, easily implemented and enforced.
- The passage of laws which complement the Water Law. If necessary, revising, adapting, editing and promoting specific laws sector-by-sector, which foster the preservation of the water cycle through the use of technology which economizes all uses of water and facilitates its economical and efficient reuse.
- Water management must involve and define the role of the Federal Government with the decentralized areas of management and democratic, participatory decision-making.
- Updating of the National Basin Plan proposed by the Minister of Water in May 2007, which uses the water basin as a basic unit for water planning and management.
- To promote and implement the development of mechanisms contributing to the conservation and sustainable, overall use of water resources in transboundary watersheds, from surface waters and groundwater, and the conservation and rational use of wetlands.
- The performance of projects for the expansion and improvement of water and sanitation services, to ensure universal access. The management of water resources must harmonize the present requirements with the needs of future generations.
- Improve tariff systems and the their collection for water services, through mechanisms which enable the subsidizing of only the most vulnerable and needy elements of the population, and promote incentive forthe population to observe sustainable and responsible conduct.
- As far as economically possible, rescue the rivers, especially in parts of the flood valleys which were occupied for urban or industrial development, and eliminate sources of contamination.
- Eliminate the discharge of untreated effluents, supporting activities that confront the cost of treatment, including the original investment, and their operation, and public awareness campaigns.
- Make the users of groundwater more aware of the importance of participating in water management, to ensure its sustainable use. Install groundwater management systems in all Governments and Departments.
- Create a database with GIS data, centralized by the Ministry of the Environment and Water, to include permits for well drilling, environmental licenses, the storage of technical information and data gathered while drilling wells.
- Promote more aggressive actions by the organizations which oversee compliance with the standards prohibiting the contamination of rivers, lakes and aquifers.

6.2 Proposals for the Development of Water Resources in Priority Areas of Water and Sanitation

The main challenge to the country in the drinking water and sanitation sector is to make these services universally available. There is an imperative need to supply millions of inhabitants who lack drinking water and sanitary sewerage.

In addition it is indispensable that projects be implemented to increase wastewater treatment. In addition, the need for rational use of water and the protection of its quality must be disseminated, and the local governments, professionals, technicians and all sectors of the population must be made aware of this.

Therefore, we propose the following:

a. The design and implementation of economically sustainable social investment projects that contemplate, as a priority, making the services universally available, that ensure their financing through the allocation of resources in the budgets of the government agencies;
b. Improving the economic sustainability of the provision of water, achieving a greater rationale in the tariff structure.
c. Increasing the levels of efficiency in the management of operations and in the effectiveness of coordination among sectors and jurisdictions.
d. Refine the system of disseminating information about water management and its results
e. Promote the active participation of the civil society and local authorities, by taking the following actions:
    - Fostering and giving priority to investments in the sector, bearing in mind the resulting benefits and the impact they have on public health, the environment, social cohesion and the economy, including the reduction of indigence and poverty.
    - The integral management of urban wastewaters should be a national priority and should be included in the programs of integral management of water resources basedon the watershed.
    - Establish explicit mechanisms with incentives for the efficient management of the operating companies, and for the rational use of the services. The tariffplans should contain incentives for the rationalization of water use and the supply of water, which could be achieved by investments in maintenance in order to reduce losses in the water distribution systems.
    - Establish tariff levels that make it possible to cover the operating and maintenance costs, and at least in part, the amortization of capital, taking into account subsidies for those users who are unable to pay and, above all, to take into account the negative environmental externalities
    - Promote coherent urban recovery plans for every city.
    - Strengthen the functions of regulation and control in the performance of services, ensuring the technical capability and the independence of action by the responsible organizations.
    - Improve the legal and institutional mechanisms involved in the participation of the civil society and the local authorities, including improvement in the dissemination and communication of information regarding the performance of the operations and the overseeing authorities, and to intensify –basically in primary and secondary schools– the measures for educating students about the problems of drinking water and sanitation.

6.3 The Ordering and Assignment of Priority to Water Resource Management Measures

The National Hydrographic Basins Plan represents a strategic instrument for the productive and sustainable management of water resources. Analyze the potentialities and the problems, establishing the priority of actions and interventions at the hydrographic basin level. The agricultural and forestry potential has been considered the most relevant factor in determining potentialities, while soil erosion and the scope of poverty as the most limiting factors.

For each of the water ecology sectors, the potential has been identified for water-earth-vegetation resources, in addition to the limitations of the soil, erosion, climate, irrigation and flooding. Then the values of the potentialities, the limitations, the deterioration of renewable natural resources and the poverty index have been weighted to determine the level of priority for interventions for each of the water ecology sectors.

6.4 Limitations and Opportunities

Decentralization has established a new relationship between the Federal Government and decentralized units (departments, municipalities). The Federal Government is still responsible for establishing standards , while the local, municipal and regional governments act as required by solving problems within their jurisdictions. This new reality requires greater interaction among governments at different levels.

The hydrographic basins are not in agreement with the administrative jurisdiction that the State has forged by applying territorial and political criteria. This complicates the coordination and the overall management of water resources.

One opportunity to resolve this problem is as follows: the Commonwealth of Municipalities. This could overcome the demarcation of basins and municipal limits, thus creating instances thatwork on the planning and investment of the use and management of water resources.

Another future alternative is to make the demarcation of original communal lands and the protected areas compatible with the basins, offering an adequate space for management by the indigenous population or management by a water resources administration unit.

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Brazil

View of Sao Paulo, Brazil, from Ibirapuera Park. The Ibirapuera is one of Latin America largest city parks.
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"It is estimated that about 12% of the world's surface water resources are located in Brazil, which has always been considered a country rich in water. But the fast urbanization process in the last decades produced several problems and challenges that the country now needs to face"

Urban Waters in Brazil

José Galizia Tundisi, Carlos Eduardo Morelli Tucci,
Fernando Rosado Spilki, Ivanildo Hespanhol,
José Almir Cirilo, Marcos Cortesão Barnsley Scheuenstuhl,
and Natalia Andricioli Periotto

Summary

In Brazil, the accelerated urbanization process in the last decades has brought many challenges such as higher demands for water, solutions to treat high volumes of wastewater adequately, alternatives for disposal of solid waste, and access to urban water facilities for the population as a whole.

An Integrated Urban Water Management plan is needed for every town, especially in metropolitan regions. This plan should address issues as the integration of investments and action plans of urban regions in the same watershed, capacity building of professionals that control urban water facilities and manage watersheds, recovery of green areas that are crucial for groundwater recharge and for the maintenance of water quality and quantity. It is also essential to monitor the quality of the water distributed, in order to prevent threats to human health like gastroenteritis and cholera.

Due to growing water demands and increasing water pollution, and to prevent the deterioration of unpolluted water sources in metropolitan regions, water reuse has become a potential solution in order to avoid import of water from other watersheds. On the other hand, water transport may be the best alternative for semi-arid regions, where there is scarcity of water sources.

1. Introduction: Challenges for Strategic Management of Cities in the 21st Century

At present more than 60% of the world population is concentrated in urban regions. The large urban expansion in the last decades of the 20th Century and in the first decade of the 21st Century brought innumerous problems of water availability and distribution, soil waste disposal, soil use and drainage.

Cities are the engine of economic and social development in this 21st Century. In the whole planet we have, at present, 600 cities that represents a Gross Product of 65 trillion dollars; more than half of the World Gross Product of 113 trillion dollars. Those cities are poles of technological, commercial, industrial and services development. In Latin America, 57 cities have this fundamental role in the economy of the South American continent.

Urbanization demands more water, more energy, produces more waste (solid, and wastewater) and degrades forest areas. Air, soil, and water pollution are consequences of this urban growth. This results in economic pressures on the municipality in order to solve the problems of impacts, with consequences on the economy and human health.

The management of cities, in general, do not have strategic nor integrated plans. These should be expressed in a Master Plan that should be the locus where aggregation of all plans –economic, infrastructure, social, environmental with a systemic view– is summarized. For a sustainable economic growth there is a need for team work, considering the city as a complex and dynamic system; integrating economic development with social and environmental processes and promoting innovations in public health, education and access to information.

Basic sanitation combined with 100% distribution of water, providing adequate access to all inhabitants is another challenge. Periurban areas of small, medium or large cities are vulnerable to the problems of water distribution, wastewater treatment, and need improvement in sanitation.

Water issues in urban areas have a direct and relevant link to human health and quality of life of the population. Human health problems caused by water borne diseases have an economic impact in the cities. Sanitary education of the population, individual and collective practices of sanitation and prevention are the best attitudes to promote a healthy environment in the cities.

The use of green spaces as Forest Parks or Ecological Stations is another public policy that can help considerably in the maintenance of the water cycle and the water availability. Water treatment of protected sources is much cheaper and economic, than water treatment of unprotected sources.

By combining projects of water protection, water distribution, wastewater treatment and reforestation with native species, the water cycle in the urban regions could be much improved considering water supply and water quality. This includes surface water and groundwater.

Water reuse is fundamental for the improvement of the water cycle in cities. Reuse of treated wastewater for several purposes can alleviate the pressure on natural water sources. Finally, the mobilization of the urban population in order to actively participate in the reduction of water demand, improvement of water quality and protection of water sources is fundamental.

Therefore, the integration of structural measures (urban river restoration, reforestation) with non-structural measures, such as environmental education, is a fundamental process in the urban water management in Latin America.

The management of cities can be advanced and creative if a true development agenda and a modernization approach are combined to promote a sustainable growth. The continuity of programs of infrastructure, education and environmental issues is a fundamental measure with social and economic long term consequences. The water problems of urban regions are at the center of this agenda.

2. Urban Systems

2.1 Concepts of Urbanization Processes and Urban Waters

Urban systems are primordially areas of consumption and housing. It is bounded by areas of high population density, sustained by biophysical systems of larger coverage than the urban area (Rees, 2003). An urban system has different sizes or integrates various urban-rural spaces such as a Metropolitan Region.

In 1900, 13% of the global population was urban; in 2007 it increased to 49.4%, occupying only 2.8% of global territory. In 2050 it was forecasted to be 69.6% of the world's urban population (UN, 2009). The world is becoming increasingly urban as a result of economic development and jobs distribution. In developed countries the population is stabilized and urban population is already large, but in developing countries the population is still growing and in 2050 the world population will be about 9 billion and most of its growth will be in the cities (UN, 2009).

Urban development accelerated in the second half of the 20th century with the concentration of population in reduced spaces. Countries such as Brazil moved from 55% of urban population in 1970 to 86% nowadays, occupying only 29% of the country area with a mean urban density[1] of 65 persons per hectare (6,500 per km^2) (Embrapa, 2008). However, the two largest countries in population, India and China, respectively, are below 40% of urban population and are moving up in this urbanization scenario (UN, 2009).

Urbanization increases the competition for the same natural resources (air, land and water) in a small space for human needs on living, production and amenities. The environment of natural resources and population (socio-economic and urban) is a living and dynamic being that generates a set of interconnected effects, which if not controlled, can lead the city to a chaos.

In the urban environment the driving force is the urbanization. Urban water infra-structure generally includes both water supply & sanitation facilities (WSS). Sanitation refers to domestic and industrial sewage collecting and treatment. It does not include urban stormwater or solid waste management systems. Urban water related facilities provided by the cities include water supply, sanitation, stormwater and solid waste. They are components of a sustainable urban environment which includes the environment conservation, health and social-economic aspects of the urban development.

The main problem related to the city and its elements has been the fragmentary way through which management is developed. The Urban Master Plan usually does not take into account all the infra-structures such as urban waters. Urban water facilities are also fragmented, since usually there is not one institution covering all services nor integration between institutions. The outputs are poor and there are no indicators of efficiency.

Urban Water facilities should deliver safe water to the population (water supply); collect and treat the sewage produced by the city before it is delivered back to the rivers, in order to protect the environment and its source of waters (conservation for the future) avoiding the spread of diseases (sanitation); develop stormwater systems for the rain water after the urban occupation and mitigate its effects; collect the solid waste and dispose it in adequate places, avoiding the spread of human waste in the natural system by the drainage (solid waste). As it can be seen the main objectives of these services are related to security (urban drainage flood control), health and environment conservation. Environment in an urban ecosystem is also related to other environmental actions in the relation of soil and air which are also related to water management.

Integrated Water Resource Management has been the main tool for sound development of water management at a basin level. The city is part of a large basin or includes several small basins in its space. The city uses water from upstream in the basin for its supply and sends its effluent downstream in the basin. These are external components of the city which should be managed together with the main basin which support these boundaries.

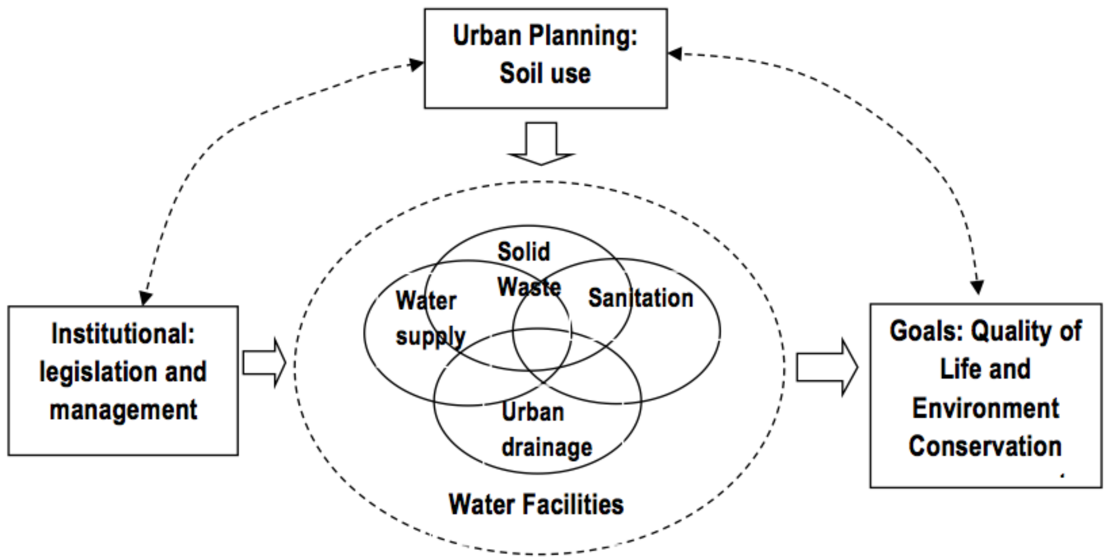
In urban environment, IUWM is referred to specifically as **Integrated Urban Water Management (IUWM)**. IUWM includes the management of the water facilities and their interactions (Figure 1). These interactions include urban development (driver based on economic and social development of the city), environment and health (main goals) and the Institutional components, represented by the legal framework, management, capacity building and monitoring.

2.2 Urbanization in Developing Countries

Urbanization increases with economic development, since jobs and incomes change from agriculture to services and industry, together with the improving facilities for education, shopping, housing and overall facilities. Large cities have been developed since the last century such as the Metropolitan area of São Paulo in Brazil, which had about 200 thousand inhabitants in the beginning of the twentieth century and 17 million in the end of the century, which represented a mean year rate of 8.5%. There are 388 cities in the world greater than 1 million inhabitants (McGranahan and Marcotulio, 2005) and 16 above 10 million. It was forecasted that in 2010 there would be 60 cities with population greater than 5 million.

1. Urban density is the amount of population in the urban areas and population density of a state, country or region is total population divided by its area.

Figure 1. Components of Integrated Urban Water Management (IUWM)



Source: Tucci, 2009.

There is a strong correlation between population density and economic production, which explains the urban areas as centers of producers, buyers, sellers, firms and workers. The country GDP grows with the population increase in large settlements. High–income countries have 52% of its population in large settlements (>1 million) and low–income countries only 11%. When the country grows its GDP, the tendency is to increase the proportion of the urban population share of consumption vis-à-vis total population (World Bank, 2009).

In developing country cities, part of the population lives in irregular or informal areas usually called slums. The growth in slums has been significant, and their increasing density is the cause of concern, since the greatest rate of population growth occurs particularly among the low income population. Slums are overcrowded with dwellings of poor quality of low income population which occupy unregulated areas without property rights. Therefore, there is the formal and the informal city. Urban management usually reaches the former. This population is lacking most of the services such as water supply, sanitation, drainage and solid waste disposal. These places are environments favorable to develop and spread diseases.

The main problems related to infrastructure and urbanization in developing countries are:

- Large population concentrations in small areas, with inadequate transportation systems, inadequate water supply and sanitation, water, air pollution and flooding. These unsuitable environmental conditions reduce health conditions and the quality of life of the population, cause environmental impacts and are the main limitations for sustainable development;
- Increase of the city's boundaries in an uncontrolled manner by rural migration in search of employment. For instance, Manaus in the Amazon basin, in Brazil, received about 40,000 migrants in 2004, attracted by jobs. This occupation causes impacts on the basins which usually supply the city and increase risks to contaminate this source. These neighborhoods generally lack security, traditional infrastructure for water, sewage, drainage, transportation and collection of solid waste and are dominated by criminal groups usually linked to drug trafficking.
- Urbanization is spontaneous and urban planning is conducted for the portion of the city occupied by the middle and upper income popu-

lation. The slums are developed by an informal market for public areas or area without control, which is invaded by the poor. These can develop into areas of risk such as those with flooding and mudslides, with frequent deaths during rainy periods.

- Urban planning is conducted for the formal city, while the informal city is developed in a spontaneous way, usually near to the source of jobs or market for low income population.
- Limited institutional capacity of the communities with lack of: legislation, law enforcement, maintenance of the facilities, technical support and economical funds. Usually the cities manage the areas of economic income where legislation is enforced and property rights are regulated, called here as regulated city. On the unregulated city usually there are not enough services and facilities for the population. The cities are not prepared to plan and manage this complex human development;
- Lack of Integrated Urban Water Management: most of the Water & Sanitation Management in the cities do not take into account all components of Urban Water Facilities, resulting in: interconnection of stormwater and sewage networks, lack of domestic sewage treatment or inefficient sewage treatment, increased floods on the urban drainage[2], losses in the water distribution systems, solids in the drainage, erosion and occupation of risky areas of flood plains and hill sides (which has been the main causes of deaths during storm events), limited garbage cleaning and education, among others.

2.3 Urban Waters in Developing Countries

2.3.1 Overview

Water is supplied by sources from upstream basins, neighboring basins or groundwater (or combination of these options). After the water is used by the population it is delivered to the streams or treated by septic tanks and delivered into the groundwater which may overspill to drainage and rivers. This system of treatment in highly inefficient, leaving a very important load to the rivers and groundwater. In that way, the water from polluted rivers cannot be used as a source for water supply. The water supply and sanitation practices use clean water upstream (not so actually!) and dumps polluted water downstream. Since the urban development spreads upstream, most of the upstream basin is or will be polluted and the source of clean water will be lost. In addition, the urbanization could also compete with agriculture for space and for water.

Since the city, in many scenarios, does not have capacity to supply all the water, the population finds its own solution by pumping from groundwater which creates risks of pumping contaminated water (shallow aquifer) or salty (in coastal areas).

The urbanization increases impervious areas and channelization which increases the flood peak and the flood frequency for the same rainfall. The urbanization also increases the flow velocity and solids production (sediments and solid waste). Due to the lack of services, most of the solid waste arrives in the rivers, decreasing its flow capacity (and increase flood frequency) and increasing the pollution since most of the storm water pollutants arrive in the rivers together with the solids. Pumping groundwater, together with the reduction of infiltration due to impervious areas, could create subsidence in low land areas which decreases its drainage capacity by gravity and increases flood frequency. In this scenario the area can be flooded by upstream and by the sea (in coastal cities).

In summary, the urban waters in many developing countries are in a contamination cycle and the main issues are (Figure 2):

- Contamination of water supply sources (streams and groundwater) by the developments and untreated sewage and diffusion loads. Deterioration of water quality due to lack of sewage treatment has created potential risks to the water supply for the population in various conditions, and the most critical has been the occupation of areas that contribute to the urban supply reservoirs, which suffering from eutrophication, present health risks to the population.
- Lack of sewage treatment: a large part of the cities do not have sewage networks nor treatment plants. The sewage is released into storm sewers, which flow into urban streams;

2. These floods are created by the urbanization due to poor outdated engineering, corruptions related to high cost design and lack of institutional measures.

- The urbanization increases the impervious areas which increases floods and decreases the infiltration to aquifers. Impervious areas and channelization of urban rivers, increase flood flow (about seven times) and its frequency, increase the erosion and degraded areas, the amount of solids to downstream affecting the quality of urban streams;
- Occupation of risk areas such as flood plains and hill slopes, suffering frequent floods and mudslides with frequent deaths. In Santa Catarina State in Brazil 110 persons died in a sequence of events in November of 2008.
- Water contamination from stormwater and agricultural areas;
- The use of groundwater by the population and the reduction of infiltration increases the land subsidence increasing flood conditions to low areas;
- The lack of management of total solids decreases the river flow capacity due to sedimentation, which then increases flood frequency;

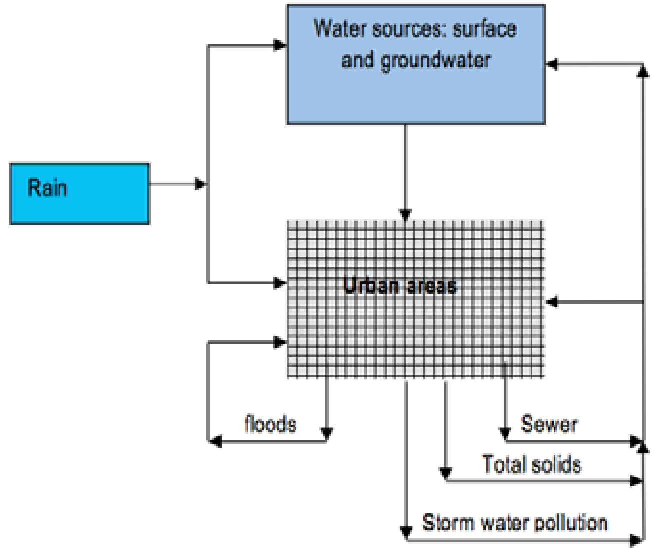
The results of all these are the high impact on the basin environment, coastal areas and the health of the population. The combination of all these factors keep this metropolitan region under risks for the future. Since the urban area is the economic engine of a country, these unsustainable conditions are likely to create an important risk to its future development.

2.3.2 Main Risks

This condition shows that the source of the problems is the uncontrolled and unsustainable way that the urbanization is developed in the city. The main risks are:

I. Health of the Population: some of the risks are:
   - the lack of effluent treatment and appropriate solid waste collecting and disposal create an internal source of contamination which could help the spread of many types of diseases or even an epidemic scenario;
   - The contamination of water sources such as reservoirs by nutrients creates the spreading of algae and the risk of toxicity in the water supply;
   - spreading diseases related to eutrophication of reservoirs and toxins in the water; in floods events diseases such as leptospirosis and hepatitis;

Figure 2. Contamination cycle on urban waters in developing countries



Source: Tucci, 2009.

Table 1. Relations of causes and impacts in urban waters

Main cause	Specific aspects	Impacts
Unsustainable Urban development	High density, impervious areas, unprotected surfaces and sediments	• Increase on flood frequency; • Higher sediment production; • Reducing river conveyance;
Lack of urban water Services	Population without water supply; lack of sewer collection and treatment; lack of solid waste services; lack of urban drainage and flood control management	• Water sources contamination; • Use of unsafe water and diseases; • Reducing river conveyance; • Environmental losses; • Land subsidence.
Bad management	Unsustainable works such as canal, conduits, etc. Lack of institutional management arrangements	• Transferring floods; •Losses in investments; •Lack of urban water services

Source: Tucci, 2009.

- contamination of groundwater and the water supply of the population which uses this type of water;

II. Flood: increase in the flood risk, frequency and the damage for the population, mainly the poor. This vulnerability decreases the economic conditions of the region and the country;

III. Environmental deterioration: degraded areas by erosion, environments of the river and the coast are decreasing the resilience capacity due to so much load deposit into the system. Usually the population pays for the environmental deterioration. The population is receiving environment subsidy;

IV. Decrease of safe water: the lack of safe water from upstream and the capacity of distribution leaves no alternative to the population, which will try to find their own solutions which are usually more risky and more expensive. The international price of 1 m^3 of safe water in the pipes usually is about US $ 1 to 3. In bottled water of 20 liters this amounts to US$ 200 to 300/m^3 and in a bottle of ½ liter in Amsterdam Metro, US$ 7,500/m^3;

V. Overall: Population vulnerability is increasing and the resilience to urban waters issues is decreasing with this type of unsustainable development.

2.3.3. Relationship Between Causes and Impacts

Urban development usually occurs without control in many cities of developing countries. The urban occupation has been developed without an Urban Master Plan which takes into account the urban water sustainability. It is developed from downstream to upstream compromising water sources and increasing flood conditions. Table I shows some relations of urban development and impacts.

The management of urban waters is fragmented by many institutions in Metropolitan Areas. There are many different plans and projects which are in conflict with each other. The institutional development is complex because of the governance changes, enforcement of water law and its implementation by water resources authorities in the basins. It is a combination of institutions at various levels: central, state and local government levels, without integration. As a result, the planning and development in the basin have been fragmented by isolated actions distributed in the area.

The management had the following issues:

- Lack of institutional arrangements which allow integrated solutions in urban water in the metropolitan area and in the basin which supply the region;
- There were many fragmented investments in flood management taking into account only

one type of solution (and expensive) of transferring peak floods to downstream without taking into account future urban growth.Lack of strategic integrated investments for water supply and sanitation in the overall metropolitan area.

- Lack of knowledge: among the population and professionals in different fields who do not have suitable information about the problems and their causes. Therefore, the decisions made result in high costs, and some companies take advantage of this to increase their profits;
- Poor conceptual knowledge among engineering professionals for the planning and control of the systems: an important portion of the engineers who act in urban areas do not have up-to-date information about environmental issues and generally seek structural solutions that alter the environment, creating an excess of impermeable areas and a consequent increase of temperature, flooding, pollution and other problems;
- Sectorial views of urban planning: planning and development of urban areas are conducted without considering factors related to the different components of water infrastructure. An important portion of professionals who act in this area have a limited sectorial view;
- Lack of managerial capacity: municipalities do not have structures for planning and management of the different aspects of water in the urban environment.

2.4 Recommendations for Integrated Urban Water Management

2.4.1. Goals and Targets

The urban water goals should be the following:

- Deliver safe water for human, animal, industrial and commercial use;
- Improve conservation, avoid degradation of areas by erosion, treatment of sewage and stormwater effluents, minimize solids in the streams coming from urban settlements;
- Reduce vulnerability to diseases and floods.

The main actions to develop a sound strategy for an integrated urban water management are:

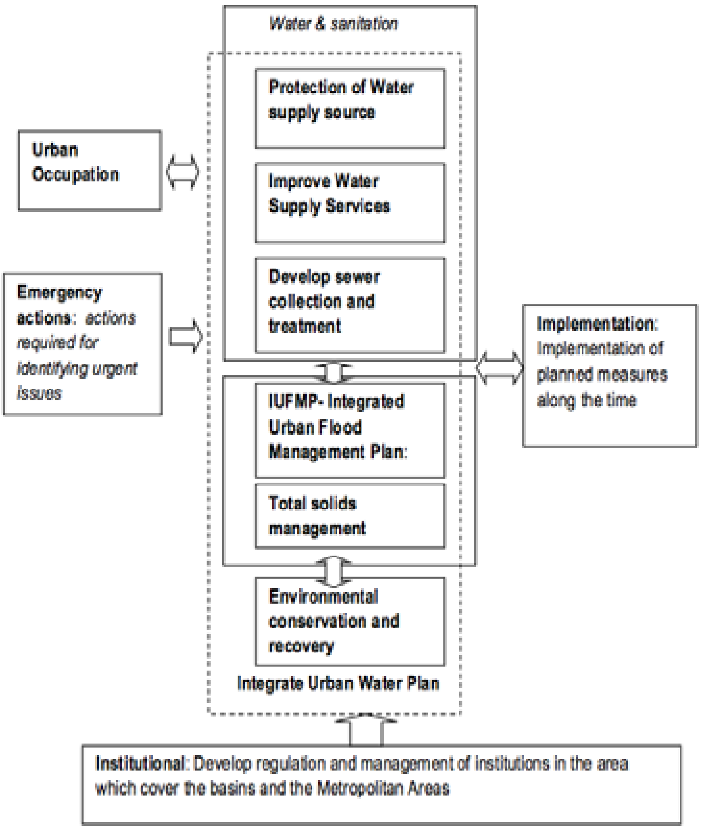
- **Sustainable urban development**. Development of new urban development standards taking into account the sustainability on water issues: (i) limits for densification and impervious areas; (ii) reserve of areas for parks and flood management; (iii) restrictions and economic incentives for conservation of urban source basins;
- **Protect the water supply sources.** Regulate the occupation of the water supply basin; control the load of water supply basin; improve its water quality;
- **Improve the water supply distribution.** Development of a program of investment in order to increase the water supply network and improve the water supply quality;
- **Develop a system of waste treatment.** Investment in the collection and treatment systems for all urban areas;
- **Flood Control Management.** Develop regulation for new development, controlling the future flood increase; develop flood management plans for each basin;
- Total Solids Management. Develop sound services for total solids in order to decrease the amount of solids in the drainage system;
- **Water and environmental conservation**. Storm water pollution control, environment recovery of selected areas;

These targets have to be achieved by an integrated management and interrelated actions inside of a space which covers more than a basin. The development of this integrated plan requires a review of strategies over the three major water sources and the metropolitan area, together with large investments over a longer period. Every component of the plan requires specific goals and strategies.

In order to achieve these goals following steps should be taken:

- **Assessment of the urban water issues:** identification of the problems in urban waters and the integrated aspects;
- **Plans and Strategies:** development of the planning for solution of the problems in the urban water services in the city;
- **Action Plan:** implementing strategies in urban waters in time, taking into account the needs and the economic and financial aspects of the investments.

Figure 3. Framework of the main activities



Source: Tucci, 2009.

2.4.2 Plans and Strategies

The main plans and strategies for the urban management in the city are (Figure 3):

- Urban occupation: develop or review the Urban Master Plan in order to include the regulation related to urban waters;
- Water and Sanitation[3]: it is related to the protection of the water supply sources, provide water supply and sewer collection and treatment;
- Total solids: it is also a plan to improve the services and reduce the amount of solids from sediments and solid waste which reaches the drainage system;
- Flood management and urban drainage is the development of the measures described in section 2.3 for a sound plan for flood control;
- Environment: it is a plan for recovery of degraded areas in the metropolitan area and for a long term recovery of the rivers and coastal environment, after the services described in the other services are provided;
- In order to have plans feasible in their implementation, there is a need for institutional construction of the water management in the basin and at a state level.

The development of this integrated plan is an important challenge since most of these plans used to be developed in an independent way without connections and sometimes with conflicting conditions. The main difficulty is to identify skilled professionals with understanding of the overlapping aspects and issues which should be solved in an integrated way.

3. Water Supply Services

3.1 Overview

As mentioned, one of the main issues to be managed in urban systems is the water supply. In general, the distribution of treated water is adequate for 90% of the population. As for the water quality of the sources, there are several impacts such as lack of wastewater treatment, deforestation, inadequate or non-planned soil uses, and contamination of surface and groundwaters.

The introduction of an integrated management of urban watersheds, the need to integrate the water resources issues in the Master Plan of the cities, the protection of the water sources and the permanent monitoring of water available versus water demand are some of the possible measures to promote a better management of water supply services.

The loss of treated water in the urban distribution network is 30%. The introduction of new and advanced technologies to treat water, wastewater, protect urban forests, reduce losses and advance in legislation such as payment for ecosystem services are some possibilities to improve management. Education and capacity building of managers play a fundamental role in the process.

3. Sanitation usually includes sewer systems, urban drainage and control of total solids. Here we are only considering sewer systems.

3.2 Urbanization and Sources of Water

The fast urbanization process of Brazil in the last 50 years produced several problems in all stages of the water supply, water treatment and wastewater treatment: supply of adequate water for the urban population, distribution of water and wastewater treatment. The urban development in Brazil has increased the frequency of flooding, production of sediments and deterioration of water quality. As the urbanization progresses, the impact increases due to the fact that the urban infrastructure is not organized during the process: problems of urban drainage, construction of roads, bridges and channels, deforestation, are not included in the evaluation of urban plans (Tucci, 2006). The significant impact on the maximum discharge is one of the important consequences of the urbanization along with changes in the soil cover, increase of floods and environmental deterioration in general. It is in this general picture that the water supply services occur in Brazil.

The sources of water for public supply in Brazil from surface waters, in most cases, are located in the peri-urban regions, or groundwaters located in the urban area or in the rural areas. In general, the urban demand for domestic supply is usually sufficient from the small watersheds around the urban area. Small watersheds (<500 km^2) in the South East of Brazil have specific discharges of 15 to 25 liters/sec/ km^2 (Tucci, 2006). This is sufficient for the domestic use of 200 liters/inhabitants/day. However as urbanization develops, the water quality of surface and groundwaters deteriorates; therefore, it is necessary to use other sources of supply.

These sources can be far from the water treatment stations, generally located in the urban center. Therefore, this increases the need for more energy for the pumping of the water from the sources. There is an additional problem that increases the cost of treatment: if the water source is well preserved with gallery forests, wetlands, or mosaics of vegetation, the cost of treatment for producing potable water is low. The figure is around 2 or 3 US dollars for 1.000 m^3 treated. This is the case when there is no need for chemical treatment. If the supply source is contaminated, the chemical treatment (coagulants, activated charcoal, and others) increases the cost to U$ 200 or U$ 300/1.000m^3 treated (Tundisi and Matsumura Tundisi, 2010). This is the cost of the deterioration of the supply source. Official statistical data inform that in Brazil, 90% of the population receives treated water in their residence. The remaining 10% uses groundwater usually from local wells at each house or village. In the South and part of the South East, deep wells (120-500m) pump water from the Guarani underground reserve, a huge water resource (43.000 km^3) shared by Brazil, Paraguay, Uruguay and Argentina. These are groundwaters of high quality, so the cost of pumping is compensated by the small cost of water treatment.

The loss of the water supply services in Brazil is approximately 30% in the pipelines after treatment. However there are cities where 60% loss is common. This is due to the old infrastructure of the pipelines. In some cases this infrastructure has more than 100 years of age. It is also to be noted that there is no information about the water quality in the pipelines after treatment and in the distribution process.

3.3 Threats to Water Supply (Quantity and Quality)

3.3.1 Competitive Uses of Water

In Brazil 70% of the water available in the watersheds is consumed by agricultural activities. In some regions (E. G. South East, South, Center West) competitive uses for agriculture and industry threatens the water supply for domestic use.

3.3.2 Water Quality Degradation

The water quality degradation is one of the biggest problems of Brazil in the beginning of the 21st Century. The main causes of water quality degradation are:

- **Deforestation.** The lack of vegetation cover is a cause for the deterioration and loss of quality of surface and groundwaters. Deforestation also impairs recharge to the aquifers.
- **Lack of wastewater treatment.** In Brazil, only 47 % of the wastewater is treated. This produces an enormous amount of organic matter that deteriorates the water quality of surface and groundwater.
- **Surface drainage.** The surface drainage of waters in most cases is full of solid waste residues (plastic, papers, glass, and organic matter). This is another source of deterioration.
- **Transport of sediment.** Due to erosion in the soil

Table 2. Classes of uses of water supplies for human consumption, and protection of water sources and ecosystems

Level 1	Level 2	Level 3	Level 4
Water supply for human consumption	Water supply for human consumption (Conventional treatment)	Water supply for human consumption (advanced treatment)	Navigation
Water supply for protection of aquatic life	Protection of aquatic communities	Irrigation of trees (fruits) or food for animals	Landscape
Water supply for recreation	Recreation with primary contact	Fisheries	Harmony
Irrigation of vegetation	Irrigation of vegetables	Recreation of secondary contact	
Protection of aquatic communities in indigenous lands	Aquaculture and fisheries	Water supply for animals	

of the urban area, a large amount of suspended sediment can be transported. This suspended sediment carries particulate phosphorus and nitrogen aggregated into the particles of the eroded soil which causes impacts on the water chemical composition and the physical characteristics of the water (temperature, light penetration and conductivity).

- **Industrial wastewater.** Clandestine discharge of industrial wastewater can contaminate surface and underground sources of water supply and produce new challenges and needs for water treatment.
- **Agricultural land discharges.** Discharges of wastewater from agriculture (pesticides, herbicides, fertilizers) are another important threat to water supply systems. These are especially complex because these are non-point sources and therefore, very difficult to control.
- **Persistent organic pollutants.** Persistent organic pollutants (POPs) have several origins but the major sources are those related with the human population as residues of hormones, cosmetics, antibiotics and substances of several origins (organic). These dissolve in the water and are not retained in the traditional technology of water treatment. They need special detection equipment and general studies to promote a better knowledge of their impact on human health (Jorgensen, Tundisi and Matsumura Tundisi, 2012).
- **Contamination of areas of recharge of the aquifers.** In many urban areas the recharge of the aquifers is impaired due to the destruction of green cover (forests, wetlands, riparian forests) by roads, house, and condominiums. Besides this, the contamination of the remaining recharge areas is another problem: deposits of solid waste (open solid waste deposit), residues of construction, fuel/tanks.

3.4 Legislation

The resolution 357 of 17 march, 2005 of the National Council of Environment of Brazil (CONAMA) establishes the classification of freshwater, saline and brackish waters in Brazil. This classification is based fundamentally in the water uses. Table II summarizes the classes of use.

This legislation is reinforced by the environmental laws of Brazil –at the federal level– that considers protection of forests, gallery forests, forests corridors, wetlands and regulates the pollution of coastal and inland waters (Tucci, 2006).

At each municipality there are specific laws regulating soil uses, urban development and construction processes. The integration of federal, state and municipal legislation is one of the main challenges to control the water supply services in Brazil.

3.5 Management of Urban Watersheds

The management, control, and recuperation of urban watersheds is of fundamental importance to the water supply services. The Master Plan of the municipality has to incorporate the integrated management of the urban water resources taking into account the watersheds where urbanization occurs. The planning and protection of the water sources and optimization of services should control and interfere with the following processes:

- Evaluation of the water quality of sources, their state of conservation or degradation;
- The relationship water availability/water demand has to be considered in the planning;
- Conservation of the water sources and analysis of future tendencies of urbanization (geographic location) in order to develop priorities for expansion and at the same time protect water sources (surface and underground) (Tucci, 2006);
- Control of land use, monitoring of soil contamination or preservation, monitoring of the water quality and permanent measurement of water availability and demand;
- Improve or introduce new legislation at the municipal level in order to prevent excessive soil use and occupation, presence of water sources, protect and develop urban forests and green spaces in order to maintain an adequate balance between urban and natural areas;
- Mobilize the population, schools, private initiative in order to develop a participatory approach to integrated watershed management. Education at all levels is fundamental;
- The capacity building of manager's, technicians and other participants of the municipal administration is also extremely relevant. The lack of a systemic vision of the municipality and its urban region, the lack of knowledge between protection of natural resources of the municipality and the areas of expansion is one of the problems that impair an efficient management of the water supply services in many urban regions of Brazil;
- Financial resources and stimulus to promote a better institutional organization in the urban regions of Brazil are other initiatives that certainly will have an effect in the management of water resources. The administration and maintenance of good governance depends upon the integration of several administrative departments such as housing, environment, science, and water services.

3.6 Policy Recommendations

The deterioration of the water sources in Brazil is a reality. Although Brazil has a competent and up-to-data legislation and available technological resources to solve the complex problem of protection of water sources and distribution, this was not achieved with the necessary efficiency to improve the water quality at the source and to decrease the vulnerability of populations (Bicudo et al., 2010). The populations of the periurban areas of large metropolis or even medium size cities are the most affected and vulnerable. Since there is a strong link between quality and distribution of water, human health and economy, it is necessary to develop a strategic vision in the evaluation of the main problems to be solved (Tundisi et al., 2012).

At present, the following issues related to the water supply services are fundamental in Brazil:

- **Protection of surface and underground sources.** Reforestation, urban forests and parks, gallery forests in urban regions should have highest priorities. Channelization should be banned. The construction of channels in the urban environment decreases biodiversity and causes loss of ecological services;
- **Improve the legislation at the urban level.** The payment for ecological services could be introduced as a complementary measure for the protection of the sources (Heide et al., 2013);
- **Improve the water treatment and technology** in order to analyze and remove the organic pollutants from the water;
- **Improve and increase the efficiency and frequency of monitoring at all levels** (from the source to the tap). Appropriate use of indicator parameters;
- As a large scale priority **wastewater treatment** is fundamental for Brazil. The wastewater treatment technology should consider advanced methods as well as new projects such as the use of wetlands to improve the process and lower the costs of treatment. Ecohydrology and ecotechnologies should be implemented;
- Another priority is to include in the Master Plan of each town or city **projects for the protection of water sources, control of urban drainage, and soil use regulation** (Tucci, 2006, 2010). Water resources should be part of an integrated management plan for the whole city;

- **Develop a statistical data bank for Human Health and Water Supply Quality** in order to establish and consolidate an integrated policy for the urban areas;
- **Vulnerability assessment of urban populations** exposed to risks of water shortage and degradation of water quality;
- The **adoption of new advanced technologies** such as the ecohydrology principles as introduced and discussed by Zaleswky (2014) in the recovery and management of urban water sources should improve considerably the new vision of water and watershed management in urban areas in Brazil;
- **Reintroduce, at the urban level, the concept of mosaics of vegetation** in order to improve the landscape, increase self-purification potential, reduce soil erosion and improve water quality;
- **More efficient water delivery infrastructure and technology** with decreasing water consumption per capita;
- Finally, one of the greatest problems for adequate water supply in Brazil is the implementation and execution of ideas projects and plans. There are sufficient financial resources. There are plans and projects. The execution is not adequate, or fails or is too slow. There is a strong need for **capacity building of managers to implement projects and plans** with great efficiency and rapidly, with a systemic and integrated vision, of the future.

4. Water and Health

4.1 Overview

Together with the problems of water supply in non-planned urban systems, probably one of the biggest challenges in the management of water resources in large Brazilian metropolitan regions is related to the impacts of waterborne diseases as a consequence of the low rates of sewage treatment and due to a very deficient legislation and parameters for monitoring microbiological quality of water (Hupffer et al., 2013).

The methods used to monitor the quality of raw water used for catchment and distribution in Brazil may partly explain the gastroenteritis as the major threats related to water contamination in Brazil. Disease outbreaks linked to classical waterborne diseases, such as cholera for example (last great outbreak occurred in 1999 in the north of the country), are sporadic or localized in specific regions, like in the mouth of the Amazon River. It is well established that the classical microbiological indicators, namely faecal coliforms, have good relationship with the presence of Vibrio cholerae and Salmonella typhi (Sobsey and Meschke, 2003). However, as mentioned, these diseases are infrequent in the present Brazilian reality. Moreover, the absence of coliforms, the main parameter for microbiological water quality officially used in Brazil, does not necessarily reflect the safety of the drinking water for the presence of pathogens resistant to water treatment systems, such as enteric viruses and intestinal protozoa (Sobsey and Meschke, 2003; Hupfer et al., 2013).

4.2 The Burden of Gastroenteritis in Brazil

In Brazil, the main threat to human health among other waterborne diseases is gastroenteritis, which is characterized by vomiting and diarrhea, and is caused by viruses, protozoa or bacteria. Gastroenteritis represents more than 80% of diseases related to inadequate environmental sanitation in Brazil (IBGE, 2011). These diseases are a great burden to the health care system, occupy thousands of hospital beds, and affect more often children.

The World Health Organization (WHO) claims the poor sanitation as a serious threat to human health. Although widespread in the world, the lack of sanitation is still very much associated with poverty affecting mostly low-income people, vulnerable to malnutrition and often by improper hygiene (WHO, 2008). Diseases related to water and sewage systems deficiencies with inadequate hygiene cause the deaths of millions of people every year, with prevalence in low-income countries (GDP per capita of less than U.S. $ 825.00). According to the World Health Organization (WHO, 2008), 88% of deaths from diarrheal diseases in the world are caused by inadequate sanitation. From these deaths, approximately 84% are children (Kronemberger, 2012). It is estimated that 2 million children die each year, especially in developing countries, due to diarrhea. There is a lack of studies about the number of cases of fecal-oral transmitted diseases in Brazil, but in a survey conducted by the Fundação Getúlio

Vargas, it was demonstrated that near 54,400 persons were admitted to hospitals presenting clinical signs of diarrhea in the 100 biggest Brazilian cities during the year 2011 (Kronemberger, 2012). From these, 28,594 were children under 5 years of age. For the whole country, 396,048 people were hospitalized due to gastroenteritis during this same year (138,447 children). This same study showed that for the 20 cities with higher rates of sewage treatment, 14.6 cases/ 100,000 inhabitants versus an average of 363 cases/ 100,000 inhabitants in the 10 with the lower levels of sewage treatment, when analyzing the data for the 100 biggest cities. It means that the average hospitalization in the cities with the worst level of sewage treatment was 25 times greater (Kronemberger, 2012). It is noteworthy that overall many cases are not included in the reports by the hospitals and many others are not attended in the public health service, thus are not included in the statistics.

Viruses are the most frequent etiological agents of gastroenteritis in human beings. There are more than 100 different types of viruses found in human waste and all are potentially transmitted by water (Brunkard et al., 2011). The types and concentrations of the viruses detected in sewage or sites contaminated by releases of untreated sewage demonstrate the flow of the virus in the population and reflect the most prevalent viral infections in the community and the level of water pollution (Vieira et al., 2012). It is known that enteric viruses such as poliovirus, rotavirus, calicivirus, adenoviruses and hepatitis A virus are present in the gastrointestinal tract of infected individuals, are eliminated through feces in large quantities (105-1011 / g of feces) and are capable of directly or indirectly contaminate water (Rigotto et al., 2010). As mentioned before, the current applied techniques to measure the microbiological safety of water in Brazil does not include the detection of viral (or protozoan) pathogens (Vecchia et al. 2012). Contamination of water sources can occur due to the lack of sewage treatment, inadequate maintenance of the pipe network, reservoirs and landfills, which in turn can contaminate groundwater. Another remarkable problem is that the technologies for monitoring and the processes currently applied to the treatment of drinking water in Brazil are not effective to avoid the risk of viral contamination (Hupfer et al., 2013).

The monitoring of viral particles is usually neglected by water companies due to the difficulty and complexity of the procedures involved to accomplish this task. However, a wide variety of viruses responsible for various diseases such as acute gastroenteritis and hepatitis have been detected in different matrices of aquatic studies in many countries, including Brazil (Vieira et al. 2012). The absence of routine analysis by virological monitoring services and supply of drinking water has been characterized as a problem worldwide (Vecchia et al., 2012). A number of different reports showed the presence of viruses and protozoa in Brazilian surface water. In many of these studies, it is recurrent that the rates found in different regions are higher than those found in surface water for the north hemisphere or even in Latin American countries with higher levels of sanitation. A survey conducted in the state of São Paulo revealed enteric viruses in 85% of 60 untreated raw water samples analyzed, of which approximately 25% were due to adenoviruses (AdV) and enteroviruses (EV) (Cetesb, 2011). In a study performed with conventional PCR on water samples collected from the Arroio Dilúvio, a water stream that crosses the city of Porto Alegre, Brazil (Vecchia et al. 2012), AdV was detected in 21.4% of samples while EV in 64.3%. In a different study carried out in Florianopolis, Brazil, 84 samples of water from different sources, collected from 2007 to 2008, were analyzed by molecular methods and integrated cell culture-PCR procedure. AdV genome was detected in 64.2% of samples. The study showed that in viral samples positive for AdV, 88.8% were infectious (Rigotto et al. 2010). A survey conducted by Vieira et al. (2012), in which 144 water samples from Rodrigo de Freitas Lagoon in Rio de Janeiro, Brazil, were analyzed by qualitative and quantitative polymerase chain reaction assays, AdV virus was less prevalent (16.7%), while group A rotavirus was the most prevalent (24.3%) followed by Norovirus (18.8%). Another study undertaken in Manaus, Brazil, analyzing water from natural streams by conventional PCR, revealed that in 52 samples collected from 13 different sites, 44.2% contained rotavirus genome, followed by AdV (30.8%), astrovirus (15.4%) and norovirus (5.8%) (Miagostovich et al., 2008).

4.3 Recommendations

Considering the high rates of detection of these viral agents in water matrices, the number of cases of diarrhea and the absence of correlation between the presence of fecal coliforms and viral or protozoan agents, the Brazilian guidelines for the quality of drinking water should be revised. Another urgent goal is to improve the levels of sewage treatment in Brazilian cities to minimize the discharge of contaminated wastewater into the water bodies used for production of drinking water. These strategies should be prioritized to diminish the burden of gastroenteritis in Brazil.

5. Conservation and Water Reuse as Management Tools

5.1 Overview

As part of the Integrated Urban Water Management, water reuse and conservation actions should be planned and implemented to protect water supplies from deterioration, protect human and ecosystem health, reduce costs of water treatment and to make water demands and uses of urban systems as sustainable as possible.

Water reuse is an urgent solution that copes with the problems of limited availability of water sources and water pollution mainly in Metropolitan Regions.

5.2 Water Availability and Reuse

Following the UN´s World Conference on Water and Environment in 1992, held in Dublin, Scotland (ICWE, 1992), water began to be seen as an economic good that should be used sparingly. In Brazil, the National Policy on Water Resources (Law N. 9433, January 1997) was instituted, which established the "charging for the use of water resource subject to licenses." This law also established the legal and administrative structure of the National System of Water Resources (Law N. 9984, July 2000) and created the National Water Agency in addition to a resolution that established general criteria for granting rights to using water resources (CONAMA Resolution N. 16, May 2001).

Charging for the use of water is an extremely beneficial tool for both the conservation of water, since it induces the management of the demand, as well as for the protection of the environment, promoting the reduction of effluent discharge into water bodies. However, due to the trend of population and industrial growth, especially in large conurbations, water availability tends to decrease over time, while the available water resources are kept relatively constant in terms of flow, but not in terms of quality (Hespanhol, 2008).

The Metropolitan Region of São Paulo (MRSP) is an example of the problem of water availability. This region is supplied by approximately 74 m^3/s of surface water and 10 m^3/s of groundwater sources, totaling 84 m^3/s. Since the MRSP is located in the headwaters of the Alto Tietê Basin, the local availability of water is not sufficient to provide water to the 20 million inhabitants and to one of the largest industrial areas in the world. Therefore, it imports water from other watersheds, such as the Piracicaba-Capivari- Jundiaí Hydrographic Basin, which contributes with a reversal of 33 m^3/s to the waters of the MRSP. The adducted 84 m^3/s generates a flow of approximately 67 m^3/s. Since the capacity installed in the sewage treatment plants of the MRSP is of 16 m^3/s, the remaining 51 m^3/s of raw sewage is dumped, untreated, into the receptor bodies of water in the region, rendering them increasingly polluted.

Sustainability of water supply systems should be viewed based on the probability in which the water supply system will be able to permanently meet demands, in satisfactory condition. The most important variables that determine (or not) a condition of sustainability are: (i) robustness, reflecting consistent performance and the ability to meet increasing demand, even under several types of stress; (ii) resilience, the ability of the system to regain its appropriate state following negative impacts, such as losing service capacity from supply sources; and (iii) vulnerability, the magnitude of the failing of a supply system (Hashimoto et al., 1982).

The system that supplies the MRSP is therefore unsustainable, seeing that it is not robust and due to the fact that it presents a practically null resilience, as it remains dependent on resources from basins which are also subjected to extreme conditions of water stress. The systematic transfer of large volumes of water from distant sources, generating additional volumes of sewage that are not treated, can no longer be accepted, both in an economical and environmental point of view. This will tend to become increasingly restrictive based on popular awareness, regimentation of professional associations and due to the institutional development of watershed committees who are affected by losing their water resources. The costs associated with new supply systems, tend to be much larger than the costs of existing systems due to nearby, less polluted water sources having already been previously exploited. A study conducted by the World Bank, analyzing the resources invested in projects of international water supply, showed that the cost per cubic meter of drinking water from a new water supply system can be equivalent to two or three times the cost of an existing system (World Bank, 1992). It would be of great importance from a humanistic point of view, to eliminate the discharge of raw sewage into water bodies in the metropolis. These bodies of water should revert into amenities, integrating the population into parks and gardens and establishing conditions for leisure and the development of aquatic sports.

Modern and sustainable solutions that will significantly enhance the robustness and resilience of the water supply system in the MRSP, consists in the management of the demand and the treatment and reuse of water, available in the form of sewage in the MRSP area, to complement public supply. The management of demand consists in the control of losses, especially from public water distribution systems, user awareness through environmental education programs and the implementation of tariff allowances programs. The management of supply is related to the search for alternative sources of provision, including treated domestic and industrial sewage water, use of harvested rainwater and groundwater, supplemented by managed recharge of aquifers. The benefits related to the use of treated water for beneficial uses, as opposed to the disposal or discharge, include the preservation of sources of high quality, environmental protection and economic and social benefits (Asano, 2007).

Water reuse is not exclusively applicable to arid and semi-arid regions or areas with difficult access to water, but also applicable to regions with abundant water resources which are however, insufficient to meet their specific high demands, as in the case of the Metropolitan Region of São Paulo.

Foreseeing at an early stage, the need to modify orthodox policies of water management, particularly in deprived areas, the Economic and Social Council of the United Nations, proposed in 1958 that "unless there is great availability, no good quality water should be used for purposes that tolerate lower quality of water" (United Nations, 1958). The waters of lower quality, such as sewage from households, residues from waste water treatment and industrial effluents, agricultural drainage waters and brackish waters should, whenever possible, be considered as alternative sources for less restrictive uses. The use of appropriate technologies for the development of these sources is today, together with the improvement of the efficiency in use and the management of the demand, the basic strategy for solving the universal problem of water shortage.

The potential for reuse depends on local factors (political decision, institutional agreements and technical availability), and economic, social and cultural factors. The basic principles that guide the practices of reuse are: the preservation of health of groups that are at-risk, the preservation of the environment, consistently meeting quality requirements related to the intended use, and the protection of materials and equipment used in water reuse systems (Hespanhol, 2002, 2008).

Reuse may be intended for urban potable and non-potable purposes, agricultural irrigation, fertilization of lakes in aquaculture practices, industrial purposes, managed recharge of aquifers, restoration of river flows and recreation.

Reused water for urban non-potable purposes, or utilities water, is already being used in the MRSP and in several Brazilian metropolitan regions. The sewage effluents that have gone through biological treatment systems undergo further physical-chemical treatment and are distributed to restricted areas with controlled or uncontrolled access, with special attention given to avoid direct contact with the public (USEPA, 2004; Hespanhol, 1997). The possible uses of water from reuse are: irrigation of parks and public, residential and industrial gardens, sports centers, soccer fields and golf courses, green areas of industries, schools and universities, lawns, trees and decorative bushes along avenues and highways; reserves in the event of fire; decorative aquatic systems, such as fountains and small shallow artificial lakes; washing of vehicles, such as cars, trucks, buses and trains; washing of floors, garages and parks; sanitary flushing in public restrooms and in public and private residential and commercial buildings; cleaning of sewer pipes and rainwater pipes; dust control; construction, for washing aggregates, for preparation and curing of concrete and for moisture control of soil compaction.

Water reuse for urban potable purposes may result from direct or indirect reuse systems. In the indirect use systems water catchment occurs from lakes or river flows that receive treated or untreated sewage (Figure 4). This system is extensively practiced in Brazil, as for example, along the Rio Tietê and the Paraíba do Sul River, and requires efficient management from the environmental agencies in order to avoid adverse impacts on the human health and the environment.

Ideally, this system of indirect potable reuse should be carefully planned, with a secondary sewage treatment unit, normally with activated sludge, and more modernly, with units of submerged biomembranes (IMBRs), followed by advanced treatment systems, and if necessary, followed by a chemical balance prior to being released into surface or groundwater receiving bodies, termed "environmental attenuators" (Figure 5). The purpose of the environmental attenuators is to, by means of dilution, sedimentation, adsorption, ion exchange, among other processes, attenuate the low concentrations of pollutants that still remain following the advanced treatment systems previously used.

The planned indirect potable reuse system would be difficult to be implemented in Brazil today, because the bodies of surface water that could act as environmental attenuators are almost all polluted and therefore would be unable to operate as secondary cleansers. The managed recharge of confined aquifers, as environmental attenuators, is rejected by environmental legislators.

Another system, would be the direct potable reuse, which consists in the advanced treatment of effluents and its direct introduction into a Water Treatment Plant (WTP) that distributes the water in the public system, or into a mix tank upstream of the WTP in which additional flows of surface or groundwater make up the total flow to be treated in the reuse system. In this system, water does not go through environmental attenuators (Figure 6).

In addition to the advanced treatment system and a chemical balancing reservoir, the system contains a retention and certification reservoir, whose goals are to compensate the variability between production and water demand; compensate the variability of the quality of the produced water (practically unnecessary with the advanced treatment systems) and, to provide a sufficient detention time to detect and act upon any possible deficiencies within the process, before the release of the treated water into the distribution system.

In view of the current situation, we are faced with the challenge of substituting orthodox mechanisms of water management, in order to address the sustainability of water supply in the urban sector. This needs to be done through the universal practice of water reuse, more specifically through the practice of direct potable reuse using existing networks of water distribution and their expansions. Many countries with localized water stress have been using this practice: Namibia, Australia, South Africa, Belgium, Singapore and the United States.

Among the factors that contribute towards changing the dogmas regarding water management in Brazil are, the pollution of the possible bodies of surface receptors, which prevents their action as environmental attenuators; the rarity, distance from and pollution of potential sources for water supply; and the lack of technical acknowledgement regarding the managed practice of aquifer recharge. The systems of water distribution and their existing extensions can be used and there is no need for building new systems, seeing that there are advanced technologies that remove traces of organic and inorganic contaminants and pathogenic organisms that are not removed in traditional water treatment systems. An assessment conducted in the United States (Tchobanoglous et al, 2011) concluded that the total cost of a parallel distribution system for drinking water, treated at an advanced level would range between R\$ 0.7/m^3 to R\$ 4.00 R\$/m^3 (0.32 US\$/m^3 to 1.70 US\$/ m^3), whereas a typical advanced treatment system, including membranes systems and advanced oxidation processes would range between 1.3 R\$/m^3 to R\$ 2.2/m^3 (US\$ 0.57/m^3 to 0.97 US\$/m^3). Investments

Figure 4. Typical scenario of unplanned indirect reuse systems occurring in a series

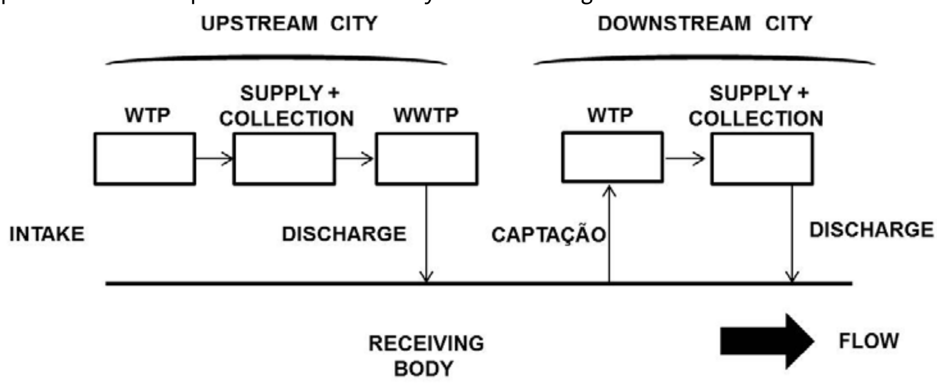
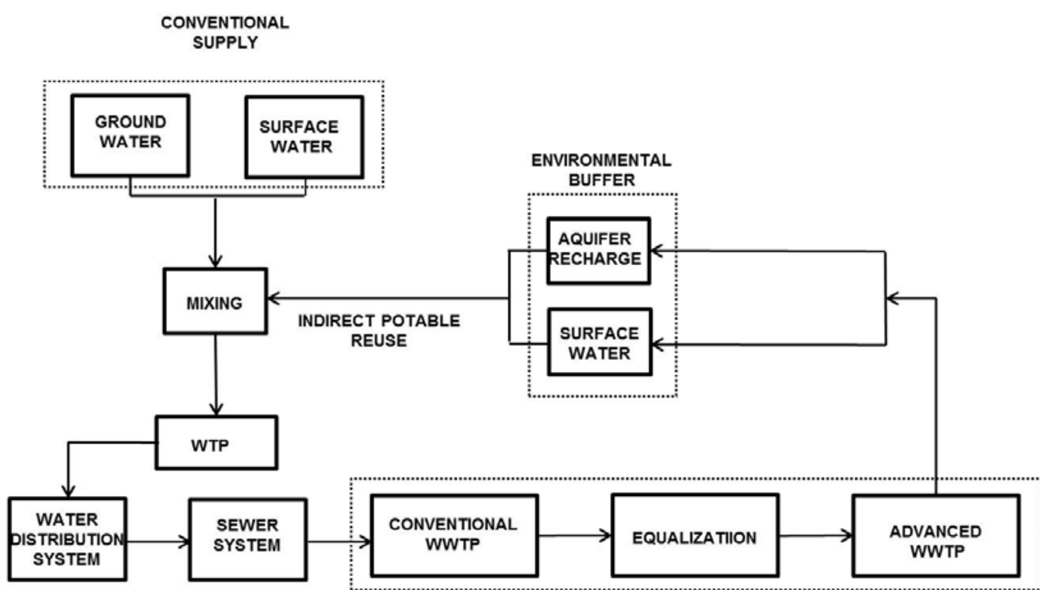


Figure 5. Basic diagram of a planned indirect potable reuse system



Source: adapted from Tchobanoglous et al., 2011

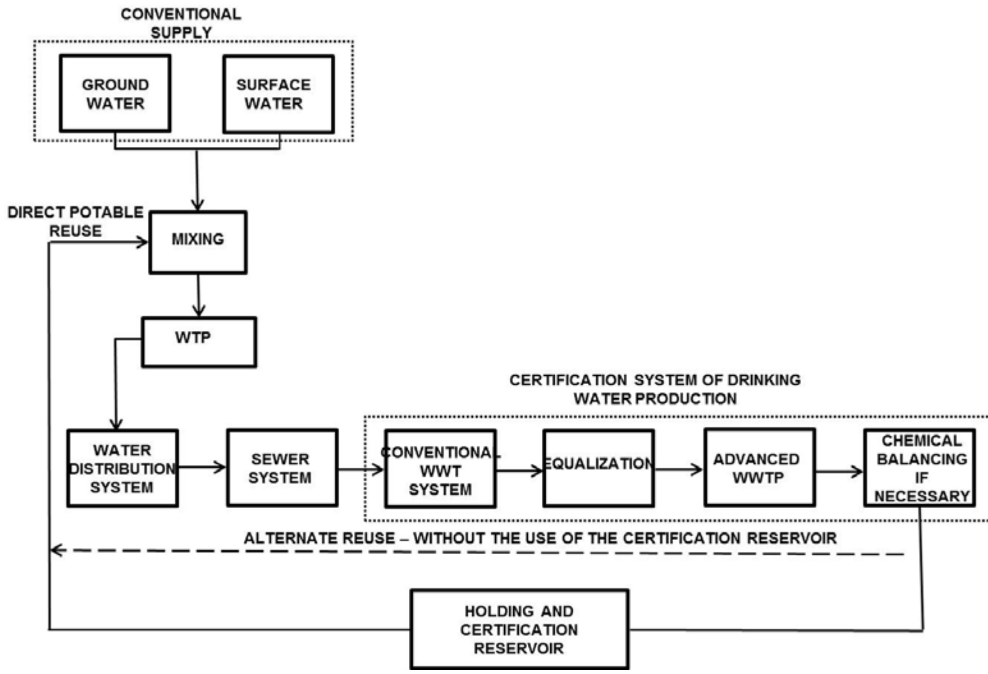
made towards the implementation of an advanced treatment, outweighs the investments for the construction of a parallel distribution network of water with conventional treatment. In the case of the MRSP it would avoid the costs of construction and maintenance of pipelines for raw water coming from other basins in addition to not jeopardizing the supply of water in basins under water stress, such as the PCJ Basin.

The factors that delay and inhibit the practice of reuse are the inadequate regulation of restrictive norms that do not represent the actual Brazilian conditions and do not protect the environment and the public health of the groups at risk. There is also a negative perception with regards to the use of recycled water and a lack of trust towards in governmental proposals.

5.3 Recommendations

Even though Brazil has a significant percentage of the world's water resources, many regions face water resources that are less than 200 cubic meters per inhabitant per year, which generates critical supply conditions and conflicts in uses of water. In cases like the MRSP, where water is imported from other water basins, it is necessary to **observe whether the regions considered apt for undergoing reversal**

Figure 6. Direct potable reuse



Source: adapted from Tchobanoglous et al., 2011

practices, possess the water resources compatible to their needs and if the additional volumes of sewage that are generated, are adequately treated and disposed of.

It is necessary to **adopt a new management paradigm** based on the keywords conservation and water reuse. The industries of the state of São Paulo are already investing financial resources in the implementation of conservation and water reuse programs, reducing their consumption between 40 to 80%. Agriculture, which accounts for approximately 70% of the water consumption in Brazil, has been assessing the benefits of reuse, which provides nutrients and micronutrients for crops, eliminating the need for the use of synthetic fertilizers. The reuse of water for aquaculture, for managed recharge of aquifer and recreation, still do not exist in Brazil.

The indirect potable reuse systems are not very viable in Brazil, since the underground springs and the bodies of surface water do not possess the technical conditions or are so heavily polluted that they cannot be used as environmental attenuators. It is inexorable that, within a maximum period of a decade, the practice of direct potable reuse, using modern treatment technologies and advanced systems for risk management and operational control, will be, despite the psychological, legal and institutional reactions that constrain it, the most plausible alternative for actually providing real drinking water. In addition to solving the problem of quality, direct potable reuse would be strongly associated with supply security, since it would use available sources of supply within the locations of consumption, eliminating, for example, the need for long and costly construction of pipelines, which usually transfer water to urban centers collected from areas affected by water stress

In order to universalize the practice of reuse in Brazil it is necessary to: (i) develop a realistic legal framework to regulate, guide and promote the practice of water reuse, including norms, water quality standards, codes of practice and institutional responsibilities for the different means of reuse, especially for urban and agricultural use; (ii) encourage reuse of water by creating awareness of the values and benefits of the practice, by creating research and development programs, by implementing demonstration programs and projects, by introducing specific credit lines, and by establishing specific criteria for funding reuse projects. The initiative for these actions could come from the National Water Agency – ANA, the Department of Water Resources of the Ministry of Environment, the state departments of water resources, the basin committees and the local and state sanitation companies.

The sanitation companies should develop studies and surveys, in conjunction with certified research centers to: (i) assess, technically and economically, operations and individual processes, as well as advanced treatment systems for direct potable reuse within Brazilian conditions; (ii) study the dimension and establish operational criteria for reservoirs and certificates of the quality for reused water; (iii) assess the possibilities and the technical and economic implications for the use of existing networks and their extensions, for the distribution of potable reuse water; (iv) develop educational and awareness programs to promote public acceptance of the practice of direct potable reuse. Relevant arguments refer to the security of supply and the provision of safe water to consumers of the public water supply systems; and (v) overcome the self-protectionist and immediatist procedures of the regulatory bodies, who should be guided towards developing realistic norms, standards and codes of practices based on studies and research and not through copying aliens rules and guidelines that do not represent our technical, cultural, environmental and public health conditions.

6. Cities in Dry Zones and How the Water Supply is Organized

Brazilian dry zones present particular characteristics of precipitation, deterioration of surface and groundwaters and great distance in relation to other watersheds, so that specific actions of Urban Water Management must be implemented concerning the water supplies and distribution of adequate water for the semi-arid population.

6.1 Characterization of the Brazilian Semiarid

The driest area in Brazil, classified as semi-arid, extends across eight states of the Northeast (Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe) in addition to the North of Minas Gerais, totaling a territorial extension of 980,133.079 km². Proportionally to the area of the states, 93.0% of the territory of Rio Grande do Norte, 87.6% of Pernambuco, 86.7% of Ceará, 86.2% of Paraíba, 69.3% of Bahia 59.4% of Piaui, 50.7% of Sergipe, 45.3% of Alagoas and 17.5% of Minas Gerais are included in the semiarid region.

The term semi-arid usually generically describes the climate and the regions where the average annual rainfall is between 250 and 500 mm, and where vegetation is composed mainly by shrubs that lose their leaves during the driest months or by pastures that dry up during the dry seasons. Typical biomes of the semi-arid regions are the steppes like those in Kazakhstan, the Australian outbacks and the caatinga, which is typical of the Brazilian Northeast.

The interannual variation of precipitation in the Northeast is very large and depends mainly on two phenomena of the ocean-atmosphere system, the El Niño / Southern Oscillation (or anti-El Niño / Southern Oscillation) and the Atlantic Dipole. The El Niño is the warming of the sea water in the tropical Pacific from the coast Peru / Ecuador up to the west of the Pacific. La Niña is the opposite, in other words, the cooling of sea water in the Tropical Pacific from the coast of South America to the west of the Pacific. The El Niño phenomenon has been identified as being responsible for the most severe droughts in the region.

6.2 Demographic Distribution

The results of the Population Census conducted by IBGE – Brazilian Institute of Geography and Statistics indicated that the population living in the Brazilian semi-arid reached a total of 22,598,318 inhabitants in 2010, representing 11.85% of the Brazilian population and 42.57% of the population residing in the Northeast.

The five most densely populated municipalities of the semi-arid are Feira de Santana – BA (556 642 inhabitants), Campina Grande – PB (385 213 inhabitants), Caucaia – CE (325 441 inhabitants), Caruaru – PE (314 912 inhabitants) and Vitória da Conquista – BA (306 866 inhabitants). According to analysis of the INSA – National Institute for Semi-Arid, of the 1,135 municipalities of which the semi-arid is composed of, the vast majority (93.4%)

Table 3. Classification of municipalities in the Brazilian semi-arid region according to the size of the resident population

Population	Number of Cities	Classification	Sum of the population of all cities in the group
Up to 5.000	190	Small	697.046
5.001 to 10.000	264	Small	1.882.695
10.001 to 20.000	373	Small	5.323.977
20.001 to 50.000	233	Small	6.836.496
50.001 to 100.000	57	Medium	3.723.683
100.001 to 500.000	17	Large	3.577.779
500.001 to 900.000	1	Large	556.642
Total	1135		22.598.318

Source: INSA, 2014; classification proposed by the Ministry of Social Development and Fight Against Hunger, 2004.

is considered small, followed by 5.0% medium and 1.6% large as can be deduced from Table III. Of the total population of the semiarid, 65.2% reside in small municipalities, 16.5% in medium sized municipalities and 18.3% in large municipalities.

6.3 Water Supply

In 2006 ANA – The National Water Agency concluded the Northeast Urban Water Supply Atlas. The study performed a diagnosis of the water supply, consisting of an analysis of the watersheds and water producing systems of 1256 municipalities within the Brazilian semiarid region. From the total of the 1256 municipalities, 737 (58.7%) are supplied by Isolated Systems and 519 (41.3%) by Integrated Systems (a single system serving more than one municipality).

In the ATLAS study area, the quality of surface and groundwater is shown to be compromised in most watersheds, due to human activities related to improper disposal of solid waste, indiscriminate use of agricultural inputs, the deficiency or absence of sewage treatment systems, the carrying of inorganic fillers from mining and processing of ores and deforestation and improper soil management, which results in erosion and siltation of rivers.

Ana´s study took into account three different time spans in order to quantify the demands over water – short (by 2005), medium (by 2015) and long term (by 2025), taking into account two distinct scenarios: (1)Trend Scenario, in which you project the use of water resources following a historical background; and (2) Optimistic Scenario, in the event that goals are met related to the reduction of losses of water supply systems; management of the demands deriving from development poles; increase in irrigated area with smaller individual demands.

The study conducted by ANA concluded that 72% of the municipalities located within the study area show a population growth trend until 2025 (24.3% with strong growth and 51.2% with moderate growth), while 22.9% will possibly suffer population loss (3.2% with significant losses and 17.2% with moderate losses). A total of 4.9% of municipalities were identified with a tendency towards stagnation.

Assuming the optimistic scenario for 2025, the Atlas concludes that:

- The total water demands of the studied cities is 734 m^3/s;
- The demands for water, for irrigation purposes represent 58% of this total (427 m^3/s);
- The demands for human supply correspond to 27% (198 m^3/s);
- Water supply for industries will require 73 m^3/s, 10% of the total estimated demand;
- The demand for watering livestock will correspond to approximately 5% of the total (36 m^3/s).

Of the expected demand for water supply in 2025, 185.4 m^3/s will be required to supply the urban areas (93.5%) and 12.9 m^3/s to supply the rural population (6.5%).

6.4 Identification of the Problem

In order to identify the supply difficulties, the municipal headquarters were classified by ANA as follows:

- Satisfactory supply –the water sources and the water production system are sufficient to supply the demands within the planning prospects;
- Critical situation per system –the capacity of water production of the system is not sufficient to meet the demands within the planning prospects;
- Critical situation per water source –the availability of water of the water sources is not sufficient to meet the demands within the planning prospects;
- Critical situation per water source and system –both the water sources and the production system indicate a deficiency regarding the balance of supply and demand within the planning prospects.

For the Optimistic scenario and prospects for 2025, the Atlas concluded that, of the 1256 analyzed municipalities, 26.8% will be adequately served by supply systems, corresponding to a population of 8.4 million inhabitants, 2.7% will be supplied by means of a deficit water source, 52.8% will be supplied through critical water production systems and 17.7% through production systems and water sources both classified as critical.

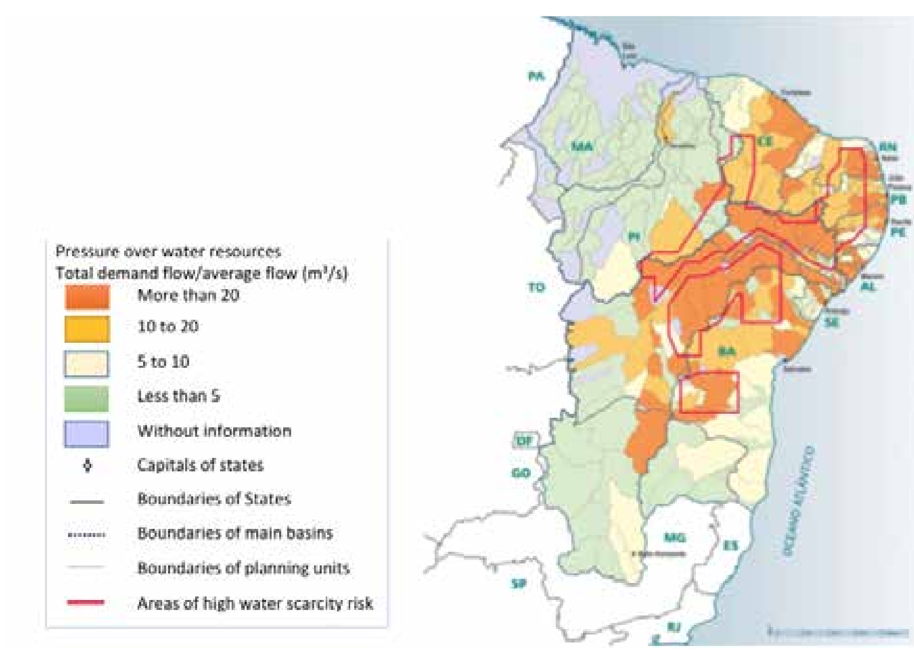
Such data indicate that if adequate solutions are not implemented, and even if actions to reduce urban water demands in 2025 are considered, 41 million people in the region will still have no guarantees of a water supply for human consumption.

Figure 7 classifies the studied cities by level of criticalness of supply, for the scenario described.

With regard to the supply of water to people in semiarid cities that do not have water sources nearby, the construction of pipelines is the most appropriate solution, whether from larger reservoirs, or from wells in sedimentary areas (with greater restriction so that the potential of these reserves can be identified, particularly in regards to their mechanisms of recharge), or from more distant reservoirs and rivers, even those located in other watersheds, thus creating the so called transpositions of water between basins.

Great water projects for water transport have already been completed, or are under construction or have already been designed over the last years, to supply water to the cities of the semiarid and provide support to the productive activities. This is the case, for example, of the Integration Channel in Ceará, destined to carry water from the Castanhão reservoir –the biggest of the Northeast located

Figure 7. Pressure over water resources under the optimistic scenario of 2025



Source: ANA

outside of the São Francisco River basin (capacity of 6.7 billion m³) all the way to the Fortaleza region, capital of the state, over a 225 km extension. Another example is the network of 500 km of pipeline in the state of Rio Grande do Norte. In both cases, it reflects the exploitation of water reserves within the territory of each state. The main ongoing strategy for increasing water infrastructure of the semiarid region is linked to the projects to transfer water from the São Francisco River toward the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco, through two large channels called axes North and East.

According to the Ministry of National Integration, by the end of the project there will be a continuous withdrawal of 26.4 m³/s of water, equivalent to 1.4% of the total water flow of 1850m³/s ensured by the Sobradinho, in Bahia, in the stretch of the river where the water will be captured. This flow is intended for consumption for the urban population of 390 municipalities in the Agreste and the Hinterland of the four states of Northeast. In years when the Sobradinho reservoir surpasses its accumulation capacity, the collected volume could increase to up to 114m³/s on average, contributing towards ensuring water supply for multiple purposes.

When crossing the state of Pernambuco, the North and East axes, will serve as a source of water for the existing or proposed pipeline systems currently responsible for supplying water to the Hinterland and the Agreste. For the agreste in Pernambuco, considered one of the most inhabited semiarid regions of the planet, 1300km of pipelines are being implemented, destined to complement the supply of water, using the São Francisco River to provide water to 68 cities and 80 localities.

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7. Conclusions

The rapid degree of urbanization in Brazil has brought innumerous environmental problems such as an increasing demand for water supply, energy, food and transportation. Urban ecosystems produce a considerable amount of solid and liquid waste that impact the natural environment downstream the cities. The urban ecosystem is a dynamic and complex system and as such the Integrated Urban Water Management has to be considered for these ecosystems. The components of this IUWM include legislation, urban planning and soil use, urban drainage and quality of life and environment conservation (Tucci, this paper).

The water supply services present innumerous problems in urban areas. Despite that 90% of the population receives water in their houses, the treatment of wastewater is only 45% of the total sewage produced. This impairs the uses of water downstream the cities and produces many problems of Public Health and dissemination of water borne diseases. Another problem that is common in Brazil is the loss of treated water in the distribution networks that is an average of 30% (Tundisi, this paper). The urban water quality degradation in Brazil is dependent upon deforestation, discharge of industrial wastewater, agricultural discharges and transport of sediment due to the erosion of soil in urban areas, as well as lack of wastewater treatment.

The water quality in the sources of supply also varies: if the source is well protected by forests the water quality in good and the costs of treatment are as low as U$ 5,00 / 1.000 m³ of water. If there is a degradation of the source, the costs of water treatment can be as high as U$250.00 per 1.000 m³ of water (Tundisi, this paper).

In Brazil, the main threat to human health among the waterborne diseases is gastroenteritis caused by viruses, protozoa and bacteria. This disease represents more than 80% of diseases related to poor sanitation and is a great burden to the health care system (Spilk, this paper). The current applied techniques to measure the microbiological safety of water in Brazil do not include the detection of viral or protozoan agents. The process applied to the treatment of water in Brazil is not effective to avoid the risk of viral contamination.

The driest area in Brazil, called by the specialists as semiarid region (rainfall between 250 and 500 mm/ year) has a population of approximate 22.600.000 inhabitants, distributed in 1135 municipalities with a majority of small cities (from 5.000 to 50.000 inhabitants) (Cirilo, this paper). In a study carried out by ANA (National Water Agency of Brazil) it was shown that the quality of surface and groundwater was impaired by the disposition of solid waste, use of agricultural fertilizers, the absence of sewage treatment systems, and deforestation with erosion and siltation of rivers as a consequence. The construction of pipelines for water transportation between watersheds is one of the adequate solutions for water supply of these municipalities in the semiarid area. Another solution is to improve and invest heavily on the management of water in the municipalities (Cirilo, this paper).

Finally, one fundamental question in the urban water management system in Brazil, is the technology of water reuse. Today the water availability for the supply of urban population in Brazil is approaching a critical level, due to extensive changes in rainfall in the last two years (summers of 2012/2013 and 2013/2014). An overall reduction of 30% occurred increasing the vulnerability of urban populations; one possible solution is the re-use of treated wastewater that only in the metropolitan region of São Paulo could bring another 56m³/s to be used in other activities. Treatment of water for re-use would be a formal component of the water resource management. The quality of water for reuse should have a permanent monitoring assessment, established standards for different uses, and an evaluation of the benefits of the re-use in urban and metropolitan regions (Hespanhol, this paper).

The concept of green cities as presented by Tundisi (this paper) should be included in all programs for integrated water management of urban regions. Forests are a vital and dynamic component of the water cycle and the implementation of municipal parks, ecological stations and other forested areas amidst the urban environment is a step forward in water conservation and quality of life in the urban ecosystem.

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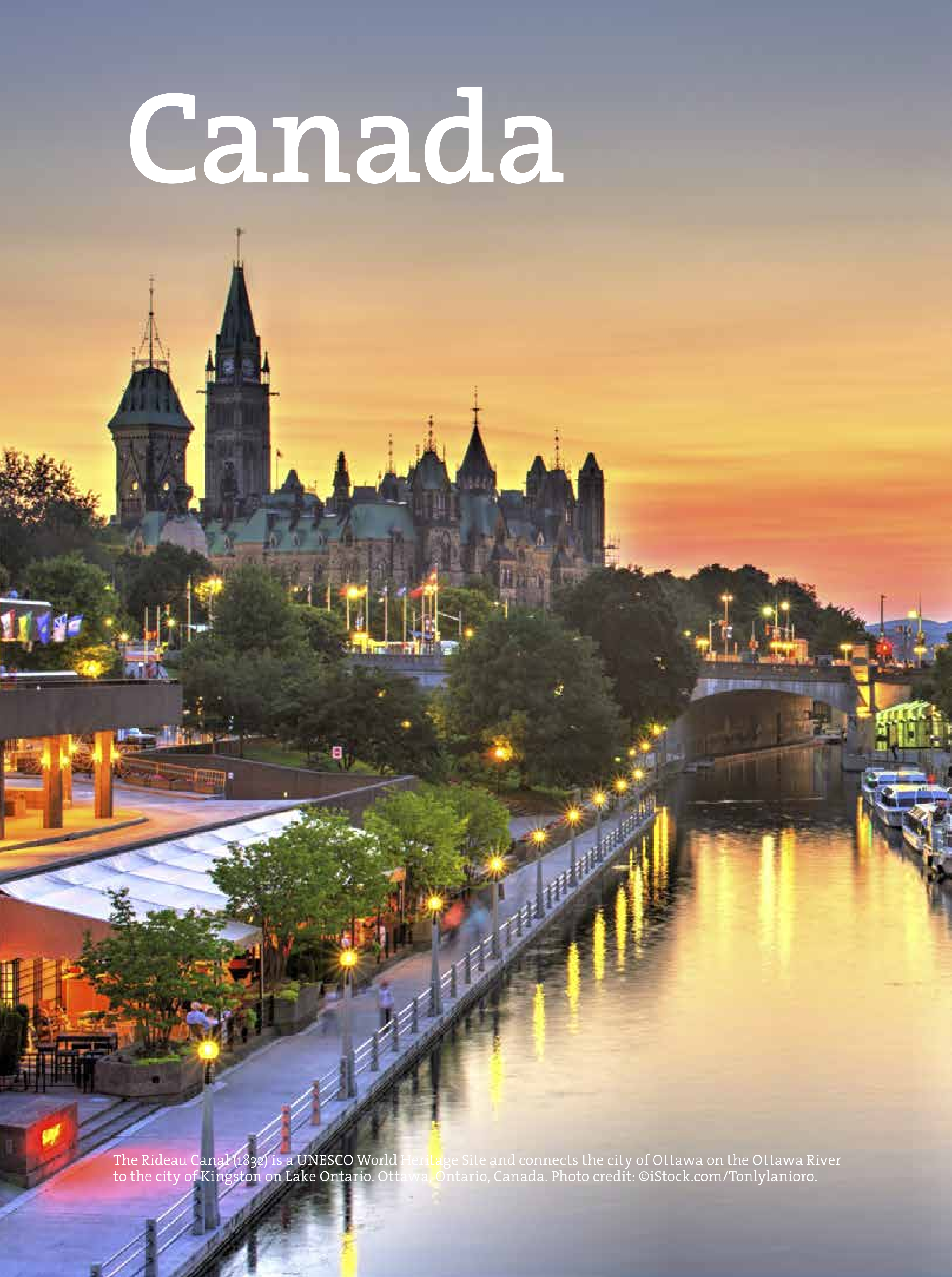
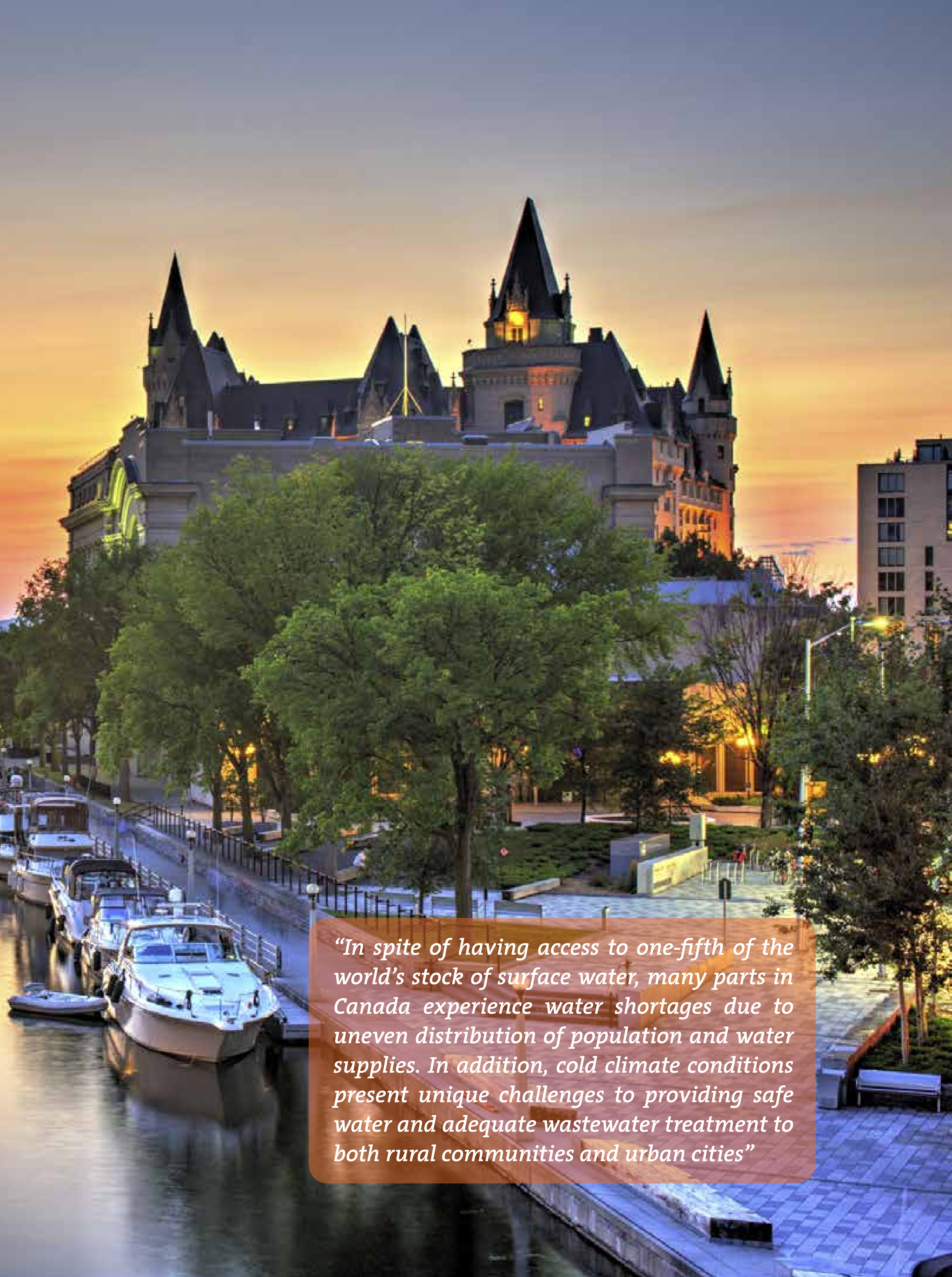
Canada



The Rideau Canal (1832) is a UNESCO World Heritage Site and connects the city of Ottawa on the Ottawa River to the city of Kingston on Lake Ontario. Ottawa, Ontario, Canada. Photo credit: ©iStock.com/Tonlylanioro.



"In spite of having access to one-fifth of the world's stock of surface water, many parts in Canada experience water shortages due to uneven distribution of population and water supplies. In addition, cold climate conditions present unique challenges to providing safe water and adequate wastewater treatment to both rural communities and urban cities"

An Overview of Water Supply, Use and Treatment in Canada

Banu Örmeci

Summary

Canada is the world's second largest country by total area and spans over 9.98 million square kilometers from the Atlantic to the Pacific Oceans. It extends to the Arctic Ocean in the north and neighbours the United States in the south. Due to its sheer size, Canada encompasses a wide range of climate regions and ecosystems, which affect the supply, demand, use and treatment of water. Cold and remote regions present particularly difficult challenges in providing safe drinking water and adequate wastewater treatment to communities.

Canada is perceived to be a water-rich nation having access to approximately 20% of the world's stock of surface fresh water, which includes some of the largest lakes in the world as well as thousands of small lakes scattered across the land (Figure 1). Surface waters cover 12% of the total surface area and wetlands cover 14% of lands in Canada. In addition, glaciers cover an area of 200,000 km^2 (Statistics Canada, 2010). Canada has an average annual renewable freshwater supply (also known as water yield) of 3,472 km^3, which is higher than the water yield in many drier countries, but only 36% of the water yield in Brazil and 60% of the water yield in India (Statistics Canada, 2010).

Even though water is abundant at the national scale, there are strategic water problems and shortages at the regional scale due to the uneven distribution of population and water supplies. Simply put water is not always available where it is needed. For example, 98% of Canadians live in the warmer southern parts of the country where the renewable freshwater supply is only 38% (Statistics Canada, 2014). In addition, most of Canada's freshwater flows north where there is relatively little population. As a result, water intake can substantially exceed water yield in many parts including Southern Saskatchewan, Southern Manitoba and the Great Lakes region (Figure 2). Prairies are particularly dry and have experienced repeated and more prolonged droughts in recent decades.

Canada is a wealthy country and most Canadians are serviced with high-quality drinking water and wastewater infrastructure. However, there are also many small communities, particularly Aboriginal and rural communities, which suffer from continuous and persistent problems with the safety of their drinking water and the contamination of their water supplies due to inadequate wastewater treatment. As a result, waterborne disease outbreaks still occur in Canada. Water supplies are increasingly under pressure from intensification of urban areas, economic and industrial growth, expansion of agriculture, and impacts of climate change, and Canada needs a comprehensive plan for water governance to address these strategic water problems with an adaptive, integrative and participatory approach at all levels of government (Hipel et al., 2013).

1. Water Resources and Problems Caused by Development

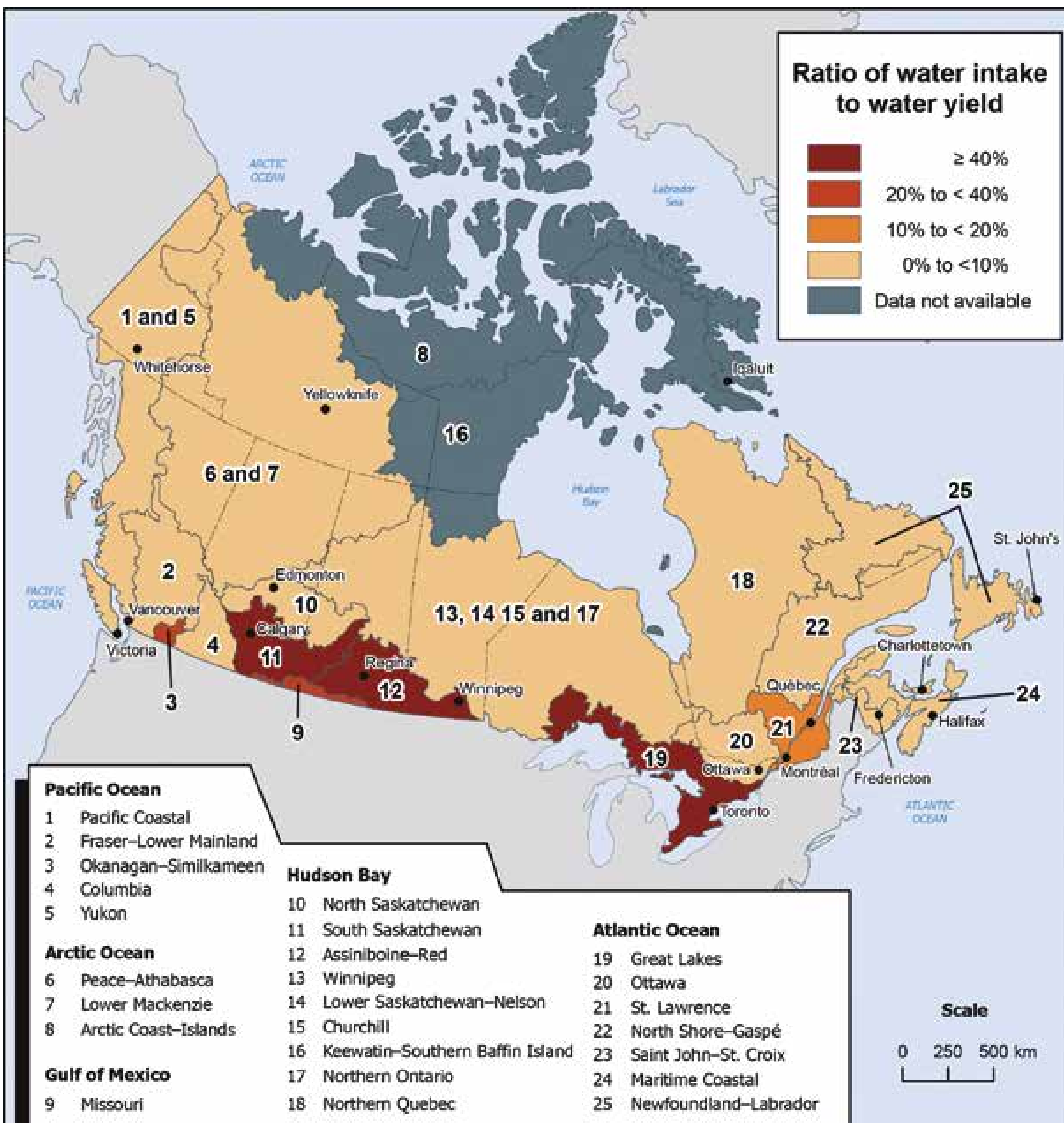
Canada used more than 42 km^3 of water for domestic and industrial use in 2005, and close to 90% of this water was used to support mainly thermal-electric power generation as well as economic activities (Statistics Canada, 2010). Pulp and paper, mining operations, and the oil and gas industries represent the three main industries in Canada. According to 2005 data, manufacturing sector, including the pulp and paper industry, used 14% of the withdrawn water, and petroleum and coal industries used another 12%. Agricultural sector was responsible for 5% of the water. Among all sectors, petroleum and coal industries had the highest reuse and recirculation of process water reaching 140% (Statistics Canada, 2010).

Economic growth coupled with urbanization play a major role in determining the water demands and withdrawals. Increasing water

Figure 1. Lake Moraine (Banff National Park, Alberta) is one of the many thousands of lakes in Canada. Photo credit: ©iStock.com/estivillml

withdrawals can put a stress on water resources and pose a threat to aquatic ecosystems and fish. In addition, anthropogenic activities are likely to cause the contamination of water bodies and may significantly decrease the overall quality of water. Eutrophication of Great Lakes, industrial activities in Southern Ontario and Southern Quebec, oil sands mining operations in Alberta (Figure 3), hydroelectric power developments in northern Quebec and Labrador, agricultural activities in Prairies, and overexploitation of groundwater are some of the main stresses on water resources in Canada (Hipel et al., 2013). In the near future, rapidly growing oil sands mining operations in Alberta and Saskatchewan, which require massive quantities of water to extract and process bitumen from oil sands, and the emerging hydraulic fracturing of shale gas, particularly in Alberta and British Columbia, are expected to increase the demand and threat to both surface waters and groundwater.

Figure 2. Ratio of August 2005 water intake to the August median water yield for 1971 to 2004



Source: Statistics Canada, 2010

Figure 3. An oil refinery located alongside the Athabasca River that processes the bitumen from oilsands. Fort McMurray, Alberta, Canada. Photo credit: ©iStock.com/Dan Barnes

Canada shares a long border with the United States and some of the water pollution originates from the US. Draining of the contaminated Devils Lake in North Dakota which empties into the Red River Basin in Manitoba and flows to downstream lakes and rivers such as Lake Winnipeg, has caused controversy between the two countries (Hipel et al., 2013). Concerns include the transfer of a wide range of chemical pollutants, sulphate compounds as well as unknown foreign aquatic species.

The Great Lakes basin is shared between Canada and the US, and is a major source of fresh water for both countries. Sewage, industrial discharges, fertilizers, and pesticides have caused adverse effects on the lakes decreasing the water quality and damaging the ecosystem. The Great Lakes Water Quality Agreement signed in 1972 between Canada and the US aims to restore and protect the water quality and wildlife in Great Lakes and was amended in 2012 to better address new and emerging issues such as climate change, invasive species, and habitat degradation.

2. Water Supply Services

Likely due to the availability and low price of water, Canadians are one of the highest per capita water users in the world. The water consumption in households was 298 litres per person per day in 2009 (Statistics Canada, 2011), which was twice as much water as compared to used in France and was slightly less than the per capita water use in the US. However, a decreasing trend in residential water use has been observed in Canada since 2006 (Environment Canada, 2011), which indicates a change in consumer behaviour towards a more sustainable approach to water use. In addition, increasing use of residential (72%) and commercial (87%) water metering over the past decade has helped to decrease the water consumption. The data from nationwide surveys indicate that non-metered households that pay a flat water rate use 65% more water compared to metered households that pay on a volume-based water rate (Environment Canada, 2011).

The 2011 Municipal Water Use Report (Environment Canada, 2011), provides the most recent results from a nationwide survey on municipal water and wastewater systems. The information obtained from the survey helps to make well-informed decisions on the efficient management of water and wastewater systems and identifying gaps where improvements and investments are needed. However, the survey does not include First Nations communities where the highest deficiency and need for water and wastewater treatment exists.

According to the survey results, 89% of Canadians are served by a water distribution system and 94% of them receive treated water. However, in smaller communities, the percent of people who are connected to a distribution system drop substantially. In communities with less than 1000 people, only 50% of the population is served by a water distribution system, while 47% rely on public wells and 2.5% use hauled water. 75% of the municipally supplied water is treated in these communities. In cities with a population more than 500,000, almost everyone (>98%) receive treated water from a water distribution system (Environment Canada, 2011).

Canadian municipalities mostly rely on surface water to provide water to their residents. In 2009, 90% of the municipal water was sourced from surface water and the remaining 10% was sourced from groundwater. The groundwater use was much higher in smaller municipalities reaching 50% for those with a population less than 1000. There was also a regional variation in ground water use. In Prince Edward Island, 100% of municipal water came from groundwater and in Territories groundwater constituted 70% of the municipal water supply (Environment Canada, 2011). It should also be noted that in Canada the entire water supply of more than 80% of the rural population come from groundwater (Environment Canada, 2014).

More than two-thirds of Canadians (68%) drank tap water regardless of whether the source was municipal or non-municipal water. In spite of a very good water treatment and distribution infrastructure, 22% of Canadians still preferred to use bottled water as their drinking water in 2011 but the bottled water use is slowly decreasing partly due to the education of the public on the safety of their drinking water. Additionally, 50% of Canadian households treated their water further at home mainly by using jug filters (33%) or using on-tap (20%) or main-pipe (11%) treatment systems. The main reasons cited for in-home water treatment units were the consumer desire to improve taste, odour, and appearance of water, and remove hardness, minerals and metals (Statistics Canada, 2011).

3. Treatment of Wastewater

Wastewater treatment is important for the protection of public health and environment. In general, Canada benefits from high-quality wastewater infrastructure and treatment in many of the provinces, but there are also places where no or little wastewater treatment is used. In rural areas, remoteness of communities and cold climatic conditions present unique challenges to the treatment of wastewater. Over 150 billion litres of untreated or undertreated sewage is dumped into to waterways every year in Canada (Environment Canada, 2012) which poses a threat to the quality of water supplies and consequently human health.

The responsibility of wastewater collection, treatment, and discharge is shared among the federal, provincial, and territorial governments and municipalities in Canada. In provinces and territories, the majority of wastewater collection and treatment infrastructures are owned and operated by municipalities. First Nations are the owners and operators of community infrastructures on reserves. Until recently, Canada did not have a national policy on wastewater treatment, which resulted in large differences among provinces and territories with respect to the level of wastewater treatment and effluent quality. In order to remedy this, the federal government established Canada's first national standards for wastewater treatment in July 2012. *The Wastewater Systems Effluent Regulations* created the basic treatment standards for wastewater treatment across Canada, requiring the use of secondary (biological) or equivalent treatment. The regulations also put in place additional requirements for monitoring, reporting and toxicity testing. The new standards apply to wastewater systems with an average daily influent volume of 100 m^3 or more, to which smaller systems do not have to comply. Wastewater systems in the far North, such as Nunavut, Newfoundland, Labrador, the Northwest Territories and Northern Quebec are exempt as well.

The new regulations do not allow wastewater systems to exceed 25 mg/L average carbonaceous biochemical oxygen demand (CBOD), 25 mg/L average concentration of suspended solids, 0.02 mg/L average concentration of total residual chlorine, and 1.25 mg/L maximum concentration of unionized ammonia expressed as nitrogen (N) at 15 °C ±1 °C. All owners and operators of wastewater treatment systems are required to monitor and report effluent quality and quantity. In addition, owners and operators of combined sewer systems are required to monitor, record and report the frequency and quantity of combined overflow discharges of untreated sewage to surface waters.

The regulations also provide timelines for treatment systems to achieve compliance based on a points system which takes into consideration the size of the community, risk factors and the sensitivity of the area. It was estimated that approximately 850 wastewater systems, which constituted to 25% of existing treatment facilities in Canada, needed to be upgraded to secondary or equivalent treatment (Environment Canada, 2012). These systems will be gradually phased in where high risk systems are given until 2020, medium risk systems until 2030, and low risk systems until 2040; and this is criticized for the long rollout time. During this period, wastewater treatment facilities can obtain “transitional authorizations” to allow them stay in operation until they are in compliance. The cost of these changes to the treatment systems, including the capital and operational costs, were estimated as $5.5 billion, and the expected benefits to Canada were estimated as $16.5 billion (Environment Canada, 2012).

According to the 2011 Municipal Water Use Report (Environment Canada, 2011), 43% of Canadians live in municipalities with a population less than 1,000 residents. On the level of wastewater treatment and connection to sewer system, 1524 municipalities with a combined population of 28.1 million responded to the survey. The results revealed that 87% of people in these municipalities were connected to sanitary sewer system whereas 12% were using septic tanks and 0.5% were using holding tanks and sewage haulage. From large municipalities with a population of 500,000 people or more, 98% had sewer access, but municipalities containing less than 1,000 people had only 47% sewer coverage. All provinces except Nova Scotia had higher than 86% of the population served with sanitary sewers. In Nova Scotia, 68% of the population was connected to sewers and 32% used private septic tanks. In three territories (Northwest Territories, Nunavut and Yukon), 76% of the population was served with sewers and private septic tank use was relatively low at 8%. Instead, 15% of population stored sewage in holding tanks, where sewage is removed and transported from homes to a central treatment or disposal facilities. Holding tanks are rarely used in other parts of Canada.

Figure 4 shows the level of wastewater treatment employed across Canada based on the population size of municipalities. The level of wastewater treatment varied from no treatment to preliminary treatment, primary treatment, secondary treatment and tertiary treatment depending on the size and location of the communities. In this context, no treatment means raw sewage as is, preliminary treatment is the removal of grit and large objects, primary treatment is the removal of solids using settling tanks, secondary treatment is the biological removal of organic matter using lagoons, secondary-mechanical treatment is the biological removal of organic matter at treatment plants, and tertiary treatment is the removal of mainly nutrients such as nitrogen and phosphorus. Of approximately 24.5 million people connected to the sewer system, 55% received secondary-mechanical treatment, 7% had secondary treatment in sewage lagoons and 17% received tertiary treatment. However, 3% received no treatment or only preliminary treatment and 18% received primary treatment. It should also be noted the percent of people with no treatment, preliminary treatment or primary treatment would be substantially higher in rural areas where there is no sewer system, which was not included in the data used for this figure.

The data also showed that municipalities with less than 5,000 people had higher percentages of no treatment, preliminary treatment and primary treatment. For municipalities with less than 1,000 people, approximately 25% of wastewater was either not treated or minimally treated, but the remaining portion received secondary treatment in lagoons. For municipalities with less than 5,000 people, lagoon based wastewater systems were prevalent (approximately 50%). Percentage of secondary-mechanical treatment increased with increasing population, and constituted for 60% of treatment for municipalities with populations greater than 500,000.

Figure 4. Wastewater treatment level by municipal size group (Source: Environment Canada, 2011).

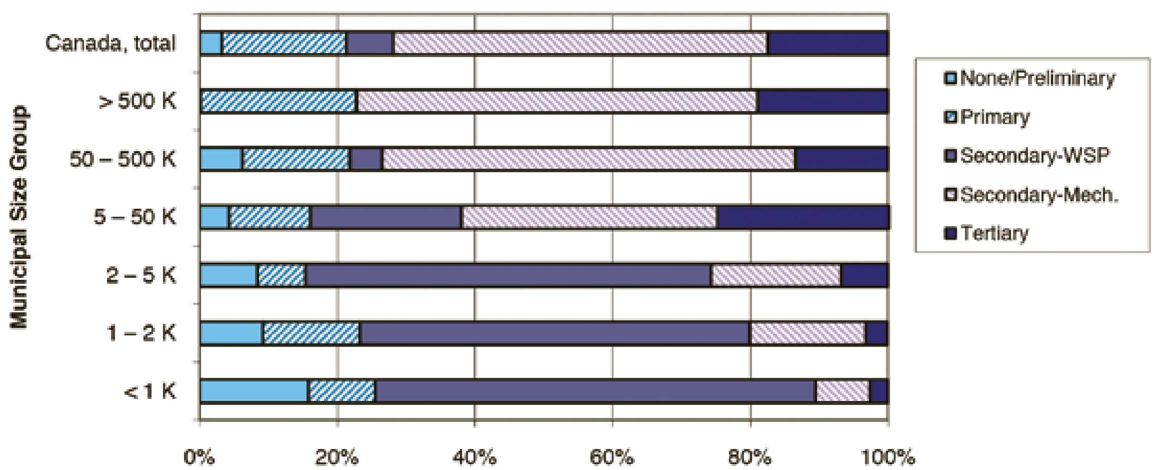


Figure 5. Wastewater treatment levels by province and territory (Source: Environment Canada, 2011).

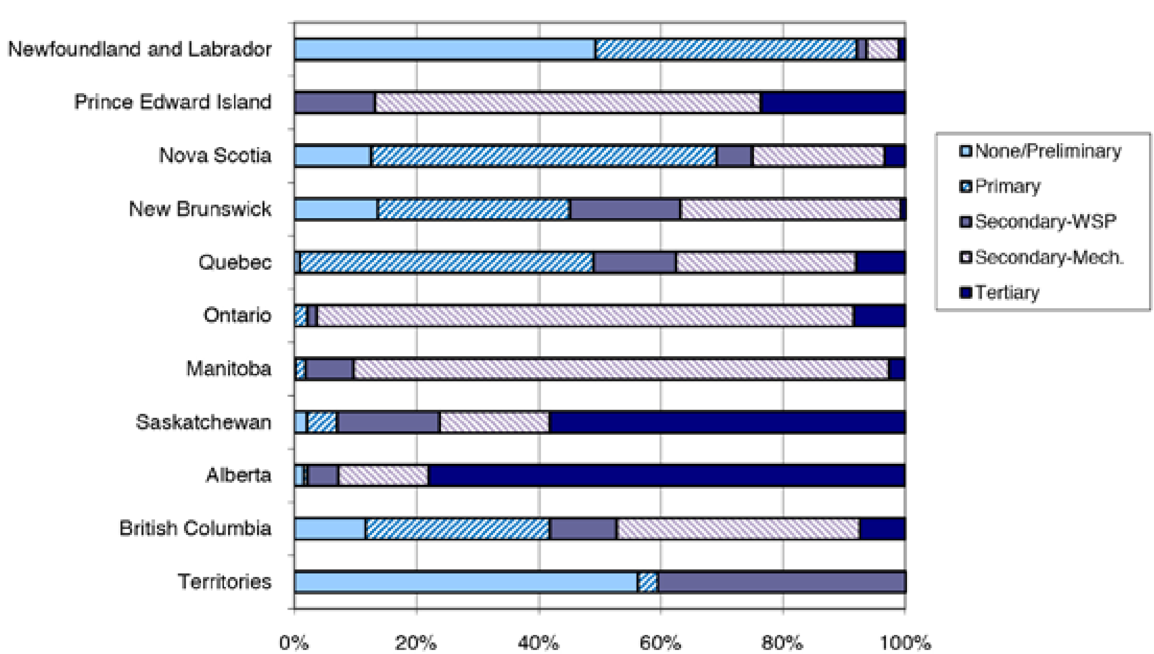
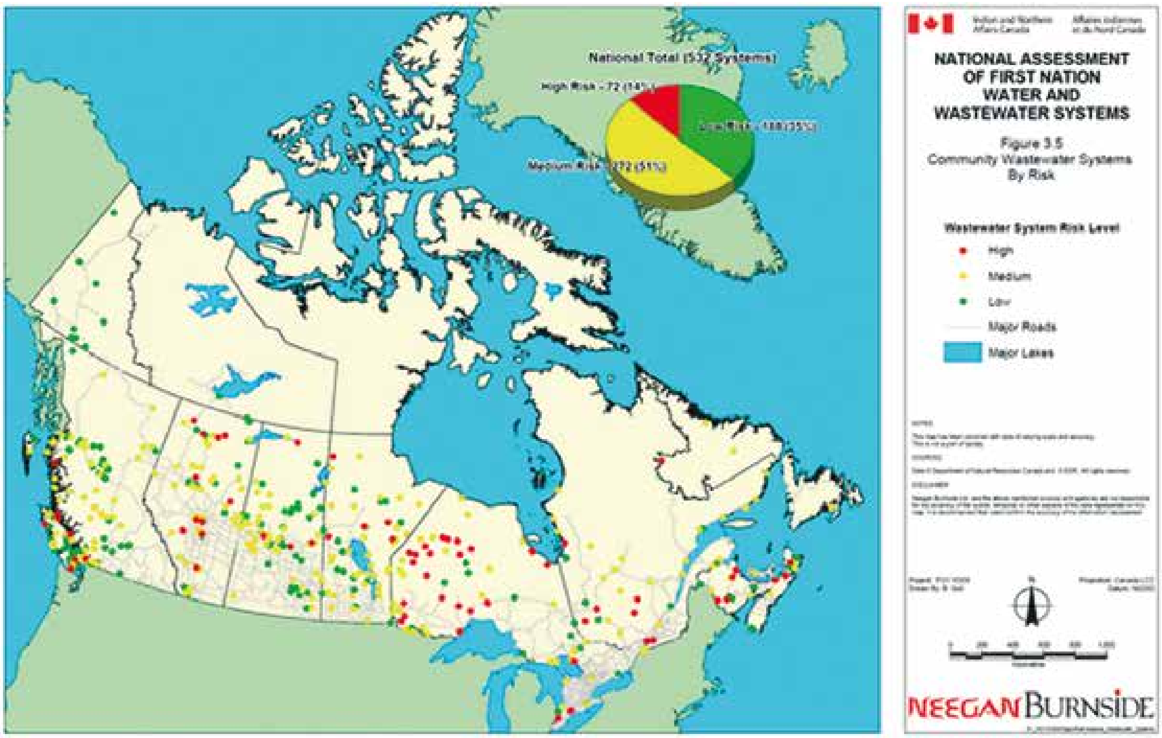


Figure 6. First Nations Community Wastewater Systems categorized by high, medium, and low risk (Source: Neegan Burnside, 2011).



The level of wastewater treatment employed in provinces and territories varies widely (Figure 5). Approximately 50% of wastewater did not receive any treatment in Newfoundland and Labrador, and 40% received only preliminary treatment. Similarly, close to 60% of wastewater did not receive treatment in territories, but the remaining 40% received secondary treatment in lagoon based treatment systems. Even in Quebec, British Columbia, New Brunswick and Nova Scotia, 40-65% of wastewater did not receive any biological treatment and was limited to preliminary and primary treatment. In Ontario, Manitoba, Saskatchewan and Alberta, more than 90% of wastewater received biological or superior treatment but tertiary treatment was minimal in Ontario and Manitoba. The best municipal wastewater treatment in Canada was employed in Alberta and Saskatchewan, where approximately 40-60% of wastewater received tertiary treatment.

The status of water and wastewater infrastructure is of particular concern in aboriginal communities and requires substantial investment to meet acceptable effluent quality standards. The federal government undertook the National Assessment of First Nations Water and Wastewater Systems between 2009 and 2010 to assess the water and wastewater infrastructure on First Nations lands, evaluate the risk factors associated with their management, and identify the needs for upgrades (Neegan Burnside, 2011). Such a comprehensive and independent survey was carried out for the first time in Canada and 97% of First Nation communities participated in the survey. The study reported that 153 First Nation communities were exclusively serviced by septic tanks and 418 First Nation communities employed 532 wastewater systems which mainly consisted of wastewater treatment lagoons. Overall, 54% of homes were connected to sewers, 36% had septic tanks and other individual treatment systems, 8% were on truck haul, and 2% had no service. The overall management risk for the wastewater systems was also evaluated where factors such as operation and maintenance, operator training and qualification, and record keeping were conjointly considered. Figure 6 shows the distribution of the low, medium, and high risk systems across Canada. For the 532 wastewater systems that were evaluated, 14% were identified as high-risk, 51% as medium risk, and 35% as low risk. Ontario had the highest percentage (36%) of wastewater systems that were categorized as high risk compared to other provinces. As predicted, least accessible First Nations due to their remoteness had higher percentages of high-risk wastewater systems. The report also identified the cost for the necessary upgrades of water and wastewater systems on First Nations lands as $1.2 billion.

4. Water and Health

Canada has a well-established network of water systems, and overall Canadians enjoy safe and high-quality drinking water. Waterborne outbreaks are rare, but they continue to occur particularly in rural regions and aboriginal communities where operation and maintenance of water treatment and distribution systems are difficult. Cold climate conditions also present unique challenges for the design and installation of water systems. Additionally, a large percentage of the population rely on groundwater systems and individual wells, which are more susceptible to contamination and increase the risk of waterborne diseases. According to an Environment Canada report, 30% of Canadians and 80% of rural population rely on groundwater for their water use (Nowlan, 2005).

There is no national surveillance system to track the occurrence and frequency of waterborne diseases and outbreaks in Canada, and it is likely that a large percentage of incidents are not recognized or reported in the first place. Canada has experienced a number of waterborne outbreaks in recent past, the Walkerton outbreak in 2000 where 7 people died and approximately 2,500 people got sick being the most important one. In Walkerton, the groundwater supply was contaminated with the O157:H7 strain of E. coli from farm runoff, and several factors including the lack of formal training and improper operating practices of the water treatment personnel contributed to the tragedy. The total cost of the Walkerton outbreak, including the tangible and intangible costs amounted to $155 million (Livernois, 2002). The tragedy led to many changes in provincial policies and legislation across Canada on the safety and quality of drinking water and resulted in improvements in the source water protection, training and certification of operators, and management and operation of water systems. More importantly, the Walkerton outbreak led to the establishment of effective programs and centres (e.g., Walkerton Clean Water Centre, Ontario Clean Water Agency) that target the training of treatment personnel and the proper operation of treatment and distribution systems with a focus on smaller, remote and older systems. Other high-profile waterborne outbreaks in Canada include the cryptosporidiosis outbreak in North Battleford, Saskatchewan in 2001 where 2,000 people got sick, and the Kashechewan outbreak in Northern Ontario in 2005 where 2,000 aboriginal people got infected due to a mechanical malfunction at the water treatment plant. Almost everyone on the Kashechewan reserve had to be airlifted to Ontario communities for the necessary treatment and living arrangements.

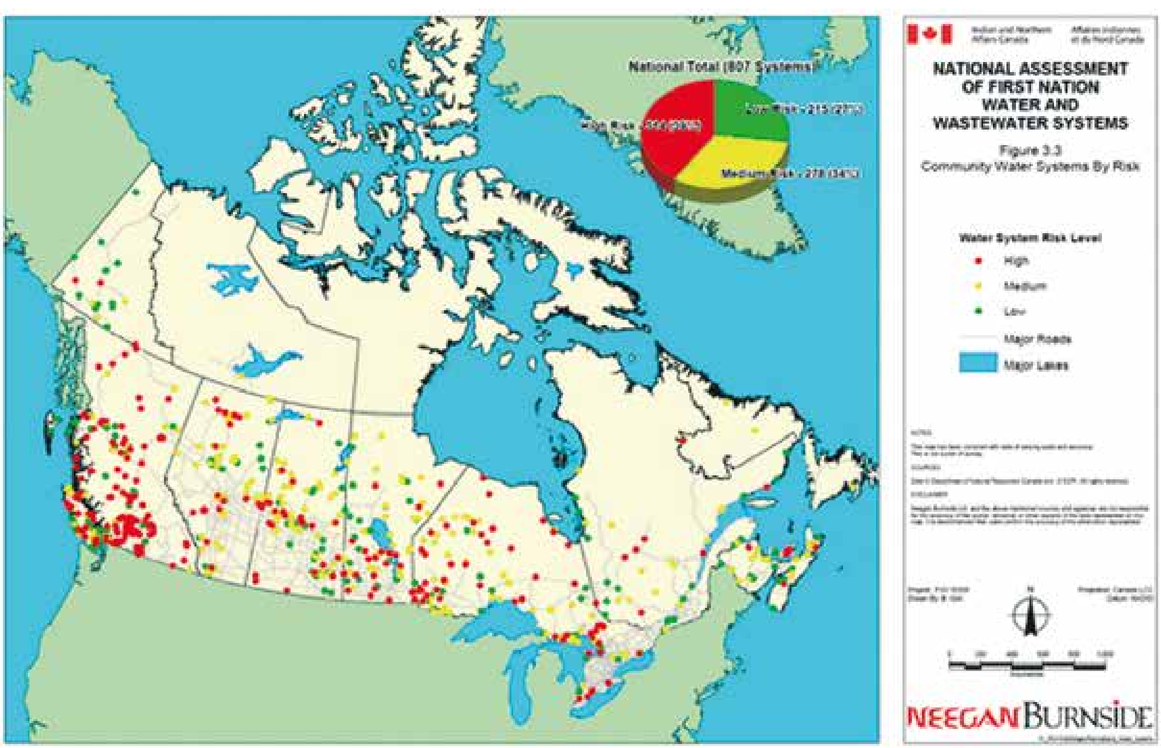
A comprehensive surveillance for the occurrence of drinking water related illnesses in Canada between 1993 and 2008 was carried out and published in a report in 2009 (Wilson et al., 2009). Based on the responses to questionnaires and interviews, 47 waterborne disease events (WBE) were identified in this time frame. On average 5-6 WBE's per year occurred before 2001, and after 2001 there was a substantial drop to 1-2 WBEs per year, which was likely due to the measures taken after Walkerton and North Battleford. *Giardia* and *Cryptosporidium* were the etiologic agents behind 40% of the WBEs. Infections due to *Giardia* and *Cryptosporidium* were most common when surface water was used as the water source and infections due to bacteria and viruses (*E. coli, Salmonella, S. aureus, Norovirus, Hepatitis A*) were most common in groundwater. In 50, 39 and 11 percent of the WBEs, the water source that caused the outbreak came from surface water, ground water, and mixed surface and groundwater respectively, indicating that half of the outbreaks were caused by source water from rivers and lakes that are more vulnerable to contamination. Interestingly, *Giardia*, bacteria and viruses were the predominant causative agents when no treatment or only disinfection was used, whereas *Cryptosporidium* was the main cause of the outbreaks in water systems that used filtration and disinfection. Frequency of the WBE's was 6 times higher in communities with less than 1,000 people compared to communities with more than 100,000 people.

The level and quality of water treatment plays a major role in preventing waterborne diseases. In 2007, 55% of treated water came from conventional treatment and direct filtration plants, serving half of the Canadian population (Statistics Canada, 2009). Approximately 8.7% of Canadians living in communities of 300 or more people received their water from a water system without any treatment. For private systems such as wells, only 35% of owners reported testing their water (Statistics Canada, 2007) and 21% reported having never tested their water (Jones et al., 2007).

Small drinking water systems are of particular concern for waterborne diseases since they often face a wide range of challenges. The factors contributing to waterborne disease outbreaks in Canada, particularly in small systems, were found to be related to lack of source water protection; precipitation, high turbidity, spring thaw and run off; inadequate or malfunctioning water treatment systems; malfunctioning water distribution systems; and other factors such as human error (Moffatt and Struck, 2011). Changes in water infrastructure, treatment operations and practices, and extreme weather events were strongly associated with the occurrence of outbreaks and it was suggested to take these changes as a warning sign for potential outbreaks and to take the necessary precautions (Hrudey and Hrudey, 2004). It was also noted that monitoring of water quality such as indicator bacteria, pathogens, turbidity and residual chlorine can be very effective in preventing waterborne disease outbreaks if implemented and maintained by government bodies rather than private owners or operators (Moffatt and Struck, 2011).

The inadequacy of drinking water and wastewater systems in First Nation communities has been well-known and well-documented. In spite of substantial investment for water and wastewater systems in First Nation communities, problems persist and there are still a staggering number of boil and drinking water advisories in these communities. In Canada, the Aboriginal Affairs and Northern Development Canada (AANDC) provides funding and advice to assist with the design, construction, operation, maintenance of water and

Figure 7. First Nations Community Water Systems categorized by high, medium, and low risk (Source: Neegan Burnside, 2011).



wastewater systems and training and certification of operators. However, First Nations are responsible for the daily operation and management of their water and wastewater systems.

The results of the National Assessment of First Nations Water and Wastewater Systems (Neegan Burnside, 2011) revealed that from the 807 drinking water systems inspected 39% were found high-risk, 34% medium risk, and 27% as low risk. Figure 7 shows that high, medium, and low risk water systems were distributed throughout Canada and were not localized to particular First Nation communities. British Columbia (53%) and Ontario (46%) had the greatest percentage of high-risk water systems. The majority of high-risk systems were found in small communities and only 30% of the risk in these high-risk systems was attributed to the design and infrastructure of the water systems. This emphasizes the importance and need for operator training in First Nations communities. The Circuit Rider Training Program aims to address the gaps in this area. The program provides on-going and hands on training to the First Nation operators on their own systems and aims to achieve the safe operation and maintenance of the water systems. The program also runs a 24-hour hotline to assist the operators with their questions and emergencies.

In Canada, drinking water advisories are issued as a preventive measure when there is suspicion that drinking water may pose a risk to the public. A boil-water advisory means that water should be brought to a rolling boil for one minute before consumption in order to kill pathogenic microorganisms. High coliform counts or high turbidity in water may trigger a boil-water advisory. According to a Health Canada report (2009), the length of the boil water advisories varied from 1 day to 13 years between 1995 and 2007. The average duration of the boil water advisories were 343 days and the median was 39 days, and the discrepancy was caused by the skewed average due to the years of ongoing boil water advisories in some communities. 35% of boil water advisories were resolved within two weeks, and 75% were resolved within one year. However, 25% of all boil water advisories lasted longer than one year and some extended for several years with no break. Data obtained on October 31, 2011 through Access to Information legislation showed that the average duration of a boil water advisory in First Nation communities continued to increase to 772.6 days, 38% of which were in place for more than 5 years and 70% for more than 2 years (Young, 2012).

5. Climate Change and Influence on Water Resources

Global climate models predict an increase in precipitation and evaporation between 3 and 15 percent when CO_2 is doubled in the atmosphere. According to a 2014 report by the Intergovernmental Panel on Climate Change, the annual greenhouse gas emissions (GHG) reached 49.5 billions of tons of carbon dioxide equivalent in 2010 and continue to increase (IPCC, 2014a). The climate models also predict severe weather events, such as major storms, hurricanes, floods, droughts, and ice melts in the near future. It is well-known that changes and variability in climate will lead to a shift in the availability and distribution of water, which are being noticed in many regions in Canada (Figure 8). Rising temperatures, increasing ice melt and evaporation will affect the seasonal variability of water and will further increase the competition among municipal, industrial and agricultural use of water in Canada in the near future (IPCC, 2014b). Water resources are already overused due to rapid economic and population growth in Southern Canada, and climate change will exert additional water stress.

One of the main climate change induced water problems in Canada is the melting glaciers of the Rocky Mountains of Western Canada (British Columbia, western edge of Alberta, and eastern Arctic) and the drought it is intensifying in Prairie provinces (Alberta, Saskatchewan, and Manitoba) (Hipel et al, 2013). Approximately 2% of Canada is covered by glaciers and after Antarctica and Greenland, Canada has the highest amount of glacial ice (CCME, 2003). Glaciers store water as ice in the winter and slowly release the melting water in the summer when it is needed most for municipal, agricultural and industrial use. Melting of glaciers has significantly changed the seasonal flow patterns of rivers that flow across the Prairie provinces, and 20-84% of reduction in summer flows were reported (Schindler and Donahue, 2006). Warmer temperatures, increasing precipitation and snow melt, and extreme weather events also impact the water quality by increasing the carriage of sediments, nutrients and a wide range of pollutants (e.g., fertilizers, pesticides, endocrine disrupting compounds) into surface waters and aquifers. In addition, the increased frequency and strength of rain and storm events will increase the sewer overflows and discharge of untreated sewage to surface waters, which is already a big problem in most Canadian cities. The negative impact of climate change on water quality is seen in many provinces, particularly in Ontario and Quebec, where nutrient-enriched lakes and warmer temperatures have resulted in toxic blue-green algae blooms making the water unsuitable for human consumption.

Other impacts of warmer temperatures on water systems include rising sea levels on the Pacific coast, potential flooding in low-lying areas and heavily populated deltas, pre-spawning mortality of the Pacific salmon, increased number of forest fires, more frequent droughts in Prairies, temperature increase in Great Lakes and decrease in water levels, disappearance of wetlands, gradual melting of permafrost, and contamination of aquifers with salt water and pollutants (Environment Canada, 2014).

Climate caused changes on water systems can have important consequences for the environment, economy and public health (TRCA and ESSA, 2012). The cost of flooding in southern Alberta in 2010 was $956 million and the impact of the 2001-2002 drought in Saskatchewan was the loss of $6 billion in GDP and 41,000 jobs. In 2005, a summer storm in southwestern Ontario and the flooding followed resulted in insurance claims of $500 million. Severe rain and storms have also played a role in the waterborne disease outbreaks in Walkerton, Ontario (2000) and North Battleford, Saskatchewan (2001), and numerous boil water advisories in remote regions and aboriginal communities.

Based on the increased severity and frequency of weather and water hazards that are seen globally, it is clear that countries need to rethink and revise their approach to water management (IPCC, 2014a; TRCA and ESSA, 2012). Canada is taking steps towards developing an adaptive, flexible, and risk-based approach to water management that requires an integrated analysis of water and wastewater infrastructure as well as adopting new policies and management practices for all water resources.

Figure 8. **Melting iceberg and glacier at the Jasper National Park (Alberta, Canada).** Photo credit: ©iStock.com/coryz.

6. Conclusions

Canada has access to approximately 20% of the world's stock of surface water. However, because of the uneven distribution of population and water supplies, many regions experience water shortages. In addition, water problems caused by population increase, urbanization, economic development, and climate change are on the rise, and have started to pose a threat to both the quality and quantity of surface waters and groundwater. Overall, Canada has a good network of water and wastewater infrastructure and can provide safe drinking water and good sanitation to its citizens. Nevertheless, there are also many small communities, particularly First Nations reserves, which suffer from continuous and persistent problems with the safety of drinking water and the contamination of water supplies due to inadequate wastewater treatment. Remoteness and cold climate conditions exert additional challenges to the design, construction and operation of water and wastewater infrastructure. As a result, waterborne outbreaks still occur in Canada but their frequency has substantially dropped in the past decade mainly due to the investments made to the water and wastewater infrastructure and training programs put in place for small system operators.

7. Acknowledgment

Figures 2, 4, 5, 6 and 7 are obtained with permission from reports published by the Government of Canada. The content of this chapter has not been produced in affiliation with or with the endorsement of the Government of Canada.

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Toronto

"a water management experience to think about"

Skyline of Toronto, Canada. Photo credit: ©iStock.com/espiegle

Urban Water Management: City of Toronto a Case Study

Michael D'Andrea

1. Introduction

The City of Toronto, with a population of 2.8 million residents, is Canada's largest city, located on the north shore of Lake Ontario, one of North America's five Great Lakes. The City of Toronto is the capital of the Province of Ontario (one of 10 provinces in Canada), and its municipal boundaries extend across a 640 square kilometer area, spanning six watersheds, where all but one of the watersheds extend beyond the City's municipal boundaries. The City has 11 waterfront beaches, eight of which have been granted the international Blue Flag designation and meet the strict Province of Ontario water quality standard for swimming beaches (Ontario, 1994) through most of the summer.

Toronto Water is a department within the City of Toronto municipal government, solely responsible for the provision of safe and reliable drinking water, the collection and treatment of wastewater, and stormwater management. Toronto Water is the largest supplier of municipal drinking water and wastewater treatment in Canada. Toronto Water was formed following the 1998 amalgamation of the former Metropolitan Toronto regional government with six former local municipalities. Prior to amalgamation, the regional government was responsible for the treatment and transmission of drinking water, trunk sewers and wastewater treatment. The local municipalities were responsible for local water distribution systems and sewers. This two tier governance structure for urban water management is typical across Canada. However, in addition to Toronto Water, Calgary Water Services and Halifax Water (a utility owned and operated by the Halifax Regional Municipality, and the only publicly owned water utility in Canada) are other Canadian examples of municipalities which have adopted the best practice of an integrated approach to urban water management. Integrating all water related operations under one organizational unit, ensures that the limited available funding is properly apportioned across all water service areas (drinking water, wastewater and stormwater) to meet the daily operational needs; and capital investment necessary to address the competing priorities of infrastructure renewal, urban growth servicing requirements, increasing regulatory requirements, protection of the environment, and climate change adaptation.

In Toronto, revenue obtained through metered water consumption supports Toronto Water's operating expenses and annual investment in infrastructure. Toronto Water operates and maintains infrastructure valued at over $28 billion CAD which includes 4 wastewater treatment plants, 4 water treatment plants, nearly 6,000 kilometres of transmission and watermains; and over 10,400 kilometres of sewers.

2. Governance

From a water governance perspective, it is important to recognize the regulatory and legislative framework under which the municipal governments in the province of Ontario operate their water systems. The Province of Ontario, through legislation, governs the provision of safe and reliable drinking water and the collection and treatment of wastewater. The Ontario Water Resources Act (Ontario, 1990a) is arguably the most important law protecting water quality and quantity for both surface and groundwater, and through which water supply and the discharge from municipal wastewater treatment facilities, stormwater management, and combined sewer overflows and treatment facilities are regulated. Complementing this Act is the Ontario Environmental Protection Act (Ontario, 1990b) which prohibits the discharge of contaminants into the natural environment unless an Environmental Compliance Approval has been issued specifying the allowable flow and concentration limits. These discharge limits are generally set, giving regard to Provincial Water Quality Objectives (Ontario, 1994), established to protect aquatic life; and recreational water use based on public health protection.

The most stringent requirements governing the discharge of wastewater effluent are captured within the Government of Canada's Fisheries Act (Fisheries Act, 1985), which prohibits the discharge of deleterious substances which would degrade or alter water quality such that it could be harmful to fish or fish habitat. Most recently, the Wastewater Systems Effluent Regulations (2012) were released under the Fisheries Act which specifically address municipal wastewater treatment plant effluents and impose strict limits for effluent quality, not previously regulated by the Province of Ontario, as well as requirements governing the annual reporting of combined sewer overflow discharges.

In Ontario, all upgrades or new municipal water, wastewater and stormwater system projects must adhere to the requirements of the Province of Ontario's primary environmental planning legislation: Environmental Assessment Act (Ontario, 1990c). This Act prescribes the process to be followed in consideration of options for these types of undertakings, incorporating public consultation. The options under consideration are evaluated based on ecological, social, cultural and economic impacts, which then frame the selection of the recommended preferred option for implementation. A guidance document produced by the Municipal Engineers Association (2011), provides a proven decision-making framework for various classes of projects (depending on their characteristics and significance) in compliance with the requirements of the Environmental Assessment Act.

An important piece of legislation governing watershed planning is the Province of Ontario's Conservation Authorities Act (Ontario, 1990d). The Act was first introduced in 1946 to enable the province and municipalities to join and form a conservation authority within a specified watershed based geographic area, to manage the province's watershed resources and protect lives and property from flooding and erosion. In 1956, following the devastating impact of Hurricane Hazel in 1954 where 81 lives were lost, thousands left homeless and massive economic losses were associated with widespread public and private property damage in the Toronto area, amendments were made to the Act. These amendments empowered the Conservation Authorities to prohibit filling of valley lands and floodplains, implement proper land use planning prohibiting urban development within flood-hazard areas such as floodplains, and the implementation of flood protection works such as dams, reservoirs, flood control channels and erosion control works.

In 2002, following the tainting of the municipal drinking water system for the small town of

Walkerton, Ontario, northwest of the City of Toronto, resulting in the tragic deaths of seven residents and over 2300 people becoming ill due to the contaminated water, the Province of Ontario passed the Safe Drinking Water Act (Ontario, 2002). The ultimate objective of this legislation was to protect human health through the control and regulation of drinking water systems, which include specific requirements governing operator training, standards for testing and reporting of drinking water quality. Licenses to operate drinking water systems are granted, conditional on the submission of sustainable drinking water financial plans. The financial plans, which must be approved by the governing municipal council, must demonstrate financial sustainability for both the utility's operations and longer term capital investment to address regulatory requirements, urban growth needs and infrastructure renewal. Toronto Water's 2010-2015 Drinking Water System Financial Plan also identifies all sources of funding for planned capital infrastructure projects (Toronto, 2010).

Complementing the Safe Drinking Water Act, the Province of Ontario enacted the Clean Water Act (Ontario, 2006) to protect drinking water, adopting a multi-barrier approach to prevent contaminants from entering sources of drinking water: groundwater and surface water. The Clean Water Act requires the establishment of multi-stakeholder Source Protection Committees, which include affected municipal water departments supplying water, the area conservation authorities, and affected industry sectors such as agricultural and land development. The Committees' overarching roles are to assess existing and potential water quantity and quality threats to drinking water sources; and to develop actions to reduce or eliminate the threats, embodied within formalized Source Protection Plans, developed with broad community consultation. Recently, a comprehensive Source Protection Plan (CTC, 2014), for an area extending over 10,000 square kilometres around the City of Toronto, directed at protecting 66 municipal groundwater supply wells and 16 municipal surface water intakes in Lake Ontario including the City of Toronto's four intakes has been completed and is awaiting formal approval from the Province of Ontario. The development of this Plan included undertaking a technical assessment of current municipal water sources to identify vulnerable areas; and existing and future water quality and quantity threats which may impair the long-term sustainability of the source. The Plan contains policies which address significant drinking water threats to ensure the protection of the drinking water sources, and identifies the responsible authorities to implement each policy.

To help support the financing of new or upgraded municipal infrastructure, including water, wastewater and stormwater systems required to service new urban growth, the Province of Ontario's Development Charges Act (Ontario, 1997) provides for the levying, by the municipality, of development charges to help pay for growth related off-site costs associated with the development. On-site costs are the responsibility of the developer. The Act requires that a ten year forecast of capital needs or upgrades are identified, which serves as the basis for the calculation of the charge. The funding accrued by municipalities through this legislation has supported significant upgrades and expansions in water systems across the Province of Ontario. In Toronto, funding accrued through Development Charges has supported Toronto Water infrastructure capital projects which ultimately support the servicing of future urban growth, as captured in Toronto Water's Drinking Water System Financial Plan (Toronto, 2010).

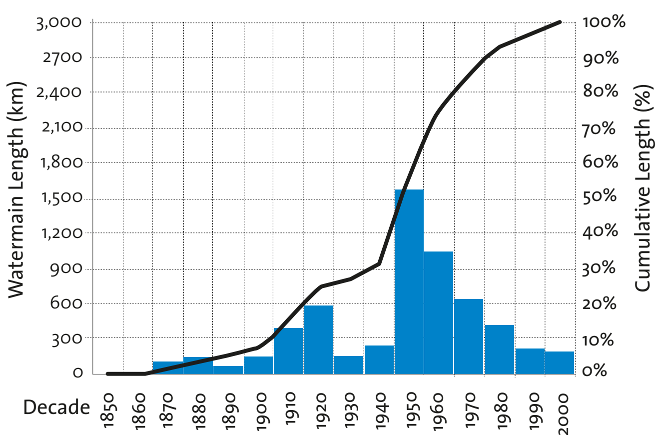
3. Infrastructure deficit / renewal needs

The water, wastewater and stormwater infrastructure renewal needs for older municipalities is a recognized problem across North America. The construction of this infrastructure has typically tracked urban development cycles; and much of this infrastructure is now at or nearing the end of its service life. In Toronto, an analysis on the longer term water and wastewater infrastructure renewal needs was last completed in 2008 (Toronto, 2008a). The analysis was undertaken by asset class: watermains, sewers, water treatment facilities and sewage treatment facilities.

The City of Toronto's water distribution system of 5,850 kilometres of pipe was estimated to have a replacement value of $5.9 billion CAD.

The construction of the water distribution system, dating back to the 1850s, is shown in Figure 1, by decade of construction. The Figure shows that the growth of the system tracks the urban development cycles in North America of the late 1800s, early 1900s and the major growth cycles of the 1950s, 1960s and 1970s. The average age of the system was estimated at just over 50 years, and where over 20% of the system was estimated to be 80 years of age or older, considered to be at the theoretical end of service life for this asset class.

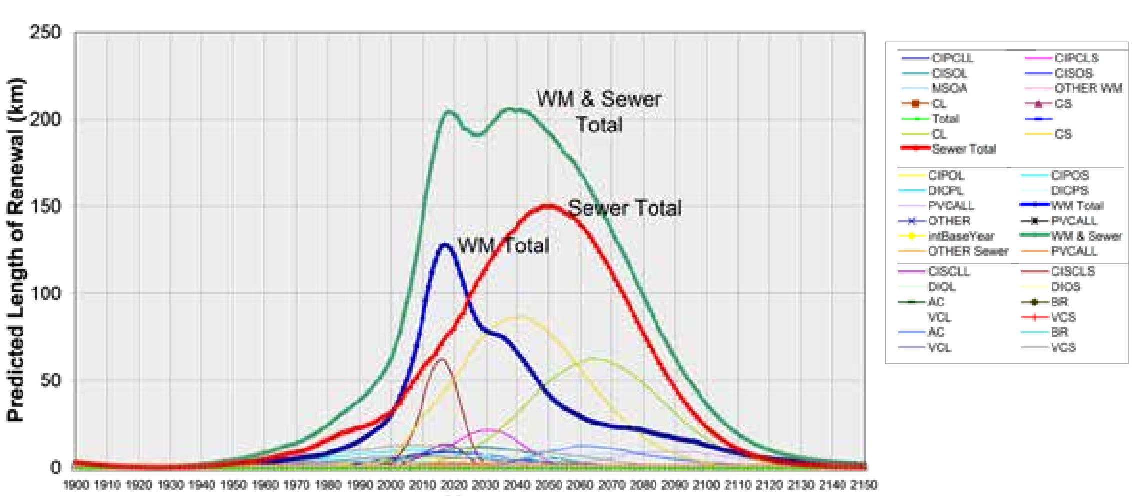
Figure 1. Watermain Infrastructure Construction History in the City of Toronto (Toronto, 2008)



By comparison, the City's sewer system of almost 10,600 kilometres of pipe was estimated to have a replacement value of $13.3 billion CAD. While the growth of this system followed similar construction cycles shown for watermains, some of the City's sewers date back to the early 1800s; and because combined sewers were constructed well into the 1950s, the age of the entire system is skewed by the fact that both storm and sanitary sewers were constructed subsequently, and therefore the overall age of this infrastructure class is somewhat newer than watermains, with the average age to be about 50 years, and 11% of the system was estimated to be 80 years of age or older.

To help assess the infrastructure renewal backlog and future renewal needs, the Water Research Foundation's KANEW model (Deb et al., 1998) was used. The KANEW model provided a methodology and software for predicting "survival" rates for cohorts of asset classes. The cohorts were established based on factors such as pipe type, age and material. A total of 12 and 8 cohorts were established for the watermain and sewer assets, respectively (Toronto, 2008a). The model was then used to generate predictions of annual infrastructure renewal needs. A summary of the modelling results, showing annual renewal rates for each cohort, all watermains, all sewers, and all pipes (watermains and sewers combined) is presented in Figure 2.

Figure 2. Predicted Annual Renewal Length by Year for: a) Watermains (WM); b) Sewers; and c) Total Watermains and Sewer Infrastructure (Toronto, 2008a)



Using this approach, the total watermain and sewer infrastructure renewal backlog was estimated to be 760 kilometres and 1,035 kilometres respectively, equating to a total renewal (defined as replacement and rehabilitation using trenchless structural lining technologies) need of $1.3 billion CAD, representing about 10% of the replacement value for these assets. However, if no additional investment is made in infrastructure renewal, each successive year adds to the renewal backlog. Based on the KANEW analysis, an estimated 70 to 130 kilometres (i.e. 1.2 to 2 percent) and 50 to 70 kilometres (i.e. 0.5 to 0.7 percent) of watermains and sewers, respectively, will be reaching the end of their service life and will need to be renewed annually, so as not to add to the backlog. Combined, this represented an annual investment of an estimated $110 million CAD, which includes pipe replacement and trenchless technologies such as the insertion of structural liners (examples can be found in D'Andrea, 2013) which can reduce overall costs and minimize disruption to the community.

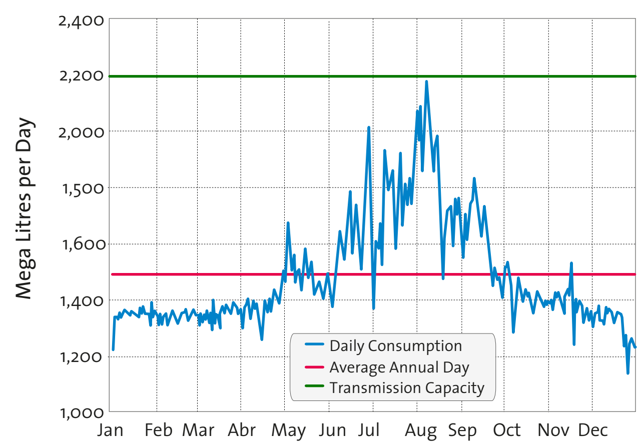
To address these needs, and the infrastructure renewal backlog at the City of Toronto's four secondary wastewater treatment plants (with a combined treatment capacity of 1.5 billion litres per day) and four water treatment plants (with a combined treatment capacity of over 2.7 billion litres per day), a longer term infrastructure renewal plan was developed, and is updated on an annual basis, as part of Toronto Water's annual capital budget submission.

4. Servicing future growth (water efficiency plan)

The City of Toronto's innovative Water Efficiency Plan (Toronto, 2002), approved by City Council in 2003, was directed at reducing water consumption across the City to create "in-system" capacity, to meet the short term projected population and employment growth (expected to increase by 10 to 12 percent, by 2011). The conventional approach was to expand water treatment and supply infrastructure which would have to supply peak day demand flows during summer months for outdoor water use (e.g. lawn watering); and wastewater collection and treatment infrastructure to support the additional wastewater flows generated.

In 2001, the typical annual water consumption profile for the City of Toronto with an average estimated consumption of 1260 ML/d and supply to York Region (a regional municipality north of Toronto) with an additional estimated annual average demand of 230 ML/d is presented in Figure 3. The figure shows a combined peak day demand of 2,210 ML/d, approaching the system's transmission capacity. The Toronto peak day demand represented an estimated 60% increase to the base (October to April) consumption of 1,155 ML/d in 2001.

Figure 3. 2001 Daily Water Consumption (ML/d) – (Toronto, 2002)



The Water Efficiency Plan's objectives were to reduce overall water consumption by 15% through the implementation of more water efficient fixtures and measures city-wide, to create capacity within the existing infrastructure and thereby defer costly infrastructure expansion, while decreasing energy use for pumping and corresponding CO_2 emissions, chemical usage at water and wastewater treatment facilities, and wastewater treatment plant effluent discharges. The underlying premise of the Plan was based on changing consumer behavior and influencing the purchase and implementation of more water efficient fixtures and measures by offering financial incentives. Measure specific financial incentives were derived based on a "capacity buy-back principle", where the value of the incentive provided was less than the cost of building the equivalent level of water and wastewater infrastructure: typically one-third the cost.

At the time the Plan was being developed, water used for toilet flushing and clothes washing represented nearly 30% and 22% of the average indoor water use, respectively (Toronto, 2002). While the Ontario Building Code mandated the use of ultra-low flush volume toilets for new home construction, high water consumption (13 litre) toilets were still being sold, typically at a much lower price point than the counterpart 6 litre and dual flush toilets. To help ensure success for the Toilet Rebate Program, which was a cornerstone of the Plan, and to address past criticism of first generation low flush toilets which often required multiple flushes to expel solids, toilet rebates were only offered for the purchase of specific toilets which met Toronto's minimum acceptable bulk solids removal requirements based on the standardized Maximum Performance (MaP) toilet testing protocol (Alliance for Water Efficiency, 2014).

The implementation of the Plan was estimated at $74 million CAD, and represented good value at one third the estimated $220 million CAD required for the equivalent expansion in water and wastewater infrastructure (Toronto, 2003a).

A number of water conservation/efficiency measures were identified for implementation by "water use sector": single family residential, multi-unit residential, industrial/commercial/institutional, and municipal; and included watermain system leak and water loss reduction; toilet replacement (to ultra low 6 litres or less flush volumes);industrial/commercial/institutional capacity buy-back program; outdoor water audits; computer controlled irrigation; and public education and community outreach.

Details regarding the methodology and derivation of the sector the specific financial incentives are contained within the Water Efficiency Plan (Toronto, 2002), which also sets out an implementation and monitoring plan. A water loss assessment and leak detection study was also undertaken, in support of the Plan development. The study found that water losses were in the order of eight to ten percent of the production totals, estimated at an annual value of $30 million CAD in treatment and transmission costs. Using the International Water Association (IWA) water audit methodology, and infrastructure leakage index (ILI) recognized as an international performance measure by which water utilities can objectively assess the level of water loss (AwwaRF, 2007), the City of Toronto was found to have an ILI of 4.2. As shown in Figure 4, the City of Toronto's results are in the middle of the range when benchmarked against municipalities across North America and internationally, respectively. Further, the study showed that an ILI of 2.5 is economically viable for Toronto and could achieve a leakage reduction of an estimated 49 MLD, valued at an estimated $15.8 million in treatment and transmission costs. To advance this initiative, the City of Toronto has developed a multi-facetted City-Wide Water Loss Reduction and Leak Detection Program, which is currently being implemented (Toronto, 2011a).

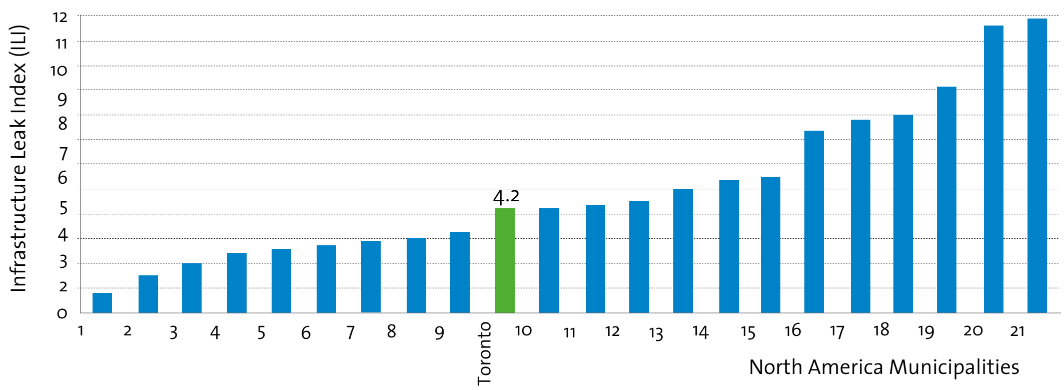
Water demands, measured as annual average daily demand (AADD) for Toronto, were analyzed and compared against the reductions forecasted through the implementation of the Water Efficiency Plan and the increases forecasted through the projected urban growth without water conservation, are presented in Figure 5. As noted, the actual water consumption reductions have exceeded the original Water Efficiency Plan projections, where the 2010 consumption dropped 14% from 2001 levels, notwithstanding that there was an estimated increase in population growth of 52,000 residents during this period.

While a number of factors have contributed to the lower than expected water consumption, including annual water rate increases, implemented to fund an aggressive infrastructure renewal program summarized below, the effectiveness of the Plan implementation must be acknowledged. Over 410,000 financial incentives (e.g. over 350,00 toilet rebates and over 60,000 rebates for high efficiency front load clothes washers) were issued at a cost of $37 million CAD, achieving a reduction in water consumption estimated at over 81 MLD, valued at an estimated $91 million in infrastructure expansion based on unit costs derived when the Plan was approved. However, based on actual construction cost escalations, this cost was re-assessed at an estimated $180 million CAD (Toronto, 2011a), representing an estimated 480% of the value of the financial incentives. Given the success of the program, changes in market conditions where the sale and promotion of water efficient fixtures and appliances have become the norm, and increased public awareness and support for conservation, most of the programs, particularly those offering financial incentives to consumers, were discontinued in 2011 (Toronto, 2011a).

Figure 4. Infrastructure Leakage Index (ILI) comparison across: a) North America; and b) Internationally (Toronto, 2011a)

Infrastructure Leakage Index Comparison
(source: Veritec Consulting Inc. & ILMSS Ltd., 2010 – PIFastCalcs V3b)

a) North American Comparison of ILI



b) International Comparison of ILI

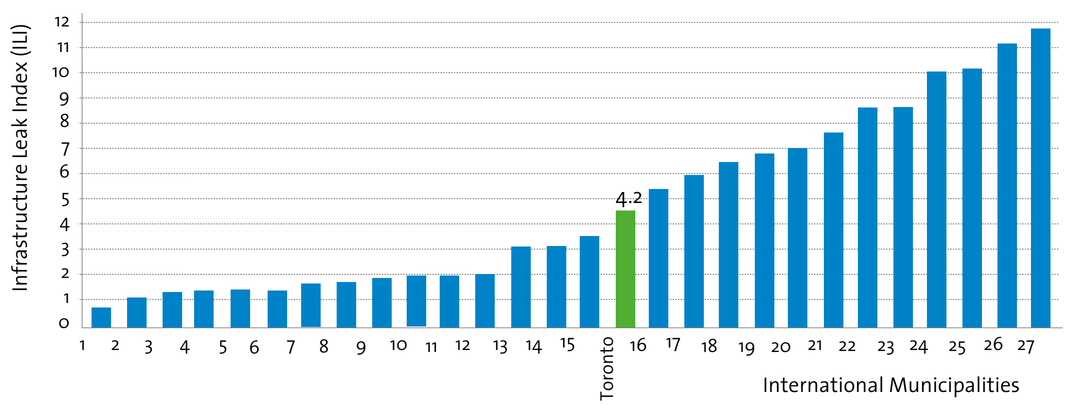
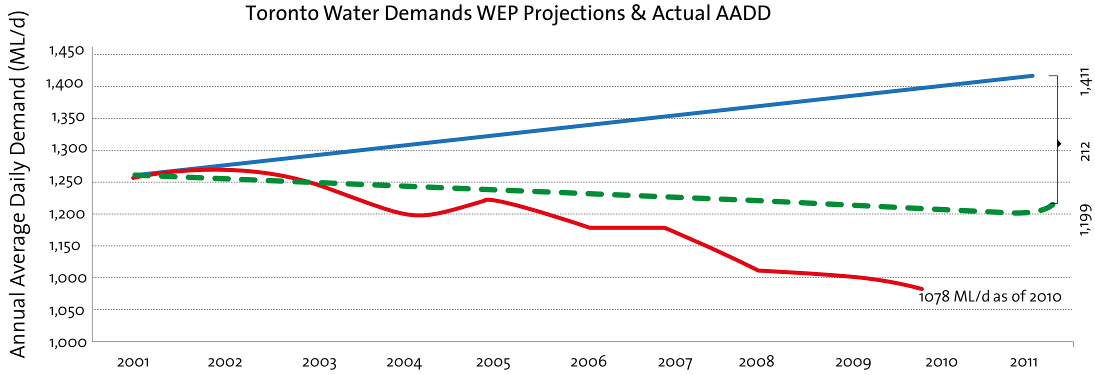


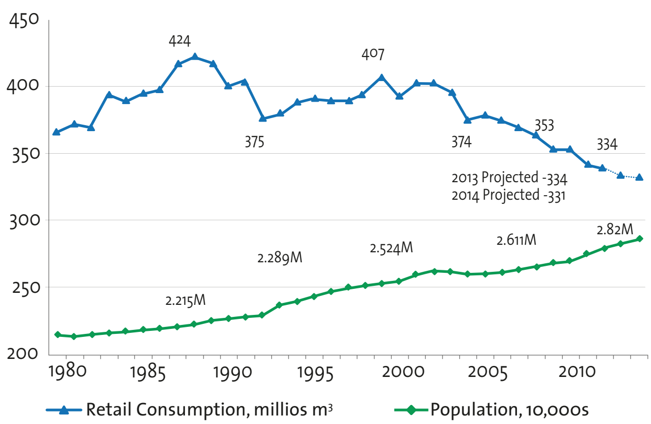
Figure 5. Toronto Water Demands: Water Efficiency Plan Projections and Actuals (MLD) – (Toronto, 2011a)

Toronto Water Demands WEP Projections & Actual AADD



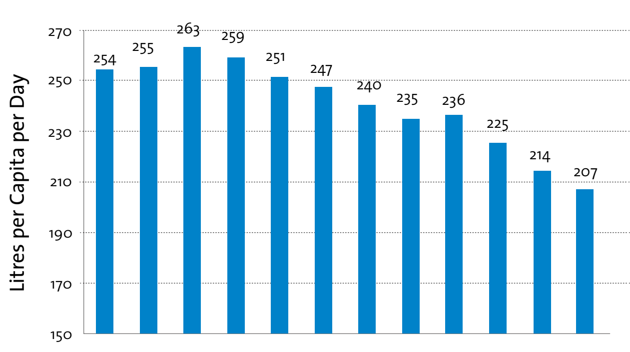
A recent summary (Toronto, 2013a) shows a more striking and continuing trend, where despite a significant population growth of an almost 8% (217,000 population) experienced between 2005 and 2013, water consumption has actually dropped an estimated 12% over this same period as shown in Figure 6.

Figure 6. Population Growth and Water Consumption: 1980 to 2013 (Toronto, 2013a)



Further, a steady drop in average residential per capita base (non summer) demand of about 2% per year, over the last 10 years, continues to be observed, as shown in Figure 7. With this trend, average per capita consumption is expected to drop to about 150 litres per capita per year by 2025.

Figure 7. Average Residential Per Capita Base Demand (Toronto, 2012)



Similarly, annual peak day water consumption associated with outdoor water use, largely for lawn watering, has also steadily declined to an estimated 1420 MLD in 2010, down an estimated 24% from the estimated 1850 MLD peak day consumption in 2001 (Toronto, 2011a).

While the reductions in consumption have been tremendously successful, this has had a profound negative impact on revenue, affecting Toronto Water's longer term infrastructure renewal plans, and water rate forecast predictions, which is discussed in more detail below.

5. Dealing with impacts of urban runoff (wet weather flow master plan)

Urban development within the City of Toronto and surrounding area has resulted in intense pressures on the ecosystem, and the alteration of the natural environment and hydrologic cycle, adversely effecting wet weather flows. In Toronto, this also results in increased stormwater runoff and polluted storm sewer discharges; combined sewer overflows (CSOs) from the combined sewer system which extends across about 25 percent of the city; and infiltration and inflows to the sanitary sewer system leading to wastewater treatment plant by-passes; which all contributed to degraded water quality in area watercourses and the Lake Ontario waterfront. The impacts of these wet weather flows have contributed to Toronto's designation as one of 43 polluted areas of concern in the Great Lakes Basin (Environment Canada, et. al., 1989). While past water pollution abatement measures focused on known pollution sources such as combined sewer overflow discharges, stormwater discharges in urban areas have also been found to be significant pollution sources. In Toronto, extensive studies of these discharges showed that event mean concentrations for storm sewer discharges were comparable to combined sewer overflow discharges (Figure 8). As shown in Figure 8, when compared against the Provincial Water Quality Objectives (PWQOs), the water quality constituent concentrations in these discharges is typically two to four orders of magnitude greater; and for E.Coli bacteria which is used as the beach water quality standard in Ontario, these discharges are typically three to four orders of magnitude than the PWQO of 100 counts/dL.

Figure 8. Event Mean Constituent Concentrations in Storm Sewer and Combined Sewer

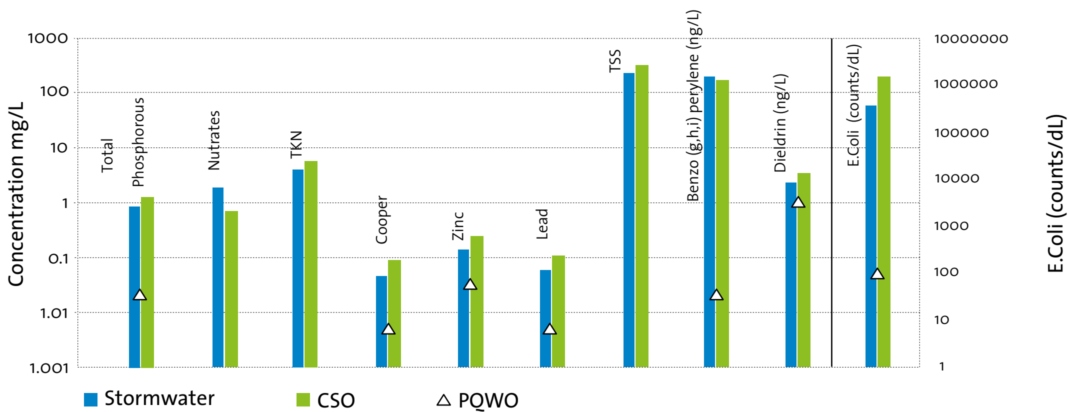
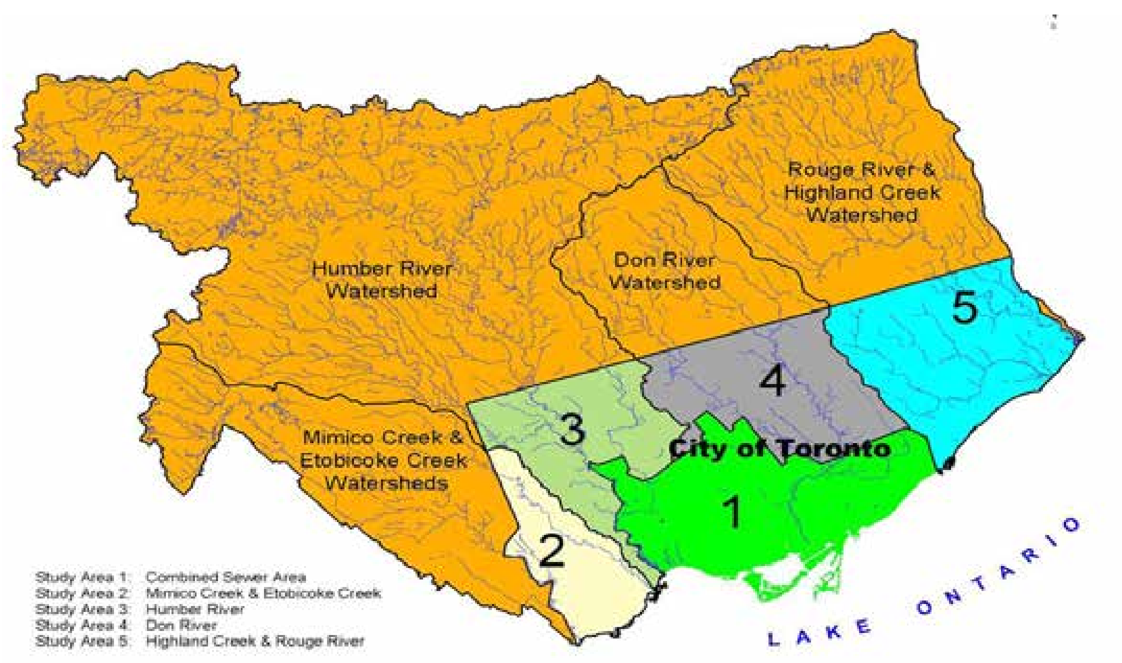


Figure 9. Study area for City of Toronto Wet Weather Flow Master Plan (D'Andrea, et. al, 2004a)



Further, more recently with the increased frequency of intense rainfall events exceeding the design capacity of the City's sewer system (typically during the summer months with characteristic high intensity shorter duration storms), the overloaded sewer systems lead to sewer back-ups and basement flooding (i.e. most homes in Toronto also have basements which provide below grade living space with floor drains connected to the sewer system).

In the Province of Ontario, new urban developments must prepare stormwater management plans as conditions of approval, in accordance with the Stormwater Management Planning and Design Manual (Ontario, 2003). In the absence of a regulatory requirement to deal with the adverse effects of wet weather flows in existing urban areas, previous wet weather flow initiatives in Toronto were driven, in large part, by the need to deal with localized flooding issues and water quality impacts on recreational beach areas. While source control options had been considered, the problems were generally addressed with hard infrastructure, and "end-of-pipe" solutions. Although these actions were significant and provided local environmental improvements, it was recognized that a comprehensive, watershed based approach was necessary across the entire City. This spawned the development of the City of Toronto's progressive Wet Weather Flow Master Plan which was approved by City Council in 2003. Consistent with the planning principles of the Province of Ontario's Environmental Assessment Act (Ontario, 1990c) and following the Master Planning process outlined in the Municipal Municipal Engineers Association (2011), the Plan was aimed at achieving set receiving water quality targets, in consideration of the Provincial Water Quality Objectives (Ontario, 1994) and incorporating broad public consultation at key decision points. Details of the Plan development, including the integration of sewer system, watershed and lake circulation receiving water computer simulation modelling to help assess the effectiveness of various options in achieving the end water quality objectives are summarized in D'Andrea et. al. (2004a) and D'Andrea et. al. (2004b). The Plan is considered the largest planning initiative of its type in Canada.

A new philosophy was adopted in the development of the Plan, which emphasized control of stormwater runoff at source. Further, following the stormwater pathway from individual property parcels to the receiving waters, a hierarchical approach to stormwater management was embodied in the Plan with measures and controls considered starting from source (lot level), followed by conveyance system controls, and then finally end-of-pipe. In parallel, a Wet Weather Flow Management Policy to guide new urban development/redevelopment and municipal works and operations was also developed.

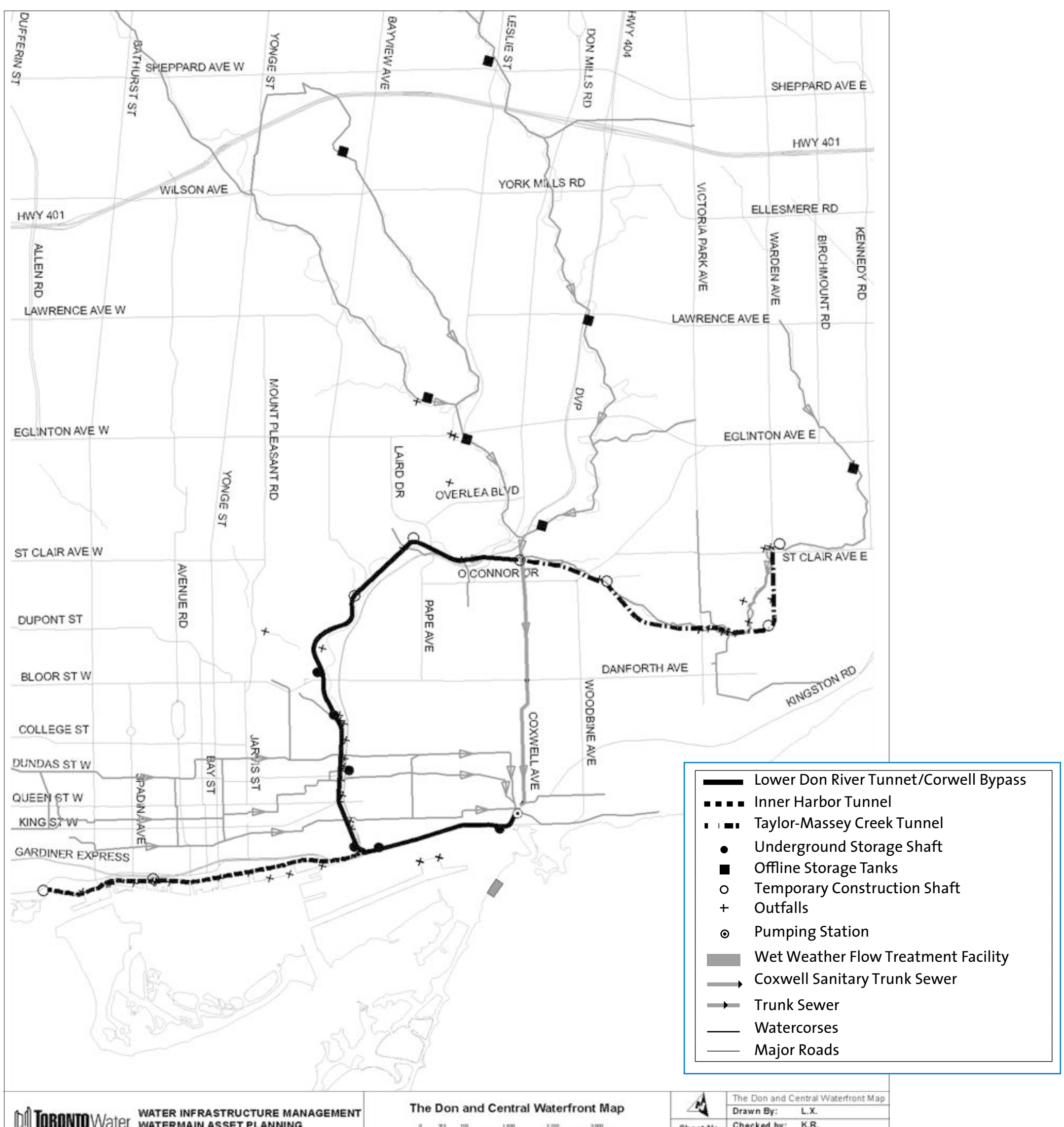
While the study area focused on the 640 km2 area contained within the City of Toronto boundaries, the study extended to include all six major watersheds (i.e. all but one of the watersheds extend beyond the City boundaries) which cut through the City, effectively representing a 2,100 km2 area (Figure 9), following an ecosystem management approach on a watershed basis (WEF/ASCE, 1998).

In developing the Plan, 13 objectives were developed, grouped into four major categories: water quality, water quantity, natural areas and wildlife, and sewer system (D'Andrea, et. al., 2004b). A number of strategies were developed, which represented a mix and varied level of implementation for the categories within the hierarchical framework of stormwater management: source, conveyance and end-of-pipe controls. Through computer simulation modelling, the effectiveness of the strategies in achieving the previously defined water quality objectives were assessed, and the costs estimated. A 25 year implementation Plan was developed, following extensive public consultation, based on the preferred strategy. The implementation of the comprehensive Plan (Toronto, 2003b), was estimated at over $1 billion CAD, and contained the following elements: public education and community outreach; enhanced municipal operations including a dry weather discharge remediation program, shoreline management, source controls (which led to the mandatory disconnection of all residential downspouts affecting an estimated 350,000 properties), conveyance controls (e.g. protecting and enhancing the City's extensive ditched road drainage systems, and construction of infiltration systems where appropriate through ongoing renewal of the City's aging sewer system) , end-of-pipe controls (e.g. including the construction of an estimated 180 stormwater ponds where sufficient open space was available; and underground storage systems for stormwater and CSOs in space constrained areas such as the downtown core), basement flooding protection works (which were expanded in scope subsequently and described in more detail below), stream restoration works (e.g. using natural channel design principles where possible); and environmental monitoring. In support of the Plan, a Wet Weather Flow Management Policy was also developed to guide actions and planning by the City on wet weather flow issues, particularly in regards to the servicing and requirements for new and redevelopment areas (Toronto, 2003c). Subsequently, Wet Weather Flow Management Guidelines were produced to direct prescribed levels of water quantity and quality control for new development (Toronto, 2006a). A summary of the progress made in implementing the Plan and priorities on a go forward basis can be found in Toronto (2011b).

One of the most significant projects contained within the Plan is the Don River and Central Waterfront Project, aimed at addressing most of the

City's remaining CSOs, and ultimately leading to the "delisting" of Toronto as an Area of Concern in the Great Lakes Basin. This project uses a "systems integration" approach to address the wet weather flow needs identified in the Plan, the longer term wastewater collection servicing needs supporting urban growth within the Don Sanitary Trunk Sewer System (the City's largest trunk sewer system, servicing an estimated 750,000 population), and along the Central Waterfront area, as one comprehensive project. The complete system (Figure 10) incorporates a 22 kilometre system of deep tunnels, underground storage elements, real time control for an existing trunk sewer, and a high-rate treatment facility to treat the flows captured (Toronto, 2011b). The project is in the engineering design phase and construction is expected to begin in 2017.

Figure 10. Don River and Central Waterfront Project Elements (Toronto, 2011b)



6. Climate change adaptation to address urban flooding: basement flooding protection program

In developing the Wet Weather Flow Master Plan, measures and system upgrades were included to address areas of the City which had recently experienced sewer backups leading to basement flooding. However, there was no consideration given to the urban flooding impacts from more frequent extreme storms resulting from climate change.

In August 2005, an intense rainfall with over 150 mm of rainfall over a two to three hour period resulted in over 4,000 basement flooding complaints across the newer areas of the City (serviced by separated storm and sanitary sewers); and caused significant damage to the City's infrastructure including the complete washout of an arterial road, a washout of a section of a sanitary trunk sewer, and extensive stream bank erosion damage. These impacts exposed the need to develop a plan for and effectively deal with the impacts of climate change. The impacts of this storm and the work plan which ensued are presented in D'Andrea (2011) and Toronto (2006b and 2008b).

A typical, post 1950s Toronto residential property has two sewer connections (i.e. previously only a single sewer connection was required to connect to combined sewers servicing the older areas of the City): one sanitary sewer lateral servicing the internal wastewater plumbing and basement floor drains; and one storm sewer lateral servicing the buildings foundation drains (although some homes have foundation drains connected to the sanitary sewer lateral instead) and downspouts (in cases where they are still connected). During periods of heavy rain (in excess of the sewer system design capacity), the sewer systems are overloaded and surcharge leading to sewer back-ups and wastewater flow into the basements, typically through the floor drains which are at the lowest elevation within the home.

Historically, there have been several instances where intense storms have resulted in widespread basement flooding. For the most part, incidents of basement flooding resulting from sewer backups had largely been eliminated except for extreme storm events, as a result of infrastructure improvements made to address this problem. In the areas of the City serviced by combined sewers, separate storm sewers to intercept road drainage were constructed to reduce flows to and surcharging of the combined sewers. In separated sewer areas, improvements were typically made to the sanitary sewer system by upsizing sewers to eliminate hydraulic bottlenecks, and constructing in-system storage facilities to address the increased levels of infiltration and inflows of stormwater to the system. Unfortunately, these upgrades were insufficient to accommodate the deluge from the 2005 storm.

A detailed engineering review was therefore undertaken to identify the problems contributing to the widespread flooding, and the upgrades necessary to reduce the risk of future flooding from extreme storms (Toronto, 2006b). The review found that the existing sewer systems were in generally good structural condition and performed as per their original design. The storm sewers, for example, were designed to intercept primarily road drainage for storms of a one in two, to a one in five, year return frequency. The storm of August 2005, was determined to have a return frequency in excess of one in 100 years, which completely overloaded the storm sewers, and contributed to a much higher than designed level of infiltration and inflow to the sanitary sewers.

As noted earlier, past attempts to alleviate basement flooding focused on the sanitary and combined sewer systems; and the storm drainage systems, both minor (sewers) and major (overland flow) were rarely reviewed. Most of the City of Toronto was serviced without a proper major drainage system, such that when the storm flows exceeds the design capacity of the storm sewer system, the stormwater remains on the road surface and flows to a low point where, ideally, it outlets via an overland flow route to the nearest watercourse. However, many areas of the City are very flat or have low points with no place for the water to outlet and therefore, during extreme storm events, significant ponding occurs on the street, often overtopping curbs and flowing onto private property (see Figures 11 and 12). Further compounding the problem, in many areas, the individual properties are poorly graded (in many cases toward the house) and, in some cases, the homes have reverse sloped driveways in which stormwater is conveyed directly to the house. As a result, this creates several opportunities for stormwater to enter the sanitary sewer system: a) within the road way, sanitary sewer access covers located in low lying areas prone to ponding provide a direct access point; b) stormwater ponding around the foundation walls of individual homes can enter through windows, doors, cracks in the wall, etc., and then ultimately to floor drains connected to the sanitary sewer; and c) where foundation drains are connected to the sanitary sewer saturated ground conditions will increase flows to the sanitary sewer, as shown in Figure 12.

Consistent with the Wet Weather Flow Master Plan, an integrated approach was used to develop the City's Basement Flooding Protection Program, to address the adverse impacts of extreme storms, which subsequently formed the City's climate change adaptation strategy dealing with urban flooding.

Figure 11. Overland Flow Paths in Residential Area of Toronto (D'Andrea, 2011)

Figure 12. Separated Sewer System Schematic: a) normal function when storm flows are within sewer design flows; b) when storm sewer system is overloaded (D'Andrea, 2011)

The key elements of the program consisted of:

a. Source control measures: promoting the installation of backwater valves on the sanitary lateral servicing residential properties and the disconnection of foundation drains from the sewer system, and having them connected to a sump pump instead, wherein the City provides a financial subsidy to help entice the installation of both; mandating the disconnection of roof downspouts through regulation; promoting proper lot grading, repairing of cracks and leaks in foundation walls, windows, doors; and promoting soft-surface landscaping that help reduce the amount of stormwater runoff generated;
b. Sanitary sewer system improvements: increasing the service standard for sanitary sewers permitting a greater level of infiltration/inflow than conventional sanitary sewer design in basement flooding prone areas; and
c. Storm sewer system improvements: increasing the service standard for storm drainage systems to a one in 100 year storm event, where feasible, where a proper major (overland flow) drainage

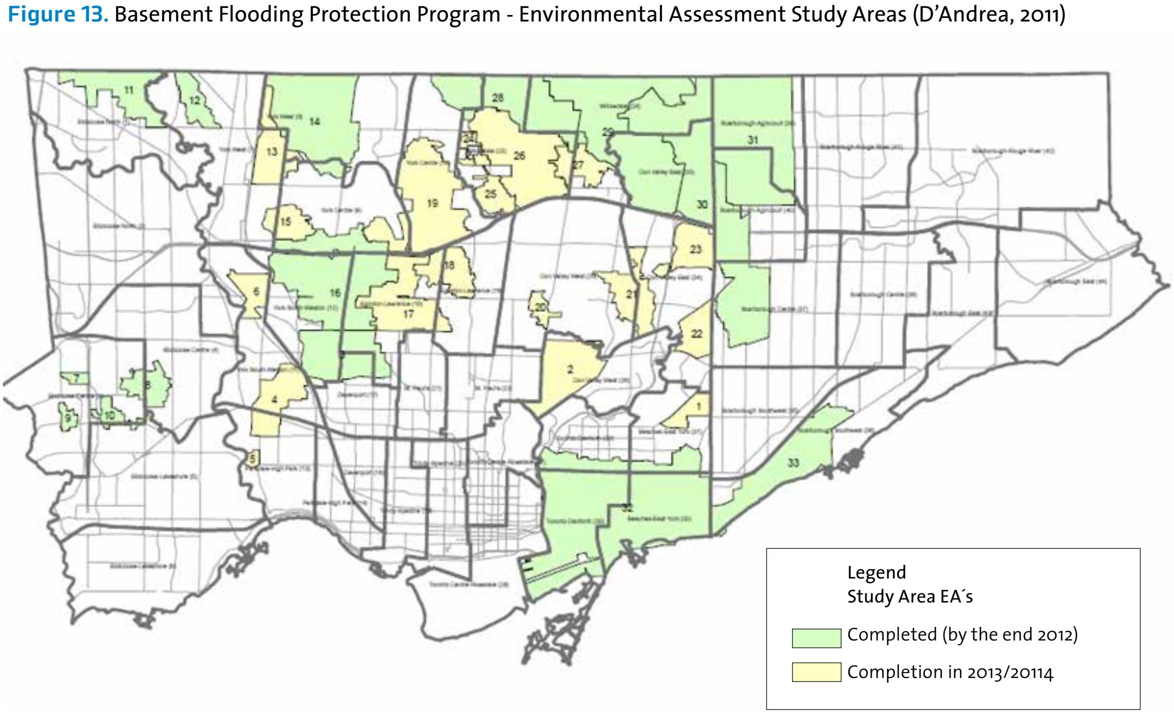
system does not exist. This typically involves construction of additional inlets in low lying areas with stormwater dry ponds where open space is available; and/or underground storage tanks or oversize pipes.

The Program was applied, initially, to 31 chronic basement flooding prone areas across the City (Figure 13), wherein environmental assessments with broad public consultation are used to identify and evaluate various options to help reduce the risk of flooding. As summarized, in Toronto (2008b), the environmental assessments were completed for the first four study areas, and consistent with the approach above, of the $230 million CAD identified in infrastructure improvements, only $20 million CAD were earmarked for sanitary sewer upgrades, the remainder was directed at storm drainage and storm sewer improvement works. Given the pent up demand and continued frustration by residents as extreme storms have continued to hit the City, where most recently in July 2013, more than 4,700 homes experienced basement flooding, the Program has grown to include an additional four study areas, and Toronto Water's ten year capital program has earmarked an estimated $1 billion CAD (Toronto, 2013a) for the implementation of infrastructure improvements emanating from the studies noted above.

7. Integrating and funding urban water management infrastructure needs

To fund the above-noted programs, the City of Toronto, through the Toronto Water Division, prepares an annual capital budget which includes a ten year plan of capital infrastructure projects and programs, necessary to meet the above-noted programs, and other projects across its three service areas: water treatment and supply, wastewater collection and treatment, and stormwater management. The projects are categorized in the following priorities: health and safety; legislated

Figure 13. Basement Flooding Protection Program - Environmental Assessment Study Areas (D'Andrea, 2011)



(e.g. projects aimed at complying with the Federal Fisheries Act -Wastewater Systems Effluent Regulations); state of good repair (e.g. infrastructure renewal); service improvement (e.g. the Basement Flooding Protection Program); and growth related (e.g. implementation of the Water Efficiency Plan and infrastructure upgrades). A summary of the infrastructure renewal and upgrades planned for 2014 and to the year 2023, by category, is presented in Toronto (2013a).

Toronto Water's 2014 approved capital budget was $613 million CAD; and the 10 year 2014 to 2023 Capital Budget and Plan was estimated at $8.97 billion CAD, of which 56, 24, 11 and 8 percent is directed at: state of good repair, service improvement, legislated and growth, respectively.

In Toronto, the capital budget submission is complemented with the submission of an annual water and wastewater rates report which contains a financial analysis of forecasted water consumption; corresponding revenue projections based on proposed rate increases; and a projection of the capital reserve balance from which the capital program is funded. The corresponding 2014 Water and Wastewater Rates and Service Fees report, supporting the 2014 to 2023 Capital Budget and Plan is presented in Toronto (2013b).

Early after the amalgamation of the City of Toronto, in 1998, annual water rates were generally set near the rate of inflation, but the revenue generated was insufficient to deal with the increasing capital program needs (Toronto, 2005). Annual rates were subsequently raised by nine percent and then six percent, respectively, however, capital reserve balances continued to be insufficient to fund the program requirements. In 2006, Toronto embarked on a nine for nine (nine percent per year – for nine years) water rate increase campaign, where all additional revenue generated was directed to funding the ever expanding capital program, with a priority placed on the ageing infrastructure renewal (Toronto, 2005). As noted earlier, a comprehensive analysis completed in 2008, across all infrastructure asset classes, estimated the infrastructure renewal backlog at $1.8 billion CAD. With the increased revenue and concerted investment in infrastructure renewal, at a rate greater than the rate of decay, by the end of 2014, the renewal backlog was estimated to be $1.6 billion CAD and with the continued planned investment, is projected to be eliminated by 2023 (Toronto, 2013a).

Toronto Water has been funded on a "pay as you go basis", where most of the funding to support its operations and capital program is funded through metered water consumption, without reliance on borrowing or debt financing. A two block rate structure is used for setting water rates: Block 1 includes all consumers including industrial consumption for the first 6,000 cubic metres per year; and Block 2 includes industrial process use water with consumption greater than 6,000 cubic metres per year with rates set as a Council approved policy at 30 percent reduction of the Block 1 rate. In 2014, the Block 1 and Block 2 rates were set at $2.96 and $2.07 CAD per cubic metre, respectively. The average annual single family residential household consumption is estimated at 300 cubic metres, representing an average annual cost of $814 CAD.

As noted earlier, despite the increase in population, total water consumption has been trending downward. Although weather conditions, particularly during the summer months affect outdoor water use (e.g. lawn watering), the steady decline is largely attributed to the continued implementation of water efficiency measures and economic factors. Currently, water consumption is estimated at 200 litres per capita per day, and if current trends continue, is expected to drop to 150 litres per capita per day by 2025. This has resulted in a significant reduction in forecasted revenue, limiting the available funding for capital project priorities, and the longer term capital program. As noted in Toronto (2013b), the current capital plan is facing a shortfall of over $1 billion CAD over the next 10 years, and additional funding needs to be raised to maintain current levels of service and to accelerate Council priority programs such as the Wet Weather Flow Master Plan and Basement Flooding Protection Program.

More recently, Toronto Water has begun exploring various options, including the introduction of a stormwater utility charge, which would create a dedicated funding source for all wet weather related projects (Toronto,2013c). In Canada, this type of charge has already been introduced in cities such as Calgary, Edmonton, Regina, London, Kitchener and Halifax.

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Chile

Skyline of downtown Santiago, the capital of Chile, featuring 300-meter high Gran Torre Santiago, the tallest skyscraper in Latin America, and Mapocho River, which divides the city in two parts. Photo credit: ©iStock.com/Phototreat.

"Chile's extreme geography, with landscapes including Earth's driest desert and the largest ice fields in the Southern Hemisphere outside Antarctica, poses complex challenges for water resource management. Chilean cities development occurs in a historical context characterized by increasing awareness on the importance of inclusive access to goods and ecosystem services, as well as of equal opportunities for human development; water is a specially important factor for achieving these objectives"

Water Security in Chile's Cities: Advances and Pending Challenges

James McPhee, Jorge Gironás, Bonifacio Fernández, Pablo Pastén, José Vargas, Alejandra Vega and Sebastián Vicuña

Summary

As it happens in many urban centers around the world, Chile's urban water sector seeks to attain water security[1] by means of enhancing water's productive potential while at the same time minimizing its destructive force through urban water systems. Chile's historical evolution shows a trajectory of success, with significant improvements in access to safe drinking water supply, sewage collection and treatment, with private services provision and effective public oversight. These improvements have reduced significantly the incidence of water-borne infectious illnesses in the population. Despite the above, outstanding challenges persist, including local water quality problems related to Chile's geology; the need for integrated and sustainable urban and natural water system management for quantity and quality; and the need for increasing water services access for population living in peri-urban environments. Given that the majority of Chilean cities are located in water-scarce areas, or in regions where climate change is expected to generate important drying effects in the long term, it is urgent to address these challenges with both existing and new, effective management tools.

1. Introduction

Eighty-nine per cent of Chile's population currently live in cities, which is more than both the world average of 54% and the 80% who inhabit cities in Latin America and the Caribbean, the estimated percentage of city dwellers for 2050

1. Water Security is understood here in keeping with the United Nations definition that it is the population's capacity to maintain sustainable access to sufficient amounts of water of acceptable quality to support the life, wellbeing and economic development of the population to ensure protection from the pollution of water systems and water-related disasters, and to preserve ecosystems in a climate of peace and political stability.

being 93% (United Nations, 2014). As with many of the world's cities, legislation in Chilean cities seeks to achieve water security, by increasing the productive potential of water and minimizing its destructive potential through Urban Water Systems, whether public or private. Chile's enormous geographic diversity means that its cities face a wide range of water security threats, from the hyperaridity and competition between users faced by cities in the north of the country through shortages and seawater intrusion in coastal cities to flooding in the southern zone and local water quality problems of various origins.

Generally speaking, cities can have stable areas or be in a state of expansion (as in the case of Chile). The former typically have an established service infrastructure, although the level of achievement of their objectives may be incomplete. Among the latter, it is often necessary to develop infrastructure quickly through processes that are not always compatible with the rest of urban development, placing excess pressure on existing systems. Although lack of infrastructure may be viewed as a weakness, it can also be seen as an opportunity to develop innovative solutions, taking into account the experiences of other cities, and new knowledge of rapid global changes such as climate change. Chile's experience is presented below, with a focus on three main issues: i) the institutional experience of the sanitation sector; ii) the challenges of sustainable rainwater management; and iii) the expected impact of climate change and the first steps towards adapting to it.

2. Governance and Sanitation Sector Management in Chile

Valenzuela and Jouravlev (2007) identify four historical phases in the development of Chile's sanitation sector. The first phase, from 1950 to 1974, was characterized by sanitation service provision by the state alone. Within the historical context of the time, public companies did not sufficiently distinguish between their supervision and service functions; users were not charged the real price of services, there was a high level of unfocussed subsidies, and investment decisions competed with other state needs. This phase saw the creation of the Directorate of Sanitation Works (DSW) in 1953, as a result of the merging of the Department of Hydraulics of the Ministry of Public Works (MPW) and the Directorate of Drinking Water and Sewerage of the Ministry of the Interior. Although the DSW was nominally the only entity with the mission of developing urban fresh water and sewerage services, in practice it shared responsibilities with other state departments, a characteristic of the Chilean water sector that has survived to this day (World Bank, 2012).

The second phase, from 1975 to 1990, coincides almost exactly with the duration of the military government (1973-1990). This period was marked by an emphasis on the liberalization and deregulation of various markets in order to reduce inflation and achieve a macroeconomic balance. Moreover, there was a drive by the authorities to limit the state's role to oversight and subsidization functions. Of particular importance during this period was the Water Code, enacted in 1981. Among other things, it established the private nature of water use rights, making it possible to reassign water through market transactions. Although several public companies were privatized during this phase, the sanitation sector remained under state control, and it was decided to perfect the system. At the institutional level, in 1977, the National Sanitation Works Service (NSWS) was founded, bringing together various scattered services at the national level. The NSWS was an autonomous territorially decentralized state institution. It had a national directorate and eleven regional offices in addition to overseeing two state companies specifically created to serve the cities of Santiago, the Metropolitan Sanitation Works Company (MSWC) and the Valparaiso Sanitation Works Company (VSWC). Various authors agree that this structure made it possible to significantly increase the efficiency of the system and promote a major increase in coverage during this phase. This was achieved by reducing the number of staff, increasing the flexibility of decision-making, and promoting greater transparency and better use of resources (Salazar, 2003; Alegría and Celedón, 2004; Fischer and Serra, 2004). In financial terms, this phase was marked by change, including increased collection through stricter billing policies, outsourcing, progressive increases in rates together with subsidies targeting low income sectors. The drive to modernize the billing system was particularly important. The process underwent several iterations before converging on a general regulatory scheme implemented during the third historical phase. At the end of the second phase, a new regulatory framework was created through the enactment of the Sanitation Services Rates Law and the General Sanitation Services Law (1988) the Law for the Subsidization of Fresh Water Consumption and Sewerage Service Fees (1989) and the law that created the Sanitation Services Superintendence (SSS) (1990). Moreover, during this period the state was allowed to undertake business activities related to drinking water and sewerage, for which the NSWS and the MSWC and VSWC offices became public limited companies with majority shares in the Economic Development Agency (EDA).[2] Although the implicit objective of these transformations was the privatization of sanitation companies, in practice, the process was not completed until some years later.

The third phase, from 1991 to 1994, was characterized by a system of public companies operating under a scheme devised for private companies. The government of the time decided to suspend the privatization fostered by the regulatory changes implemented at the end of the military government and instead encouraged improvements to the management of these companies using the tools available. A key step involved setting prices according to development costs, together with targeted subsidies, which increased the companies` profitability with minor political costs. With the gradual increase in rates, by 1997, all the state sanitation companies were generating profits and contributing funds to the State Treasury for financing of other social programs (Alegría and Celedón, 2004). By 1995, the MSWC's net annual profits were approximately 11% higher than its total assets. This ideal situation was partly due to the country's solid economic performance, which meant that people had higher incomes and were more willing to pay for drinking water and sewerage services. This phase was also characterized by the start of SSS's operations, meaning that there was a state agency overseeing publicly owned companies.

2. EDA is a state body tasked with promoting productive development.

The fourth phase, which began in 1995 and has continued until the present, corresponds to the privatization of the public sanitation companies existing in 1994. The government of the time justified the decision to privatize these companies by citing the need to increase their investment capacities and meet the country's growing need for wastewater treatment services.

This issue was perceived as a debt that had dogged the public companies in the sector which, although they had notably increased coverage of drinking water provision and wastewater collection services in previous decades, had failed to achieve a similar level of success in wastewater treatment coverage. Likewise, it was argued that the state would thereby use the public funds required for financing social programs to invest in infrastructure that could be covered by private capital. Between 1995 and 1998, triggered partly by specific events that created a public scandal, measures were taken to correct the laws enacted in previous years.

Thus, in 1998, the Law of Sanitation Service Rates was modified, together with the General Law on Sanitation Services and the Law on Sanitation Service Supervision. The state was to control 35% of regional sanitation companies, a percentage which could be reduced if this did not contribute to capital increases. Despite this, the state would be able to maintain veto power over certain decisions provided its share was over 35% or else for 10 years after the moment when its share first fell below 35% of the capital with the right to vote, as long as its share was equal to or greater than 10%.

The modifications can be summarized as follows:

- Strengthening the SSS with greater resources, autonomy and skills and increased control measures. Of particular interest was the modification of the regime of sanctions for companies failing to fulfill their obligations.
- The participation of companies providing other public services, operating within the same concession territory of a sanitation company was restricted, thereby preventing the institutional concentration of basic services.
- Restrictions on company ownership were introduced to prevent the formation of monopolies and encourage comparative competition.

- Transactions with related companies were regulated.
- Measures were adopted to regulate conflicts of interest and prevent the manipulation of information.
- The procedure for conflict resolution was improved.
- The process and methodology for tariff setting was improved and made transparent.

Aspects of Sanitation in Urban Sectors: Drinking Water Provision and Wastewater Management

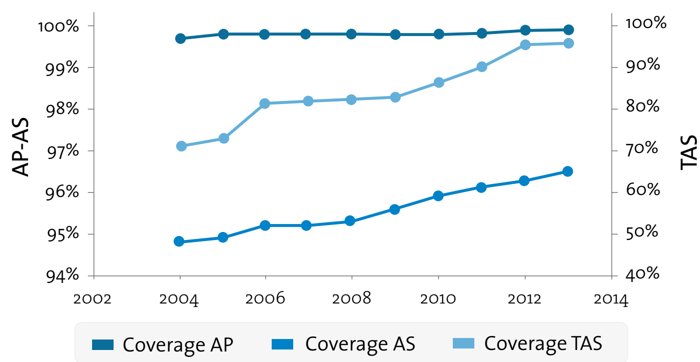
Service Coverage

Drinking water and sewerage infrastructure coverage has reached high levels in Chile. The World Health Organization (WHO) and UNICEF document entitled Drinking Water and Sanitation (updated 2014) states that Chile met the United Nations Millennium Development Goals for both drinking water and sanitation for the whole population (UNICEF/WHO, 2014). The total population (urban%) of Chile rose from 13.2 (83%) to 17.5 (89%) million inhabitants between 1990 and 2012. Sanitation coverage increased from 91% to 100% in urban areas, with access to improved drinking water sources rising from 99% to 100% during the same period.

Figure 1 shows the evolution of drinking water coverage, the sewerage network and wastewater treatment services for the past 10 years (2004-2013). In 2013, drinking water coverage was 99.9%; the regions with the lowest coverage being Araucanía (99.8%), Atacama (99.7%), Coquimbo (99.7%) and Valparaíso (99.4%); sanitation coverage is 96.5% with a minimum of 88.2% in the O'Higgins region, while 99.9% of the population are connected to the sewerage system and wastewater treatment services. Maule is the only region where the entire volume of collected wastewater is not treated (98.4%) (SISS, 2013a).

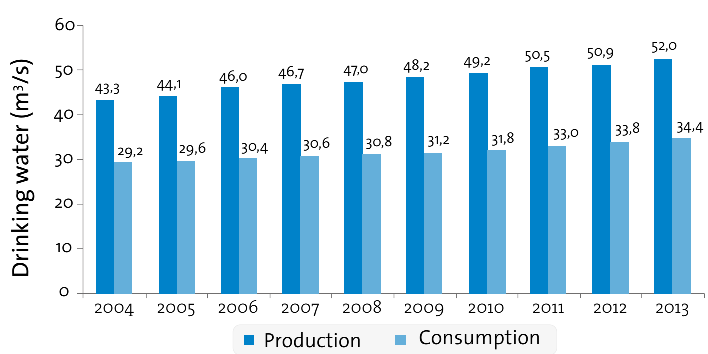
In 2013, sanitation companies produced a total of 1,639,247 thousand m³ (equivalent to ~52 m³/s), of which an average of 33.7% were not billed, corresponding to losses in the production and distribution phases (SISS, 2013b). Figure 2 shows the evolution across time of average water production by sanitation companies and average water consumption over the past ten years (2004-2013).[3] On average, considering the population served by sanitation companies, the estimated allowance per capita is 139 l/day[4] (138.5 and 138.9 for 2012 and 2013 respectively), with a maximum of 531.4 l/day per inhabitant for the Aguas Manquehue company(which supplies water to the eastern section of Santiago) and a minimum of 70.4 l/day for the area of Melipilla Norte (2013).

Figure 1. Urban coverage for drinking water (PW), sewerage (S) and wastewater treatement (WWT) between 2004 and 2013.



PW and S coverage can be read along the left vertical axis, and WWT coverage can be seen along the right vertical axis. 2004-2013. Las The calculation was made with consideration to the entire urban population. (Source: Prepared by the authors using information published by the SISS)

Figure 2. Average production and consumption of drinking water in the last ten years (2004-2013). Prepared with information on SISS reports of production and billing.



3. Information from the 25 main companies, which together provide sanitation and drinking water services for 99.4% of the clients in Chile's urban zone.

4. 1 m³/s = 86.400.000 l/day

Urban sector coverage is substantially higher than in rural sectors. Drinking water coverage through the rural drinking water system is in the order of 70-80% (the value depends on the estimated size of the rural population). However, WHO-UNICEF cites Chile as having achieved the greatest reduction of the gap between urban/rural drinking water coverage for the period between 1900-2012 among countries with over 95% coverage in urban sectors in 1990 (UNICEF/WHO, 2014).

Drinking Water Quality

Drinking water quality is normally controlled by current regulations and is available through the SSS, which provides a record of divergences from drinking water parameters (NCh 409/1 Of. 2005) (SISS, 2014). To obtain a general notion of the main areas of non-compliance, a sample of five months between February 2012 and March 2014 was analyzed. For this period, a total of 156 incidences of divergences were found out of a total of 81,725 measurements, meaning that fewer than 0.2% of the samples measured failed to meet the standard. Table 1 presents a summary of the parameters whereby the divergences and locations affected were identified. The highest percentages of divergences in relation to the number of times the parameter was reported were sulfates (1.37%), arsenic (1.21%), suspended

Table 1. Non-compliance with drinking water quality parameters

Parameter	Norm	Units	Deviances			Locations		
			Total	Devian-ces TKTK	%	Northern Zone	Central Zone	Southern Zone
Arsenic	0,03 0,01	mg/L	1906	23	1,21	Alto Hospicio, Diego de Almagro, Huara, El Salado	Barnechea, Lampa, Quilicura, Chacabuco	
Bromodichloromethane	0,06	mg/L	1897	1	0,05			Coronel
Free residual chlorine	0,2 to 2	mg/L	1917	8	Northern Zone	Central Zone	Southern Zone	Empedrado, Constitución, Lebu
Chlorides	400	mg/L	1900	7	0,37	Copiapó, Totoralillo		
Total coliforms	Absence	-	1917	10	0,52		Barnechea, Valdivia de Paine, Los Álamos, Los Molles	Labranza, Pillanlelbún
True color	20	Pt-Co	1912	1	0,05			Porvenir
Flouride	1,5	mg/L	1907	5	0,26	Copiapó, Caldera	Maipo Laguna Negra, Coinco	
Total iron	0,3	mg/L	1903	5	0,26	Totoralillo	La Ligua	Iloca
Total manganese	0,1	mg/L	1901	5	0,26	Totoralillo	La Ligua	Bulnes
Nitrates	50	mg/L	1899	18	0,95	Chañaral, Caldera, Copiapó	Quillota, Lo Aguirre	
Smell	No smell	-	1906	1	0,05		Puchuncaví	
pH	6,5 to 8,5	Units	1889	6	0,32		Santo Domingo, Lampa	San Pedro de la Paz, Punta Arenas
Proportions of nitrates +nitrites	1	Proportion	1900	13	0,68	Caldera, Chañaral	Lo Aguirre	
Taste	No taste	-	1904	1	0,05		Puchuncaví	
Total suspended solids	1500	mg/L	1899	22	1,16	Arica, Copiapó, Caldera, Chañaral, Tierra Amarilla		
Sulfates	500	mg/L	1899	26	1,37	Caldera, Chañaral, Copiapó, Inca de Oro, La Tirana, Tierra Amarilla		
Turbidity	2	mg/L	1917	3	0,16	Antofagasta,	Los Molles	
Trihalomethanes	1	Proportion	1898	1	0,05			Coronel

Source: Prepared by the authors with information published by SSS (www.siss.cl) solids (1.16%) and nitrates (0.95%). Non-compliance regarding sulfates and suspended solids was mostly found in the northern zones, while non-compliance regarding arsenic and nitrates was concentrated in both the northern and central zones of the country. In the southern zone, non-compliance for the months analyzed was marginal compared to the northern and central zones.

One of the contaminants of drinking water sources that has caused the greatest concern in recent years has been arsenic. The cases of the cities of Antofagasta and Calama became known in the 1970s when coagulation-flocculation with ferric chloride process plants were built (Sancha, 2006). In fact, exposure to arsenic in Antofagasta has been essential to world science as a case study for elucidating the effect of arsenic ingestion on human health (Ferriccio, 2006). Recently, the maximum permitted arsenic concentration in drinking water was reduced from 0.05 to 0.01 mg/l, which has led sanitation companies to adopt new measures to comply with this regulation while meeting the growing demand for drinking water. Figure 3 presents a summary of the drinking water systems that have adopted arsenic reduction technology. Plants built in the 1970s continue operating with coagulation-flocculation processes with ferric chloride, and their systems have been recently optimized to meet the more stringent limits (Granada, 2003). In recent years the setting up of desalinization plants in Antofagasta (Edwards, 2012) has served to control the concentration of arsenic in the city. Desalinization plants produced 1.3 m^3/s for drinking water and water for mining (in equal parts in 2010 in the Antofagasta region); it is estimated that by 2019 the production of drinking water through desalinization will increase 2.7 times while production for mining (the primary economic activity in the region) will increase 6.4 times. It is important to note that certain drinking water systems with sources with levels of arsenic above current standards have not required the implementation of specific arsenic removal processes beyond diluting with sources with a lower arsenic content. Nevertheless, in order to meet the growing demand for water, sources with arsenic will presumably have to be used and therefore systems for their control will have to be implemented.

The literature identifies contaminants other than arsenic in drinking water sources that will require attention in the near future. These are:

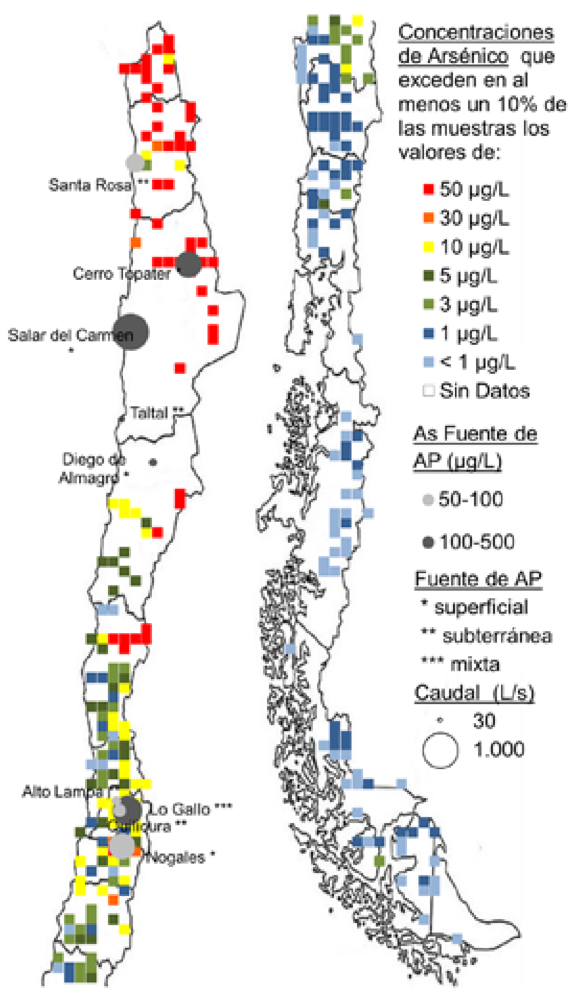
- **Boron:** in northern Chile there are drinking water sources with high boron levels. The highest level recommended by the WHO for boron in drinking water is 2.4 mg/l (WHO, 2011), yet Chilean drinking water standards do not yet include this parameter. Given the difficulty and cost of removing boron from drinking water sources, the WHO recommends that each country carefully set its own parameters based on the different sources of exposure . A study recently undertaken in the city of Arica between 2006 and 2010 (Cortes, 2011) measured a range between 0.22-11.3 mg/l of boron in public drinking water systems, with a median of 2.9 mg/l in a total of 173 samples. The same study found that boron concentrations in urine (r=0.64) correlated positively with the boron levels measured in the homes of the individuals who participated in the study. The study recommends that systematic measurements be taken and that this parameter be included in Chilean drinking water standards.
- **Perchlorate:** Exposure to this pollutant is related to thyroid malfunction (Brechner, 2000). Chile is one of the few countries where naturally occurring perchlorate has been detected in soil and water, primarily in association with nitrate deposits. Although the WHO has yet to include recommendations for perchlorate (WHO, 2011), its regulation is subject to debate in the United States and is on the legislative agenda. The state of California currently stipulates a maximum value of 6 ug/l, and there is pressure to lower it to 1 ug/l. There are still very few measures in Chile, but once further monitoring are carried out, areas in the north of Chile will be found to have levels of over 6 ug/l. A recent study measured levels of 1480 and 744 ug/l respectively in the areas of Pica and Canchones (Calderón, 2014). An earlier study (Téllez, 2005) found concentrations of 114.6 and 0.5 ug/l of perchlorate in drinking water sources in the cities of Taltal, Chañaral and Antofagasta. (Téllez, 2005)
- **Other pollutants:** There is a currently concern about the micro-pollutants present in

drinking water sources into which treated wastewater is discharged. Although concern has traditionally focused on the presence of organo-chlorate compounds, the presence of pharmaceutical compounds and personal care products in drinking water has recently elicited concern. Mainstream literature does not provide systematic measurements of this type of compounds in Chilean drinking water, probably due to the fact that methods for their quantification are not widely available.

Sanitation and environmental aspects: outlook: The analysis of water in cities cannot be separated from the basin in which it originates. On the one hand, the basin imposes hydraulic and biogeochemical conditions that determine the particular challenges to the quality and quantity of water available for a city These conditions may be natural (e.g. geological) or man-made (e.g. mining and industrial activities and energy production). On the other hand, the city has a metabolism that consumes resources, generates residues and discharges elements that may significantly affect the quality and quantity of water in its basin, thereby creating a complex interaction between urban systems and their basins, turning the latter into their natural units of analysis. The sustainability of treatment systems to provide drinking water certainly depends on the quality of its sources, while the true effect of discharges of treated wastewater clearly depends on the characteristics of the receiving water bodies. For example, in February 2014, of a total of 278 wastewater management systems (including treatment and supply plants), 20 (~7%) failed to meet the standards required by current norms. Nevertheless, there is no available information for the specific evaluation of the environmental impacts of this non-compliance. In this respect, it is important to recall that Chile has only recently begun the process of defining secondary quality norms for hydrological basins. These norms will not only allow increased regulation of wastewater and drinking water treatments plants but will also define goals for rainwater management and quality control.

Consequently, there is still a long road ahead before a database is constructed to achieve a better understanding of the processes that regulate interactions between the city and its basin.

Figure 3. Main Treatment Plants in urban sanitation services that include arsenic reduction processes (Source: Prepared by the authors; information on surface and groundwater quality, DGA and PTAS, Ahumada, 2014).



3. Sustainable Rainwater Management

Urban population growth in Chile has led to many similar urban developments during the second half of the 20th century; Santiago alone was urbanized at a rate of 8 km^2/year (Fuentes and Sierralta, 2004). This growth has produced radical changes in the hydrology of natural basins, which in turn has translated into problems such as flooding, changes in riverbeds and the pollution of receiving water bodies (Estelle et. al., 2012). Moreover, unplanned territorial occupation has forced housing and public and private infrastructure to be built on riverbeds, gorges, wetlands, lowlands and areas subject to river flooding. These changes translate into periodic flooding problems in various Chilean cities and costly investments in infrastructure to solve them.

Below is a brief outline for rainwater management designed to address these problems in Chile. It begins with a brief description of the history and current situation of rainwater management in the country, followed by the new approaches and recently incorporated tools that will make it possible to take a step towards better urban drainage management. Lastly, future challenges are outlined.

Rainwater Management in Chile

Urban drainage dates from the beginning of the 19th century when it was necessary to solve the problem of wastewater flowing through open ditches. During this period, the sewerage and rainwater collection systems in downtown Santiago were built, in 1906 (Bertrand, 1908). Subsequently and until the 1960s, networks of collection units, intended to drain both wastewater and urban runoff with a significant return period were built in various cities throughout the country. In the 1970s and particularly the 1980s, rainwater became a secondary problem to drinking and wastewater. In 1992, its management was assigned to the municipalities due to the lack of legislation on this issue.

The 1997 Rainwater Law Number 19,525, makes the state responsible for drainage systems and rainwater drainage in populated centers. Each of these systems is separated into a primary and secondary network, managed respectively by the Ministry of Public Works (MPW) and the Ministry of Housing and Urban Development (MINUH). The Law created the Directorate of Hydraulic Works (DHW), tasked with creating Master Plans (MPs) for urban drainage and checking the connections between the secondary and secondary network. Subsequently, in 2000, the Subdirectorate for Rainwater (now called the Urban Riverbed and Drainage Division) was created to evaluate the drafting of master plans, and the design, construction and use and conservation of rainwater works in conjunction with the MPW and MINUH.

The 33 MPs already created together with others at the development stage cover cities from all over the country that are home to 85% of the population. They have been transformed into a rainwater management guide, mainly from the perspective of the primary network. The MPs define primary and secondary networks and contain basic hydrology and hydraulics studies, in addition to the technical and economic analysis of various management alternatives for the primary network. For its part, the MINUH, through the regional Housing and Urban Development Services offices, has established a series of norms for secondary networks typically associated with housing developments. In particular, MINUH has proposed design guides for helping urban developers and construction companies develop and implement urban drainage (MINVU, 1996; MINVU, 2008).

Nevertheless, both MPs in particular and urban drainage management in general have a number of shortcomings closely linked to the widespread inaction before Law 19,525 was passed and to the old paradigm that regarded urban runoff as a nuisance and even a threat rather than as a potential resource to be protected. Some of these drawbacks include the following: (1) lack of an integral vision in which the basin rather than the administrative unit is the key territorial unit, (2) lack of environmental objectives (i.e. preserving riverbanks, controlling the quality of water in the receiving bodies), which depend on the reality of each basin, (3) low or nonexistent levels of spatial integration (from domestic to regional) in alternative runoff management, since the focus of the MPs is the primary network, (4) emphasis on the use of conduction solutions rather than techniques and public works based on infiltration and storage, (5) weak or nonexistent links with the Land Planning Instruments (LPIs) and (6) despite the fact that thesystems are structural in nature, the measures adopted are non-structural and flood area management techniques are only partially addressed.

Sustainable Urban Drainage Planning and Management

The above problems require integrated, long-term management that will incorporate the various spatial scales and actors involved.

To this end, in 2013, the MPW published the Urban Drainage Manual (UDM) (MOP-DOH, 2013), which addresses this task by bringing together into one document all the concerns, interests and responsibilities of the stakeholders involved (i.e. private companies, urban developers, municipalities, attorney generals and sanitation companies) This document applies to the whole country and guides stakeholders' participation in the planning, design, operation and conservation of urban drainage systems. Since the UDM represents the state of the art of rainwater management in Chile, its main focuses and standpoints are summarized below. The summary is recommended for further details on any issues of interest especially with regard to public works design.

The Foundations of Urban Hydrology

Urban development implies the large-scale removal of the top layer of soil, vegetation and the natural drainage network and their replacement with impermeable areas (i.e. streets, houses and urban infrastructure). This entails the loss of the natural capacity for infiltration, storage and evaporation-transpiration, essential processes in the natural water balance and an increase in direct surface runoff (Akan and Houghtalen, 2003). This, together with the construction of an artificial drainage network, involves a change in the local hydrology and flow rate systems, creating larger flow rates and runoff volumes during precipitation and losses in the base flow. This alteration can be seen in the frequency curves and flow-duration curves before and after the urbanization process (Nehrke and Roesner, 2004; Rohrer and Roesner, 2006). These changes not only cause urban flooding but also lead to radical but more silent impacts on the receiving courses and water bodies and the ecosystems that develop therein (i.e. erosion and sedimentation of riverbeds, washing of diffuse urban pollution, frequent collapse of unitary systems and so on) (Akan and Houghtalen, 2003; UDFCD, 2013). In fact, the greatest differences in flows and frequency of occurrence in relation to the natural situation occur precisely with small, frequent amounts of rain (Roesner et al., 2001; Nehrke and Roesner, 2004). They are therefore the ones that are largely responsible for the environmental impacts described earlier, despite the fact that they do not usually cause large-scale flooding or damage to people and infrastructure.

Urban Drainage Policies

The consideration of the bases of urban drainage previously identified has led to the development of rainwater policies structured around a central guiding policy: *maintain or restore each component of the water cycle to its natural level while simultaneously considering rainfall as a resource that may be polluted and affect receiving waterways and water bodies rather than as a residue or a threat in itself.* Adhering to this policy largely ensures proper rainwater management and the control of the many problems arising from it. Operationally, the following specific policies have been proposed to guide the development of a variety of urban drainage activities at different spatial scales, including (1) drafting, updating and modifying MPs, (2) projects to mitigate or improve existing urban developments and (3) urban drainage projects for future urban developments:

1. The planning, design and management of rainwater systems are integral activities to be undertaken at the basin level, transcending administrative divisions and addressing the process from downstream. This prevents transferring problems downstream and encourages the sustainability of long-term solutions.
2. In new urban developments, levels and volumes of surface runoff and loads of pollutants must be maintained or reduced during both the construction and operating phases.
3. An integral drainage system entails, as far as possible: (1) local household control, (2) local retention in public soil, (3) slow surface transport, (4) larger-scale storage in public soil, and (5) controlled conduction through transport elements and its subsequent discharge into receiving waterways and bodies of water.
4. The natural drainage network must be respected and become part of the urban drainage network during the urbanization process. The flood zone must not be occupied for T=100 years, allowing the characteristic movement of basins within it and ensuring its geomorphological integrity.
5. All existing urban territory or territory considered for territorial planning must have a

MP linked to the LPIs that considers the related basin(s)(s). The master plan should explicitly include (1) aspects relevant to land planning and management, (2) the flood zone T=100 years for riverbeds and gorges within urban space, (3) a definition and description of the primary network, and (4) conditions for unloading and evacuating secondary and household networks.

The new rainwater networks should be independent and separate from wastewater unless their proximity is technically justified.

1. Urban drainage should seek to minimize the disfunctionalities, disorders and environmental effects caused by frequent rainfall and provide safe management of less frequent flooding to prevent human and infrastructure losses. The public works chosen to meet these goals should not be detrimental to the urban landscape.
2. Rainwater management should minimize the impact of runoff on the quality of surface and underground receiving bodies and their environmental integrity .
3. The rainwater management system and its various elements should be periodically maintained to guarantee the service level considered in its design.

Policy 1, largely absent from rainwater planning and management, is crucial to a sustainable drainage system. It seeks to change the old paradigm of rapid drainage through collectors that drain larger conduction elements, which become obsolete when upstream contributions increase. By contrast, the new paradigm, based on downstream management, allows one to reduce the risks of flooding and effectively use the natural drainage network within the flooding zone. This can be achieved by imposing discharge conditions from the receiving riverbeds and bodies of water upstream to the local scale. This encourages the spatial integration of various storage, infiltration and conduction mechanisms, particularly the use of local works compatible with the urban landscape and alternative uses of green or recreation areas known as Sustainable Urban Drainage Techniques or Low Impact Development (UDFCD, 2013). Lastly, this management scheme makes it possible to define similar restrictions on the quality of discharges from upstream, eventually enabling water quality objectives to be included in urban drainage systems as is done in developed countries (Dodson, 1999).

Policies 7 and 8 deal precisely with the issue of recipient water pollution by washing pollutants and discharges from unitary systems. To this end, the concept of catch amount (CA), defined as a significant portion of average annual runoff (i.e., 80% – 90%) to be controlled by infiltration or retained and released over an extended period of time (6 – 40 h) (UDFCD, 2001; WEF-ASCE, 1998) is introduced. Retention of this amount allows the majority of storms to be controlled, or at least the initial, most polluted portion of major runoff events, known as initial washing or first flush (Stenstrom and Kayhanian, 2005; Froehlich, 2009). One is thereby able to act on the volume of annual runoff responsible for a significant portion of diffuse urban pollution and a large number of unitary network discharges. Precipitation for the CA calculation has been calculated for various cities and areas in Chile (MOP-DOH, 2013; Padilla, 2014).

Benefits of Sustainable Urban Drainage

Planning and management of sustainable urban drainage yields many benefits beyond flood control and its impact. A well-planned and managed drainage system is typically associated with harmonious, regulated territorial planning and growth, which means shared benefits for both activities. These benefits tend to be more relevant

Figure 4. Identification of household (pink), secondary (yellow), primary (green) and natural (blue) networks within the urban environment.

Table 2. Organization of urban drainage networks, specific features and common complementary projects

	Networks			
	Household	Secondary	Primary	Natural
Persons responsible and major players	Private citizens, real estate construction companies	MINUH, municipalities, real estate companies, EE.SS1	MOP, EE.SS	MOP, MBN2, DGA3
Specific features	Roofs, pavement, patios	Streets, green areas, parking lots, sidewalks	Riverbeds, parks, squares	Rivers, lakes, flood plains
Objectives	Local household control	Slow transport and storage in public soil	Storage in public soil, controlled conduction and discharge to natural network	Receiving bodies of water
	Drainage projects			
Infiltration	Green roofs, rain gardens, wells	Permeable pavements, wells, ponds, drainage ditches		
Storage	Barrels, small ponds	Ponds, lagoons	Ponds, lagoons, wetlands	
Conduction	Rivulets and canals, drainpipes	Drainage ditches, sumps, ditches, collectors.	Urban riverbanks, canals, collectors, discharges	Rivers, estuaries, lagoons, lakes, sea
	Design conditions			
Internal control	Do not storm flood dwellings for 100 years. Do not storm flood outside pavements for 2 years.	Do not exceed the foundation level for rains for 100 years. Maximum flooding width in streets limited for 2 years' rain.	Do not cause rain flooding for 100 years. Do not cause rain-related inconveniences for 2 years.	Do not increase rain flood areas for 100 years. Do not urbanize at-risk zones. Control quality effects.
Discharge conditions	Retain and use catch amount. Maximum discharge rate according to MP.	Retain catchment water for the entire drainage area. Maximum discharge rate according to MP.	Control quality and quantity effects. Maximum rate to be discharged according to MP.	

1 Sewage Companies, 2 Ministry of National Assets, 3 Directory of Water

when the perspective of civil engineering, the environment and transport, hydrology, urban planning and architecture, sociology, law, public health, economics, geography, ecology and landscaping are included. Benefits include: (1) fewer problems of interaction between upstream and downstream areas; (2) lower construction, infrastructure and road maintenance costs; (3) improved vehicular traffic; (4) improved quality of urban runoff and receiving water bodies and public health; (5) protection and enhancement of environmentally sensitive areas; (6) availability of more open spaces and green areas at a lower cost; (7) sustainable behavior of the aquifer after urbanization; (8) strengthening and improvement of initiatives where drainage is an input (renovation, public health and recreation, road infrastructure programs and so on).

Urban Drainage Network Design

The urban drainage system is a global system formed of four converging networks: the household, secondary, primary and natural networks. The design of these networks seeks to organize its elements and public works in order to meet the global objectives of the system while considering the conditions under which it operates. Each network requires the explicit identification of: (a) its operating and downstream discharge requirements, (b) design ideas for the sizing and control of the operation, (c) the organization and sizing of the operation, (d) works needed to meet operation and discharge requirements. Table 2 shows the relationship between the networks, major players and persons responsible, their specific features and examples of typical drainage systems. Moreover, their objectives in relation to policy 3 are defined.

Local and Household Network Design

The household network, the system inside private property upstream from the public system (e.g. businesses, dwellings condominiums), receives 60-80% of rainwater, which has a high impact on the urban complex (Figure 4). The drainage system in this network must be designed, built, operated and preserved by private individuals, bearing in mind the conditions of the MP, municipal ordinances and rules, and MINUH and LPI indications for the zone. It is also proposed that at the very least, the design conditions defined in.

Secondary Network Design

The MP defines the secondary network as the one located upstream of the primary network. Its function is to control the water received from urban developments, property and eventually discharge them into the primary network . Together with the discharges from the household network, this network directly receives 20-40% of rainwater, mainly on streets and sidewalks (Figure 4). Thus, practically all urban runoff can be managed, at least partially, by this network. A typical feature of secondary networks are sumps which remove runoff and channel it into other drainage works. These works are sometimes not only used for underground conduction, but also for surface conduction and infiltration or storage, which ensures the retention and/or slow transport of runoff.

Design of the Primary Network and its Discharge into Channels and Receiving Water Bodies

The primary network defined in the MP is the central network of the urban drainage system that channels runoff from household and secondary networks into receiving waterways and water bodies (rivers, lakes and sea). Although this network includes artificial transportation features, it is essential that it also include the natural drainage network as well as regulating features such as lagoons, ponds and wetlands. Unfortunately, large, expensive works with a limited useful life (e.g. collectors, artificial canals, etc.) have typically replaced the dendritic drainage systems formed of brooks, riverbeds and rivers that naturally converge on large water bodies. This is avoidable if runoff volume is limited from downstream upstream by adopting infiltration and storage mechanisms rather than just conduction features. Territorial planning, in conjunction with the MP, also determines the characteristics of the primary network, its cost, capacity and operation, since it makes it possible to implement a set of non-structural measures that limit occupation of the natural drainage system and its flood zones.

Challenges to Urban Drainage in Chile

Developing and implementing a new form of urban drainage constitutes an important step in the integrated management of urban waters and the basins in which cities are located. The creation and improvement of regulatory instruments for urban drainage to strengthen this new development entail the following challenges:

- Improving hydro-meteorological information and its use in design and analysis applications. It is particularly important to better understand the space/time variability of rain.
- Defining the channel flood zones, which serves as an essential input for the downstream management described earlier.
- Using distributed modeling and continuous simulation tools, which will make it possible to simulate and better understand the hydrological and environmental functioning of the entire urban system and its components, facilitating their management.
- Implementation and monitoring of pilot programs to validate and/or improve the design of drainage works and understand their interaction with the community.
- Formally incorporating water quality aspects in which the discharge of urban runoff and dumping of unitary systems is regarded as a pollution event. This would lead to more complete urban drainage planning and management.
- Boosting the role of local reality in the definition of the specific goals of the MP in order to achieve a healthy situation in which "global tools [are used] for local problems".
- Educating the community about urban drainage problems so that people understand the operation, goals and benefits of the various works. The community is the user, beneficiary and, to a certain extent, chiefly responsible for these works.

4. Climate Change and Security of Supply

Geographically speaking, half of mainland Chile's area is associated with relatively severe climate change projections. From a demographic

Figure 5. Projected annual average temperature change during the historic period (1991-1990) for three emission scenarios: RCP 2.6, RCP 8.5 and SRES A2. (Source: Ministerio de Medio Ambiente, 2013)

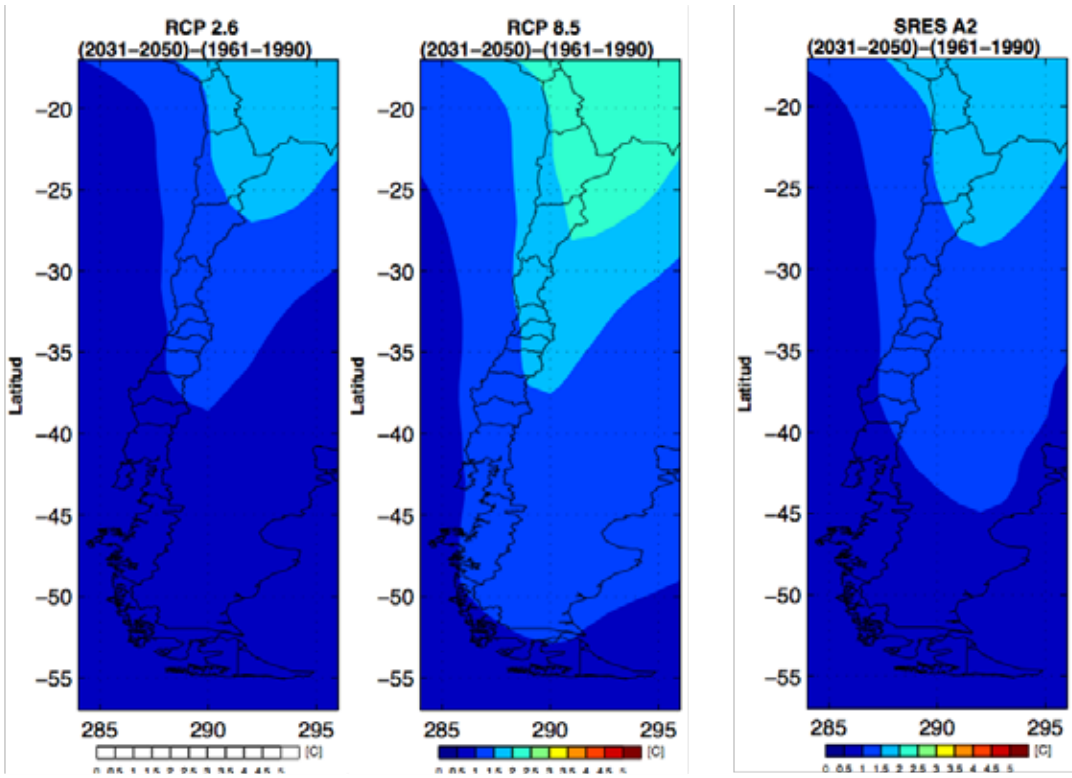


Figure 6. Projected annual average temperature change during the historic period (1991-1990) for three emission scenarios: RCP 2.6, RCP 8.5 and SRES A2. (Source: Ministerio de Medio Ambiente, 2013)

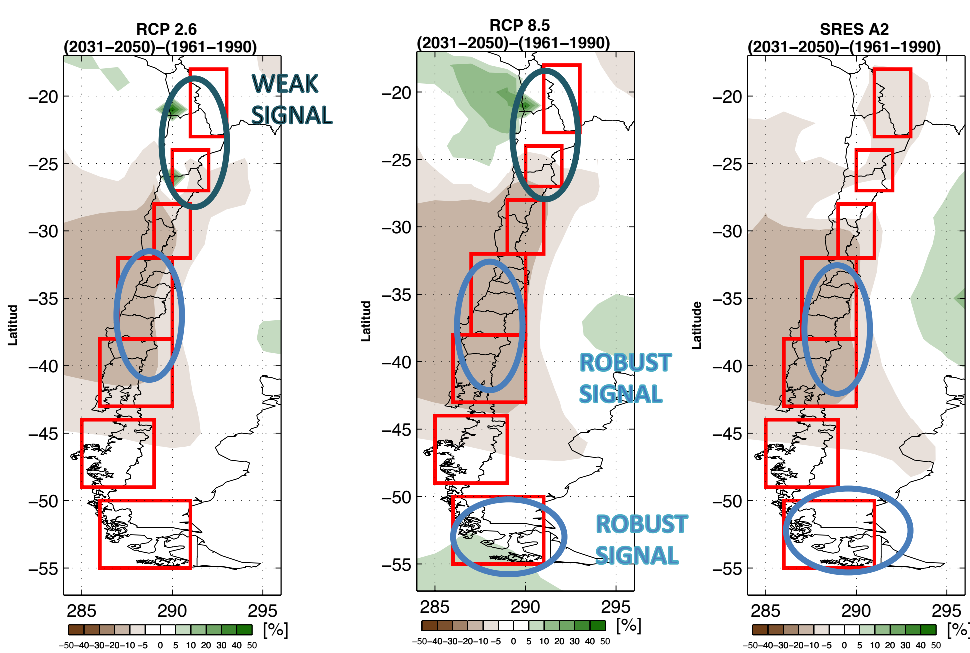
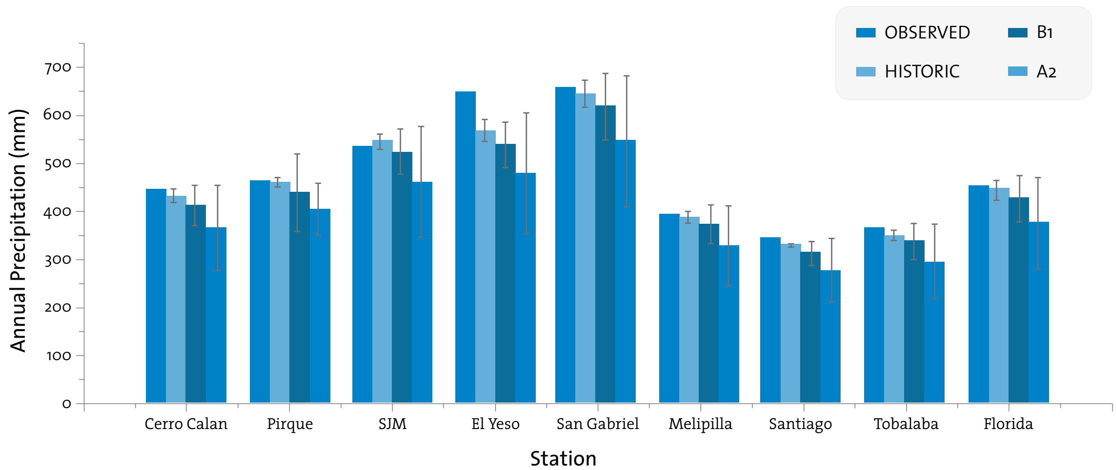


Figure 7. Projected changes to annual rainfall during meteorological seasons in the metropolitan region of Santiago de Chile. Source: McPhee et al., 2014

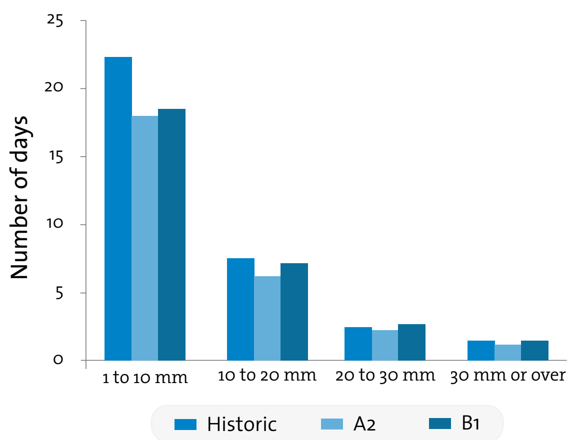


point of view, approximately 50% of the national population, just over 8 million people, live in cities where climate change projections indicate not only increased temperatures but also a significant decrease in precipitation towards the second half of the 21st century. This situation is superimposed over other rapid changes such as the increase in the urban population, the loss of agricultural land, and the urbanization of areas near the mountains, resulting in a situation where it is possible to envisage significant changes to the hydrological conditions that determine access to water supply sources, and the population's degree of exposure to extreme hydro-meteorological events that affect people's quality of life, the reliability of urban infrastructure and provision of public health and transport services, among others. Figures 5 and 6 show the temperature and precipitation projections for Chile in the second half of the 21st century (Ministerio de Medio Ambiente, 2013). In terms of temperature, more severe warming is expected to occur in northern Chile in the order of 2°C more than the historical average. Where precipitation is concerned, the extreme north and south areas do not show significant changes, although a 15 to 30% decrease in average annual rainfall for the Copiapó (Latitude 27° S) and Puerto Montt (Latitude 41°S) can be observed. It is important to note that these estimations are drawn from various global general circulation models (GCM), and that projections of individual models vary. However, all the available models used in this analysis[5] foresee a reduction in rainfall towards the end of the first half of the 21st century, adding a level of reliability to these projections. They can therefore be used as base assumptions for the analysis of water issues and the evaluation of adaptation measures.

A number of studies have been conducted to understand the scale and effects of the projected climate changes on various human activities. At the urban level, McPhee et al. (2014) provide a specific analysis for the city of Santiago, based on the analysis of projections for the daily rhythm of temporal resolution of 10-15 general circulation models (depending on the variable studied) with climate scenarios A2 and B1 presented in the IVth IPCC report. Projections for the years 2045-2065 were made for a number of locations where meteorological stations exist, using spatial and temporal scaling techniques. From the point of view of temperatures, a tendency towards rising mean, maximum and minimum temperatures has been confirmed, with monthly deviations of between 1.5 and 2°C. In some cases, the deviations are greater during the winter and spring months (June to November) with less warming being observed during the autumn months.

5. 21 General Circulation Models, included in theCMIP5 study (http://cmip-pcmdi.llnl.gov/cmip5/).

Figure 8. Changes in daily rainfall distribution in the the Quinta Normal meteorological station, located in the center of Santiago, Chile. (Source: McPhee et al., 2014).



A simplified analysis allowed McPhee et al. (2014) to estimate changes in the position of the 0° isotherm, resulting in increases of approximately 100 m in the monthly average of this parameter during the winter months. Garreaud (2013) presents an analysis of warm storms in Central Chile, showing that for certain historical events, a rise of the For the Rio Maipo's high basin, which drains towards Santiago, an increase of 100 m in the average isotherm on rainy days could increase the potential runoff average during these events by 50%. Although this is a preliminary analysis that must be complemented by other studies, it outlines the threats from floods one could expect due to climate change, which is complemented by the following analysis of rainfall.

A decrease in the annual average has also been observed, even though the discrepancy between models is large enough for historic values to fall within the range of expected variation in most cases. For the meteorological seasons analyzed by McPhee et al. (2014)an average reduction of 25% in annual mean rainfall is expected for the period from 2045 to 2065 (Figure7).

One aspect worth noting in this study refers to the change in the distribution of frequencies of days with daily rainfall located in various classes. Rainfall events were grouped according to the amount of rain accumulated in 24-hour periods. It follows from this analysis that the reduction of total annual rainfall projected by future models is fundamentally expressed as a reduction in the frequency of days with slight or moderately intense rainfall (daily rainfall > 30 mm). Conversely, the frequency of days with more intense rainfall (daily rainfall > 30 mm) remains fairly constant according to the simulations of future climate scenarios (Figure 8).

The hydrological changes it is possible to foresee obviously depend on the specific local conditions of each city and its contributing hydrographic basin. Furthermore, the degree of severity of the impact of hydrological changes on the urban water system in each case is a function of the severity of the hydrological changes, combined with the nature of the adaptation measures each city may implement. For example, for the city of Santiago, Meza et al. (2014) showed that on the basis of a numerical model exercise, the decrease in the average supply in the health and agriculture sectors is slight, even for scenarios with greatly reduced rainfall. For example, for scenarios with a 40% reduction in rainfall, the reduction of the average supply during a 30-year window would be approximately 10% for the sanitation and agricultural sectors (with the agricultural sector suffering the greatest reductions in supply). On the other hand, the minimum supply during the same time window is more heavily impacted than the average. Thus, for example, scenarios with a 20% reduction in average annual rainfall entail a 25% to 50% reduction in the minimum annual supply in the sanitation and agricultural sectors respectively.

How Urban Water Systems Adapt to Climate Change Context and Examples from the City of Santiago de Chile

Adaptation to climate change requires first answering a series of structural questions that will help design adaptation options and the process of implementing these options. The first question concerns the need for adaptation. Why do the Urban Water Systems (UWS) need to be adapted? A key concept for answering this question is Water Security. In short, UWSs must be adapted when there is a climate event that threatens Water Security. This adaptation must either preserve or improve

Water Security within the limits of the city, ideally without harming other users (whether productive or otherwise) of the water in the basin. Once this first problem has been dealt with, a second key question involves the adaptation process itself: How can the UWSs be adapted? This can in turn be broken down into a series of questions such as: What options for adaptation are available? Who should adapt? When should this adaptation take place? And lastly, how can the adaptation process best be implemented?

Water Security and the Need for Adaptation

Climate change in UWS may occur in the two main dimensions of water in cities: water as a resource and water as a threat. As a resource, the availability of good quality water is the basis of the wellbeing and way of life of a city´s inhabitants. It is also essential to the many economic activities undertaken in and around cities including periurban agriculture, the food and beverage industry and other industrial activities. Meanwhile, excess or insufficient water can give rise to threats such as the concentration of pollutants (with negative effects on health), the lack of a proper flow of water for drainage systems and damage to physical assets related to flooding.

How can Urban Water Systems be Adapted?

Assuming the need for adaptation, the problem is therefore to decide how to achieve this adaptation. In order to answer this question, it is important to consider the different options available and once a decision has been reached about which ones are best, it is necessary to design a stage for implementing the measures including financing, the roles of the various players involved and the times when measures must be implemented.

Using the Water Security framework helps identify adaptation options for addressing a particular aspect of security that has been threatened by climate change. In terms for example of access to adequate amounts of water, we find ourselves with options that have to do with the supply of water, such as water transfer between sectors, reuse, the construction of storage works and improvements in the distribution systems. On the other hand, it is also possible to redefine what is understood as an "adequate" amount of water supply by incorporating options that alter water demand without reducing the wellbeing or productive utility achieved through water consumption. Measures such as these are associated with changes in behavior resulting from effects on rates, awareness campaigns, or regulatory changes that may affect the availability of technologies or consumption habits.

With regard to water distribution, the type of options available will depend on the relative position of cities within a basin (Vicuña et al., 2014). For example, a city located near a headwater basin has a limited number of options, associated, for example, with transferring water to other sectors that use water or building storage works. Cities in coastal zones can use this type of options, but may also choose options such as desalinization or transferring water from other basins.

The city of Santiago in Chile is a good example of cities that have limited capacities for adaptation measure due to their proximity to mountains. Santiago is the largest city in Chile, and home to approximately seven million people producing nearly 40% of the country's GNP. Water use in Santiago is mainly residential, accounting for 73% of total consumption (SISS, 2009). Average per capita water consumption in Santiago is 150 l/day, although consumption can reach over 600 l/day when high-income neighborhoods are considered. The remaining consumption is associated with industrial and commercial uses, parks and so on. As for water supply sources, the city of Santiago is located in a region with a semiarid Mediterranean climate at the food of the Andes. The Maipo River basin is the main source of water supplies (80%) for the city. Moreover, the city depends on groundwater extraction to cover 20% of the remaining needs and to operate a dam in the mountains in order to be able to manage the differences between water supply and demand that occur within and between years.

As with other basins in the central part of Chile (Vicuña et al., 2010) described in detail above, the city of Santiago faces not only pressure to meet the demands of a growing city, but also the potential impacts of climate change. A series of adaptation options have been studied by Bonelli et al. to address the consequences of the complex water supply conditions (accepted). One option is to reduce the inefficiencies in water distribution and consumption. Currently, almost 30% of the surface water extracted fails to reach end consumers, mainly because of leaks in underground pipes. One way of improving efficiency is therefore to improve the network infrastructure. Efficiency can also be addressed through a demand-based approach, for example, through policies that encourage the conservation and efficient consumption of domestic water. According to estimates, an increase in efficiency of over 20% could be achieved through the short-term installation of more efficient accessories and appliances in households and offices (Observatorio de Ciudades, 2009).

When considering a basin perspective, the main option available to the city is to increase the proportion of water rights owned by the sanitation company that distributes water throughout the city in relation to those owned by the agricultural sector. Water companies currently own 25% of the total amount of water rights for the Maipo River. According to Bonelli et al. (accepted), this share should reach 40% by 2050 in order to cope with the impact of climate change and population growth. Transferring water rights from the agricultural sector to the urban sector has been one of the main strategies used by the city to meet the city's growing needs. In the past 40 years, the city has doubled its area and increased its population from three to nearly seven million people. Despite the fact that the total agricultural area depending on the basin has remained relatively constant, total water consumption has decreased thanks to a progressive increase in the efficiency of irrigation due to the introduction of new technologies. By way of an example, in 1997, drip irrigation accounted for less than 10% of the total area of irrigated land, increasing to over 30% by 2007 (INE 1997-2007). The majority of these water savings have been transferred through the sale of water rights, to water services in the urban sector. Water rights are a peculiar characteristic of Chile's water system, which grants private ownership of water regardless of its predicted use and land ownership (Vicuña and Meza, 2012). The purchase of water rights is one of the main new sources of water that water companies have historically used to supply the growing population and the prevailing dry climate (ANDESS, 2014). Overall efficiency of irrigation in the basin remains low (approximately 50%), which suggests that this water transfer strategy could continue growing in order to offset possible supply shortages due to climate change.

In order to evaluate the various adaptation measures that could be implemented by the urban sector and other water users in the Maipo River basin, a project called MAPA (Maipo Plan de Adaptacion (Maipo Adaptation Plan) is being developed, which is designed to link the development of an adaptation plan to variability and climate change in the Maipo River basin. More information on this project, funded by the International Development Research Center (IDRC) is available at <http://maipoadaptacion.cl/>.

5. Conclusions

Over the past four decades, Chile's urban water sector has achieved significant progress as regards water coverage and quality and in wastewater treatment levels in the past 15 years. This progress has been helped by the country's economic stability and public policies that have prioritized the decentralized management of health services. Although improvements in the efficiency of sanitation companies' management has been verified, the theoretical reductions in rates this should entail have not been verified. The population with the lowest income receives cross-subsidization that helps to relieve their situation and has made the privatization policies implemented in recent years feasible. Likewise, the robustness of the supply system in many cities has been enhanced by the possibility of acquiring water use rights from other users, which in practice has meant transfers from the agricultural to the urban sector.

Despite the progress described above, there are still enormous challenges to be addressed. In certain regions, the arrival of industrial and mining sectors has constituted a threat due water transfers to this activity, although in the case of major cities in the north of Chile, there have been institutional agreements that have made it possible to guarantee domestic supply. In the central zone, companies such as Aguas Andinas and VSWC have achieved high coverage and credibility, and even in drought situations such as the one experienced by Chile since 2011, no problems have arisen in supplying the majority of the population. One source of concern are the smaller periurban populations, which often have local supply systems not covered by larger regional companies, which are much more vulnerable to drought and other disruptions in the supply of water. In some cases these populations have had to be helped by tanker trucks, resulting in a significant deterioration of the population's quality of life.

Rainwater management in Chile continues to revolve around the construction of large infrastructure works to drain water, with less being invested in water retention and infiltration works. Likewise, non-structural measure such as better territorial planning are underrepresented, partly because of the conflicts and gaps in the definition of the competences of various government entities.

Lastly, the climate change perspectives envisaged for a significant portion of Chilean territory suggest that progress must be made on a nationwide adaptation agenda that will seek to preserve current average supply levels and attempt to improve the robustness of systems during periods of drought. This adaptation agenda should of course consider local realities, but must be guided by the common principles of reliability and the preservation of ecosystem services within the concept of increasing global water security.

6. Acknowledgments

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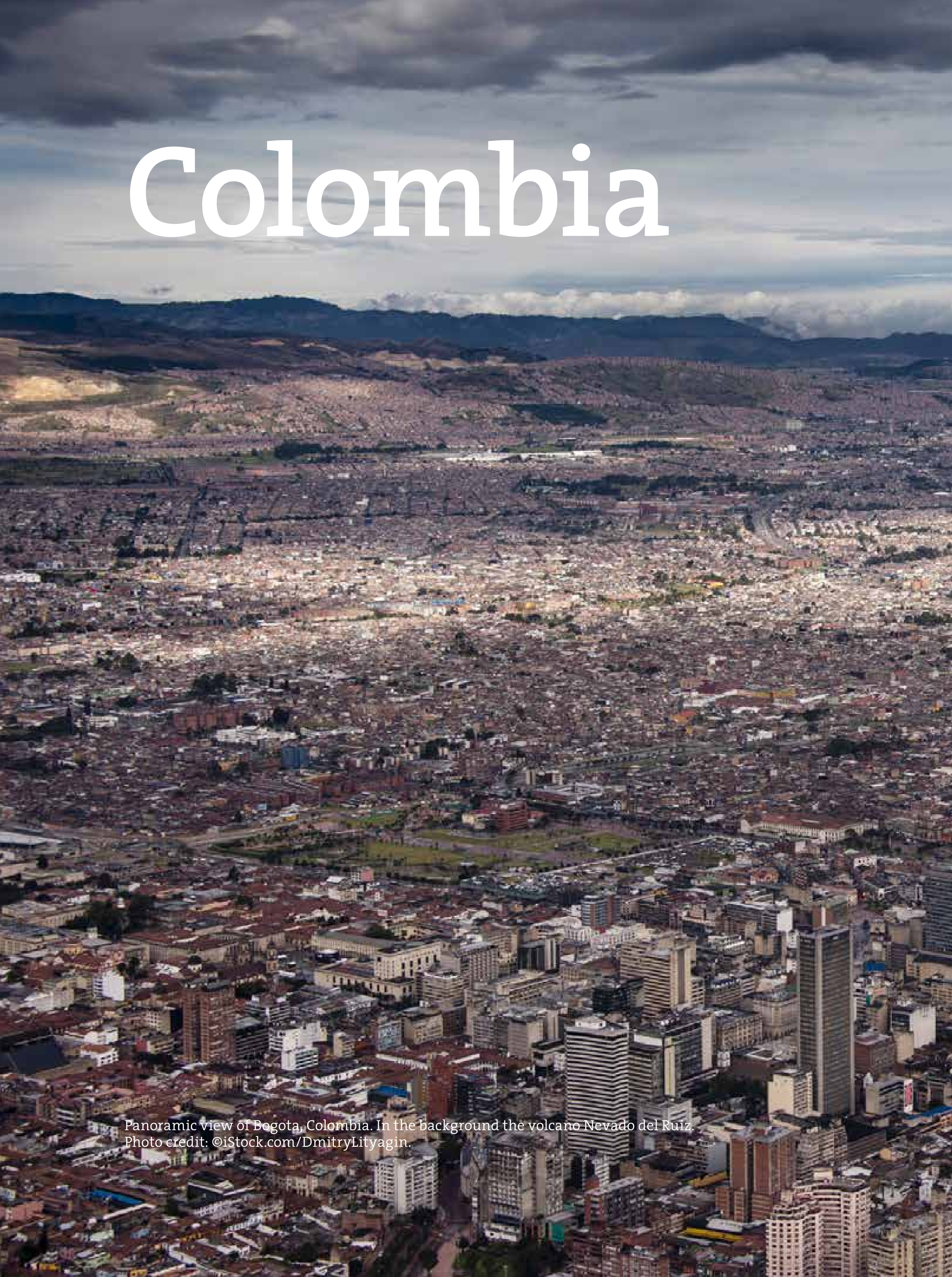
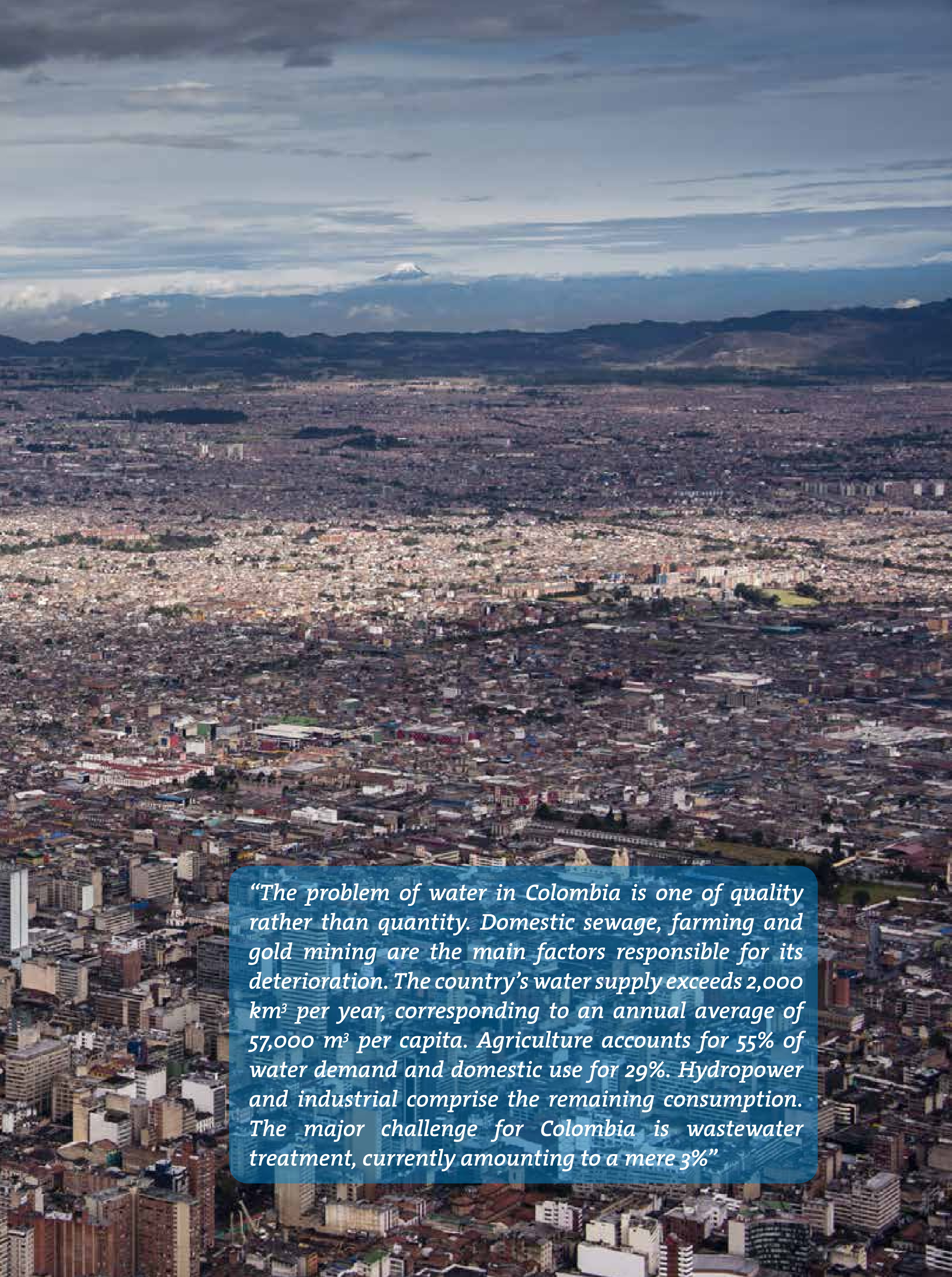
Colombia



Panoramic view of Bogota, Colombia. In the background the volcano Nevado del Ruiz.
Photo credit: ©iStock.com/DmitryLityagin.



"The problem of water in Colombia is one of quality rather than quantity. Domestic sewage, farming and gold mining are the main factors responsible for its deterioration. The country's water supply exceeds 2,000 km^3 per year, corresponding to an annual average of 57,000 m^3 per capita. Agriculture accounts for 55% of water demand and domestic use for 29%. Hydropower and industrial comprise the remaining consumption. The major challenge for Colombia is wastewater treatment, currently amounting to a mere 3%"

Urban Water in Colombia

Coordinators
Claudia P. Campuzano Ochoa and Gabriel Roldán

Authors
Claudia P. Campuzano Ochoa, Gabriel Roldán, Andrés E. Torres Abello, Jaime A. Lara Borrero, Sandra Galarza Molina, Juan Diego Giraldo Osorio, Milton Duarte, Sandra Méndez Fajardo, Luis Javier Montoya Jaramillo and Carlos Daniel Ruiz

Summary

According to the 2013 Census, the population of Colombia that year was 48,321,405, an increase of 616,978 inhabitants versus 2012 when the population was 47,704,427 persons. There are more women than men, with a split of 50.83% (64,562,767 women) /49.16% (23,758,638 men). The population density is moderate with 42 inhabitants/sq. km. and Colombia is the 57th most densely populated country. The country's geographic location, its variable topography and its climate make it one of the countries with the best water supply on the planet, although it is not distributed evenly across its whole territory. Its volume is more than 2,000 cubic km/year averaging 57,000 cubic meters/inhabitant/year. It is estimated that in 2011 potable water reached between 87.3% and 96% of urban areas while reaching only 56.3% of rural areas. It is estimated that the rate of wastewater created by the urban centers and subsequently released into bodies of water is 67 cubic meters/s. The most common water transmitted illnesses are dengue, malaria and diarrhea. Colombia's water problem is not its quantity, but rather its quality, given its improper use. Also, rubbish and garbage dumped directly into the water sources or along their banks or shores is a frequent source of pollution in many areas of the country.

1. Introduction

During the last 50 years, Colombia has managed to successfully establish a decentralized, innovative framework for environmental management that assigns specific tasks to the many players involved. There are still problems, however, that have not been able to be eradicated.

Human activity is a major threat to the well-being of current and future generations. Poor air quality is the result of industrial, commercial, residential and vehicular emissions; the lack of water, drainage systems and hygiene is the result of policies of intervention that have lacked force and responsibility; natural disasters are brought about not only by natural threats, but also by human activity nationwide.

Although Colombia has made significant progress in environmental matters, it still has to face the enormous challenge of reducing the rate of environmental deterioration still affecting the country, the impact of which is clearly seen in urban areas.

2. Water Sources and the Impact of Urbanization

It is estimated that almost 60% of the world's population will live in urban areas by the year 2030 (United Nations, 2004), a population density that has been identified as a possible source for dramatic environmental consequences, due mainly to the increase in impermeable surface areas in densely urbanized zones. These increases directly affect the ability of water to filter into the soil and the subsequent storage and flow of groundwater. Also, the urbanization process has altered the quality of runnoff due to the presence of chemicals such as zinc, copper and lead, organic composites such as polycyclic aromatic hydrocarbons, herbicides, pesticides, and fungicides and more recently, the remains of medications consumed by the population.

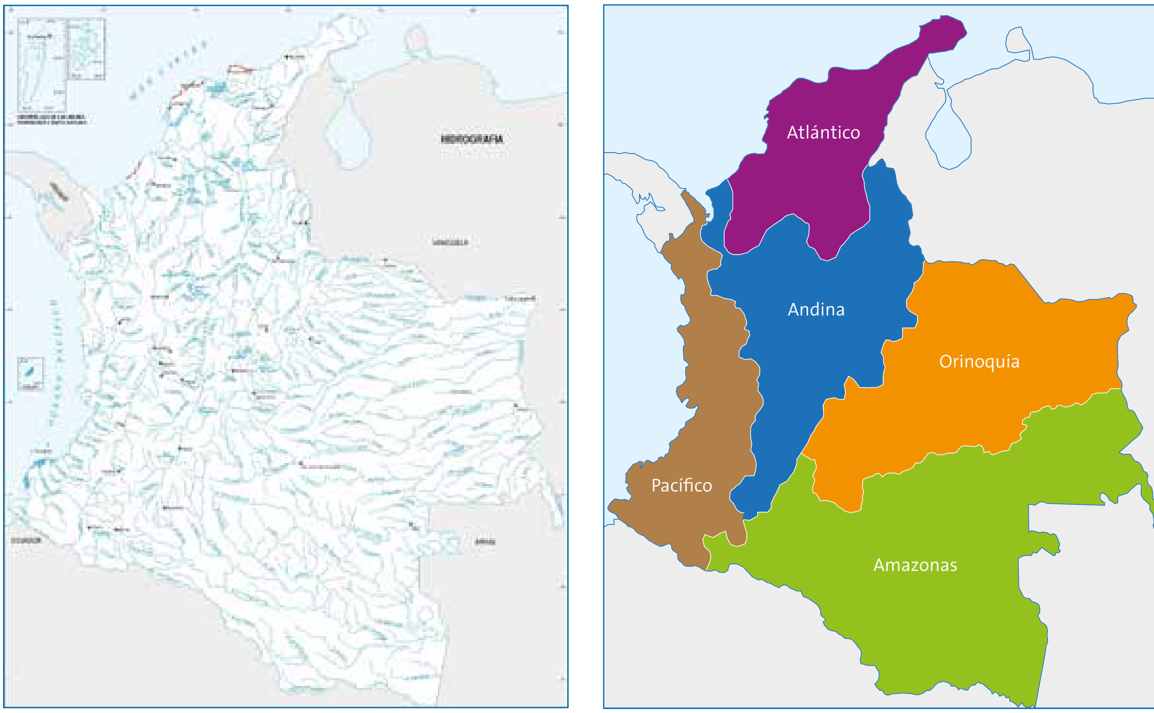
The country's geographic location, its variable topography and its climate make it one of the countries with the best availability of water on the planet. Figure 1. According to the Institute of Hydrology, Meteorology and Environmental Studies (Spanish initials IDEAM) (2008), at the end of the 20th century, Colombia occupied fourth place in water availability/capita, while the United Nations' report on the development of water resources in the world "Water for Everyone Forever" places Colombia 24th among 203 countries in this respect; this position still showsthat Colombia has high hydric potential worldwide, in spite of its current water shortage problems and the degree to which its natural water resources have been affected. In fact, the water supply is not evenly distributed across the entire country and is subject to many variables that determine its availability. In addition, use of the potential water resources is restricted by a series of human factors that affect the hydrological cycle and especially water quality. It is also affected by the form of exploitation characterized by improper or inefficient use of water.

According to IDEAM, estimates made in its National Water Study (2008), the country's water supply is more than 2,000 cubic km/year, the equivalent of an average of 57,000 cubic meters/inhabitant/year. Similarly, it is estimated that if reductions caused by the change in water quality and its natural regulation is taken into account, this figure is reduced to an average of 34,000 cubic meters/inhabitant/year. And if the country experiences a dry year, this figure drops further to 26,700 cubic meters/inhabitant/year. The IDEAM study (2008) allows us to confirm that in spite of the relatively favorable situation regarding water resources and its availability in Colombia, its spatial and temporal distribution is highly variable. Also, the conditions of vegetation cover, land-use, geological and hydrological characteristics of the different watersheds, vary a great deal and for this reason the country's watersheds differ in their ability to be regulated.

This variability in the availability of water is a cause for concern and even alarm in some municipalities and urban areas, given that there is not enough regulation for the use of water resources.

Most of the water in urban water mains that are, generally speaking, supplied by small rivers and streams (more than 80%), is not covered by watershed protection programs or by regulatory systems for its storage, transportation and treatment, and economic previsions are not provided for financing these activities.

Figure 1. Hydrological Map and Regions of Colombia



Colombia has become an urbanized country. The dynamics of urban configuration have remained constant in the last few years, so it is reasonable to expect that the current trends in population concentration in urban settlements will also not change. It is estimated that about 80% of the population of Colombia will be urban by the year 2020 (Ministry of the Environment, Housing and Land Development, 2008) (Spanish initials MAVDT).

Although urban areas are seen to be opportunities for social and economic development, it is also true that Colombia has been urbanized with little or no environmental planning which has had an undeniable cost to the environment, caused by random occupation and the heavy demand for resources entailed (MAVDT, 2008).

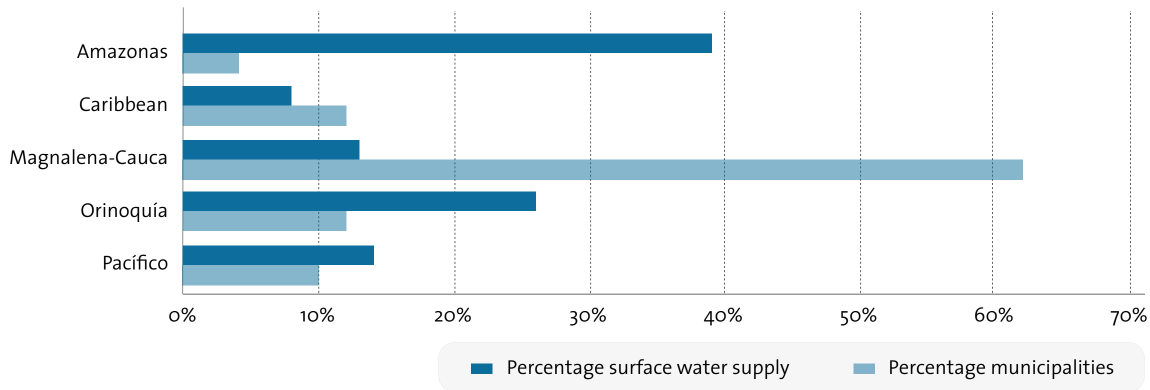
On the other hand, the development of multiple economic activities and services in the urbanized areas tend to cause the accumulation of environmental problems inherent in urban development to the point that they have become the main cause of the deterioration of the quality of life in these areas, to health and well-being of the population, and possibly have other, indirect consequences on the national and global environment (Ministry of the Environment, Housing and Land Development, 2008) (Spanish initials, MAVDT).

The National Water Studies carried out by the IDEAM (2005, 2008, and 2010) show water consumption by sector (Figure 3); the sector that consumed the most in 2004 was agriculture (this is the same around the world) consuming 59% of the country's water supply. This increased to 61% in 2005 and then decreased in 2010 to 55%. Domestic consumption in 2003 was 29% of the total, increasing to 43.9% in 2005 and then decreasing to 27% in 2010 (including non-consumptive use, as in the case of energy).

The use of groundwater (Figure 4) across most of Colombia is still in its early stages, due, among other reasons, to a lack of knowledge of the potential of this resource regionally and locally.

Large areas of the country are likely to be incorporated into the country's development plans; these areas have groundwater resources that could be used to satisfy different needs, mainly domestic. (IDEAM, ENA, 2010).

Figure 2. Distribution of Municipal Seats and Relation with Surface Water Resources per Hydrographical Area



Source: Encuesta Nacional Agropecuaria. IDEAM, ENA 2010

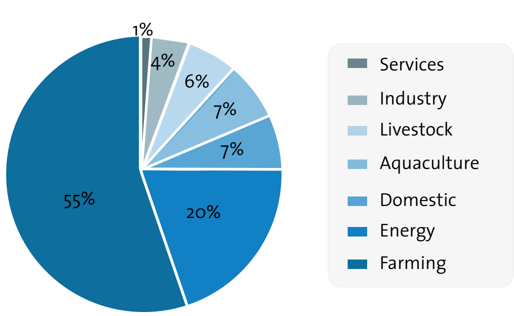
The studies carried out by the IDEAM in 2010 show that 74.5% of the country's surface area is made up of hydrogeological provinces and only 25.5% of igneous or metamorphic rock in areas whose hydrogeological features are as yet unknown, limited or restricted; this suggests the existence of large resources of groundwater that has not been formally evaluated. The total volume of groundwater is in the order of 5,848 cubic km, with 52% of the hydrogeological provinces lying in Amazonia, Orinoquía and Chocó where water is not a priority given these areas' low population and high water yield of these zones; the remaining 48% of the hydrogeological provinces is important nationally, and this resource should be the focus of future sustainability strategies. Figure 4 shows that the agriculture sector has the highest demand for groundwater with 75%, followed by domestic with 9%.

Of the total demand for water in Colombia, 82% of domestic use is by urban areas or municipal seats and 18% by the rest. Moreover, the five main cities account for 30.7% of domestic demand (Bogota, 13.6%, Cali 6.4%, Medellin 5.9%, Barranquilla 2.8% and Cartagena 2.0%)

Regarding the quality of the country's water, the main sources of pollution are: domestic, industrial,agricultural and livestock wastewater, rainwater, and water in transportation over land, rivers and maritime carrying dangerous substances and petroleum products and its derivatives; infrastructure works, water used in mining extraction activities, solid waste of sanitation deposits or released directly into receiving waterbodies. Additionally, the domestic sector is the main source of river pollution (IDEAM, ENA, 2010).

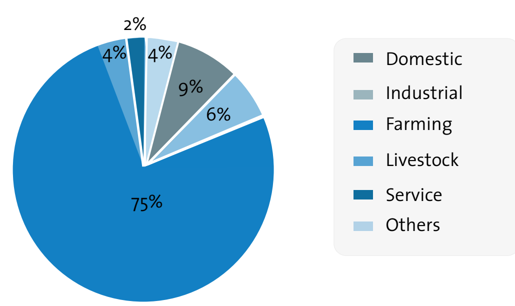
Population density and industry has traditionally been located in the areas surrounding

Figure 3. Potential demand by sector in Colombia



Source: IDEAM, ENA, 2010

Figura 4. Use of Groundwater by sector in Colombia



Source: IDEAM, ENA, 2010.

Colombia's main cities in the Andean region (Figure 1) and therefore affects the water resources in the basins of the Magdalena and Cauca Rivers. The tributaries of these rivers receive most of the pollutants affecting water quality.

These conditions, added to human activities such as occupation of the land and the indiscriminate felling of the vegetation are the main causes affecting the country's water regulation.

Approximately 80% of the water supply is provided by surface waters. However the water supply to some rural as well as to some urban areas is threatened by quality problems in those areas; the water's progressive deterioration is caused mainly by developing urbanization combined with poor or non-existent water resource planning and management activities, improper use of the land, the lack of protection of the watersheds, uncontrolled discharges of domestic, industrial and mining wastewater, deforestation, as well as deficient management of domestic and urban solid waste (Guerrero et al., 2013).

In addition, the main cities are also the destination of the large number of families that have been ousted from their original homes by violence. In 2005, according to the Human Rights and Displacement Consultancy (Spanish initials CODHES), more than 260,000 persons were registered as displaced, the equivalent of 3.8% of the total population of Bogotá (CODHES, 2006). Studies show that the displacement phenomenon is growing in the city confronting the reduction in care services; Bogotá has become the main destination for displaced persons, as pointed out by the High Commissioner of the United Nations for Refugees (Spanish initials, ACNUR), (2003). Also, the 2007 Quality of Life in Bogotá Survey showed that in areas of poverty and misery, the indicator for homes with inadequate public services (this indicator is used with four other simple indicators to calculate the composite indicator of Basic Needs not Supplied (Spanish initials NBI, (Feres, et al., 2001)) is higher than in other towns/cities (Office of the Mayor of Bogotá, Secretariat of Planning, 2007).

Although the potable water and sanitation sector in Colombia has improved significantly since the passing of Law 142 in 1994, potable water and sanitation services are provided by public or private firms that all have different management styles (Bernal and Rivas, 2011); however, in peri-urban areas and in informal settlements, these basic services are provided by small local operators (Colombia Ministry of Social Protection and the Ministry of the Environment, Housing and Land Development, 2007). It has been confirmed that there are deficiencies in providing of public services in some peri-urban areas of Bogotá, an example of which is in Usme (Cárdenas Quiroga and Solano Peña, 2007). These supply conditions generate a big threat to the health of the population that coincides with the area's incidence of disease, corresponding profiles of morbility in these zones, mainly to respiratory infections, diarrhea and intestinal intestinal parasite ailments (Cárdenas Quiroga and Solano Peña, 2007). Similarly, the supply of potable water and sanitations services in the city of Medellin does not reach the population living in settlements considered to be illegal; the city's poorest population is concentrated in those areas (Balcázar, 2008).

According to a study carried out by the Colombia People's Advocacy office that evaluated the degree of compliance with potability laws in 959 municipalities (approximately 86% of all municipalities in Colombia) only 18% were found to comply with the norms for potable water. The evaluation was carried out considering physical-chemical and biological parameters. The total population covered in this of research was 22,464,114 inhabitants of the municipal seats. As already mentioned, a large percentage of this population -55%- consumes water that does not fulfill the requirements of the norm (Colombia. People's Advocacy office, 2005).

As a result, the Colombian Government has recognized that since 2008 the illegal use of water is one of the problems related to renewable water resources. Also, it recognizes that regarding the settlements and the living conditions in those areas, it is well known that the homes do not have an adequate supply of potable water and that their occupants use alternative or illegal systems (Colombia Ministry of the Environment, Housing and Land Development, 2008). The cost of potable water in some cities is very high, making it unaffordable to economically vulnerable populations (see the example of Barranquilla as reported by the United

Nations Development Program, 2006). These particularities force the city's poorest inhabitants to obtain water from the only available source, even if it is contaminated or presents serious risks to their health. Many Colombian communities collect rainwater for different domestic uses, such as flushing toilets, washing the floor and the walls, garden watering systems, and for animal as well as human consumption (Torres et al., 2013). This practice is common in rural areas and in indigenous shelters. However, demonstrations have shown that rainwater is not suitable for these domestic uses due to its high degree of turbidity and high concentrations of suspended solids, biochemical oxygen demand and some heavy metals (Torres et al., 2013).

The management of solid waste is also an important source of water pollution in urban areas and in public spaces when it causes rainwater gutters and drains to block; this, in turn, is one of the main causes of flooding in vulnerable areas. The lack of land appropriation impedes the preservation of public spaces being a priority in a community. In Urban and peri-urban areas, illegal settlers from distant cities or towns do not regard the land they settle on as their own, and therefore dispose of their waste in streets, parks, canals and in streams. Within the scope of waste management, the practices and behavior of those who create the waste bears considerable weight. The attitudes and interests of the inhabitants are the key to creating public spaces and sources of water that are free of trash. Proof of this can be seen in activities aimed at introducing waste recycling in cities.

It is of vital importance that the environmental authorities and the providers of services strengthen their technical strategies and public policies that will reduce the numbers of people in the marginalized areas acquiring diseases through the consumption of contaminated water, be it because the water was accessed illegally or because it became polluted by poor waste management. But in either case, educational programs on the environment and citizen responsibility play an important role. Similarly, creating programs and using technologies that involve the community increase the probability of success not only to to appropiate these measures but also this allows people to identify with the land and therefore treat it with more respect.

3. Potable Water Service

In Colombia, it is the responsibility of the State to provide public services, including potable water under which it guarantees the quality of the service, extension of coverage and a supply which is efficient, continuous and uninterrupted. Public services companies, both private or public or in some cases a mixture of both- are allowed to offer the service of potable water. The state encourages competition and promotes for economies of scale. The water tariff regime is governed by economic efficiency, equality, solidarity and redistribution, and creates a system whereby commercial, industrial, and high income consumers help those in low income areas to pay for their water, thus helping them cover their basic needs. Also, there are several entities involved in water management; it is primarily regulated by two agencies: The Potable Water and Basic Sanitation Regulation Commission (Spanish initials CRA) whose main functions include: regulating the competition between the companies offering the service; establishing norms for tariffs and defining the criteria for the efficient supply of the service. There is also the Domestic Public Services Superintendency (Spanish initials SSPD) that, as a regulatory entity, is responsible for the sector's systems of communication and information; it also resolves consumer conflicts and supervises the suppliers, sanctioning them when they do not comply with the sector's rules and regulations. In order to properly protect natural resources in the provision of potable water, all companies or entities that offer services related to water supply, sanitation, irrigation and drainage, and hydro-electric production must carry out a series of actions to ensure efficiency and economy in the use of the resource. Their five-year action plans must be presented to the autonomous regional corporations that are responsible for monitoring and controlling the country's natural resources.

It was estimated that potable water services reached 96% coverage in urban areas in 2011 (National Department of Statistics, Spanish initials DANE, 2012) and 97% (WHO/UNICEF, 2013); the water supply reached 87.3% of the country, though only 56.3% of rural areas (DANE, 2012). Previous census information for the whole country in 2005 showed that water was provided to 47.1% of rural areas and

94.3% of townships (Figure 5) (DANE, 2005). Water supply distribution was observed in the different urban centers with 98% of the inhabitants of 475 urban centers having access to mains water supply, and between 90 and 98% of the inhabitants in 425 urban centers had similar access.

This coverage is concentrated in the Andean region of the country where the main cities are located. In the north, water supply coverage to the Caribbean region is a little less, though greater in the urban areas with coveragesare between 80 and 90%. Potable water services in the Orinoco and Amazon regions (the eastern part of the country) and Pacífica in the west, however, have the lowest coverage (less than 60% in some cases). According to the 1993 Census and estimates provided by the Colombia Department of National Planning, water supply to the big cities by 2015 will be extensive; it will not, however, reach the entire population of those cities. More efforts are required in medium- and small-sized cities to provide potable water to their populations. This is particularly true in regions that are socio-economically underdeveloped. In some department capital cities, the water supply reaches less than 60% of the city populations, the city of Quibdó being a good example.

Table 1 shows some water supply indicators in some important Colombian cities. Universal water supply has not been achieved in Colombia's cities, including those that reported having superior water supply services. The indicator for the efficient use of water refers to the amount of potable water sold over the total raw water extracted.

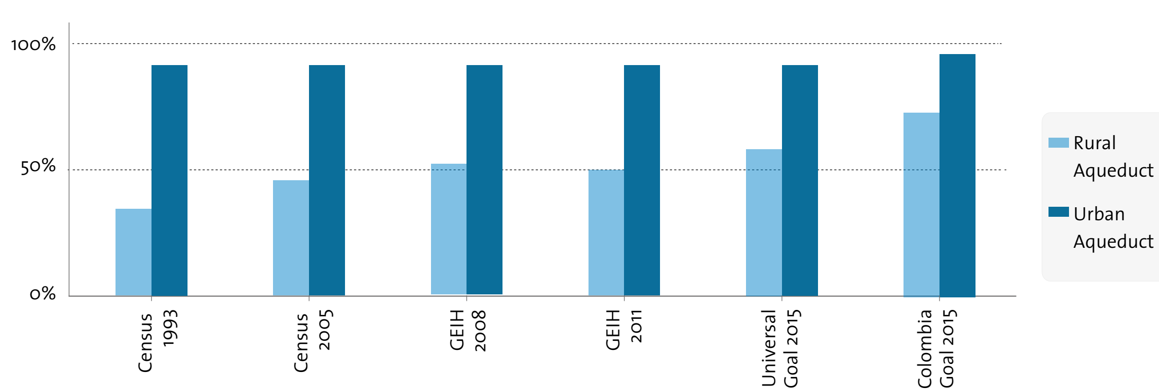
Some cities reported poor efficiency. The daily per inhabitant consumption varied between 98.82 L/inhab/day and 143.57 L/inhab/day; this difference may be due to climactic factors and to a higher rate of wastage in some of the cities. Losses in the network are the percentage difference between the amount of water in the network and amount that reaches its destination; some studies estimate that a 20% loss of this type is acceptable; the high values reported by the cities studied are a cause for concern.

According to these figures, basic water consumption in Colombia is in the order of 20 cubic meters/subscriber-month (CRA, 1994), the equivalent of 110L/inhab-day (SSPD, 2007). However, several studies consider this to be a high level of consumption. The Pan-American Health Organization (Spanish initials OPS) has determined basic water consumption to be between 80 L/inhab-day and a maximum of 100L/inhab-day.

Table 2 shows the trend in the number of subscribers to the water service in the most important companies in the potable water and sanitation sector. Classification by level refers to the financial position of the population, with 1 being those with the lowest income and 6 with the highest.

In the case of small urban centers, using the information reported in the Public Services Registry System of the Potable Water and Basic Sanitation Regulatory Commission (CRA) for 2013, only 64% of small urban centers have a master plan for connecting to the mains water supply and drainage networks, with 46% of these reporting that their plans are actually being implemented.

Figure 5. Trend in access to potable water in Colombia according to different sources of information



Source: Census 1993 y 2005, GEIH 2008 and 2011, DANE.

Table 1. Water supply indicators in some Colombian cities, 2011

City	Population	Population connected to the main potable water supply	Efficiency in water usage	Daily consumption/ inhabitant (L/inhabitant/day)	Water loss in networks % water supplied
Bogotá	7,467,804	98%	55.87%	98.82	43.99%
Medellín	2,368,282	97%	56.81%	143.57	40.87%
Cali	2,269,653	97.54%	60.85%	126.15	47.79%
Barranquilla	1,193,667	91.21%	38.17%	123.1	61.23%
Cartagena	955,709	89.70%	49.93%	137.71	41.99%
Cúcuta	624,661	94.45%	35.39%	132.18	55.34%
Ibagué	532,020	96.22%	48.93%	129.18	51.83%
Pereira	459,667	97.57%	55.49%	102.76	34.09%

Source: GRTB-ADERASA Annual Report- 2012.

Table 2. Subscription to water services trend by level, 2006-2011

Levels	2006	2007	2008	2009	2010*	2011
Level 1	797,885	856,013	891,574	935,560	1,025,481	1,125,441
Level 2	1,803,405	1,874,624	1,891,114	1,941,870	1,904,253	1,954,729
Level 3	1,723,888	1,762,615	1,750,679	1,779,813	1,598,642	1,662,325
Level 4	528,810	552,514	575,780	605,809	471,907	504,124
Level 5	238,936	248,682	256,685	266,174	219,274	226,594
Level 6	137,547	146,124	152,504	159,143	120,928	124,921
Industrial	20,656	22,500	21,350	21,254	16,106	17,327
Commercial	351,994	372,512	379,573	393,023	359,797	379,306
Official	24,257	22,617	21,744	21,520	23,264	23,377
Other	58,634	68,474	71,708	19,286	42,519	47,183
Total	**5,686,012**	**5,926,675**	**6,012,711**	**6,143,452**	**5,782,171**	**6,065,327**

SUI, Consolidado Comercial. *Different companies did not report their information in 2010.

Such plans are an articulation mechanism between urban management and the development of their sanitation systems; they contain strategies, programs and projects that guarantee current and future supply of potable water and sewage systems in the cities. Of these municipalities, only 86% report that the water consumed there is potable; only 91% of the townships who reported having a water treatment plant have them in operation. Of the townships that reported water quality information, 86% report the water is potable, but when analyzing the risk levels in the water supply, only 11% reported that there was no risk. A large proportion of the rest reported that they did not monitor water quality. The above indicates that although coverage ofwater supply has grown in urban areas, greater efforts must be made in managing water supply systems, in improving water treatment processes and in monitoring water quality, especially in more remote, low-income urban areas.

It is important to mention the vulnerable condition of the municipal water mains. In 2007, "close to 200,000 inhabitants were affected by flooding (or the collapse of the sewage system), and about 500,000 inhabitants suffered a suspension in the water supply as a result of avalanches, of the increase in the turbidity of the water in rivers, of blockages or the collapse of water withdrawal systems, and more than 20,000 inhabitants had their water supply cut off as a result of landslides that threatened the stability of the water supply service infrastructure". To date, the country still has no plan for reducing this vulnerability, and no research or inventories is being carried out on this subject.

4. Water Treatment in Cities

Population density and industry has traditionally been found in the areas surrounding Colombia's main cities located in the Andean region and therefore affect the water resources in the basins of the Magdalena and Cauca Rivers. The tributaries of these rivers receive most of the pollutants affecting water quality.

According to the study "Requirements for the formulation of a National Wastewater Plan" (Andes University-Ministry of the Environment, 2002) an estimate of the volume of wastewater produced in urban centers suggests that in Colombia close to 67 cubic meters of wastewater are being dumped into bodies of water per second, with Bogotá accounting for more than 15.3%, Antioquia 13%, Valle del Cauca 9.87% and the other departments under 5%. Coastal areas are polluted mainly by domestic and industrial waste. Most domestic waste is deposited untreated into the coastal waters or into rivers, mainly those in the Magdalena River basin, with the Cauca and Bogotá Rivers being the main destinations of all kinds of pollutants.

According to an analysis carried out by the Domestic Public Services Superintendency (2006) the treatment systems used by the companies providing sewage services in the big cities (Bogotá, Medellín, Cali), treat only 32% of the wastewater dumped into bodies of water.

Even more alarming is the fact that only 17%, 26% and 11% of wastewater is treated in such cities as Barranquilla, Bucaramanga and Ibagué respectively. Also cities such as Cartagena, Cúcuta, Pereira, Manizales, Neiva, Pasto, Valledupar, Popayán, Palmira, Florencia, Sincelejo, Buenaventura, Piedecuesta, Tuluá, Armenia, Tunja, Rionegro, Cartago, Sogamoso and Girardot do not treat any of their wastewater.

The country's underdevelopment in terms of wastewater treatment is due to both the lack of treatment infrastructure systems and the low coverage of the existing treatment plants. Only 354 (33%) of municipalities nationwide have waste treatment systems and it is known that 29% of those are not in operation. It is estimated that of the 159 cubic meters collected per second nationally, the volume of water that is treated is close to 5 cubic meters/second, the equivalent of 3.1% of this volume.

Given the deterioration in the quality of water and of the watersheds. the low coverage, capacity and the poor maintenance of water treatment plants, as well as the lack of control, follow-up and monitoring of water quality, it can be said that a high percentage of Colombians receive water that is not fit for human consumption.

Between 2002 and 2006, advances were made in the number of municipalities that have wastewater treatment plants, rising from 218 in 2002 to 355 in 2006; this figure, however, represents only 32.33% of the country's municipalities (including the Capital District) which can be considered a low coverage.

It is also worth mentioning the departments with more than 100 municipalities, such as Antioquia, Boyacá and Cundinamarca, whose percentage of municipalities with wastewater treatment systems in 2006 was 31.2%, 20.83% and 38.79% respectively, figures that are well below the national average of 41.39%. This is less than in other regions in the country and is undoubtedly due to the enormity of the task required to provide this service to a higher portion of the population.

Table 3 shows the trend in the number of persons connected to sewage system services in Colombia.

5. Water Reuse

The increase in the consumption of potable water due to the increase in urban populations around the world (United Nations Population Division, 2008) and especially in Latin America and in Colombia, (DANE, 2005), and the deterioration of the water eco-systems due to hydrological impacts and in the quality of the water produced by urbanization, has generated increasing interest in alternative water sources such as the reuse of wastewaters, the use of "gray water", water from urban runoff, and the utilization of rainwater (IDEAM, 2008).

These alternative sources of water are becoming an attractive option for communities with insufficient potable water or for those that foresee having a supply problem, given that, in theory, they can: (i) use this water when good quality

Table 3. Trends in connectivity to the drainage system by level 2006-2011

Levels	2006	2007	2008	2009	2010*	2011
Level 1	584,209	635,338	672,295	704,706	698,831	804,758
Level 2	1,620,039	1,728,577	1,759,061	1,807,590	1,729,719	1,792,205
Level 3	1,619,037	1,713,498	1,726,782	1,750,545	1,529,554	1,623,322
Level 4	503,009	544,323	571,922	599,248	444,039	492,719
Level 5	228,126	241,435	524,505	260,123	210,809	221,566
Level 6	130,234	141,256	146,418	253,636	113,688	119,464
Industrial	18,661	20,451	19,872	19,647	13,733	14,647
Commercial	331,328	360,628	372,612	383,211	337,290	362,632
Official	21,273	19,840	19,286	19,131	19,461	20,280
Other	54,401	66,778	70,151	73,287	40,509	43,827
Total	**5,110,317**	**5,472,124**	**5,882,904**	**5,870,851**	**5,137,633**	**5,495,420**

Source: SUI, Consolidado Comercial. *Different companies did not report their information in 2010.

potable water is not required, such as: toilet flushes, irrigation, washing of hard surfaces, etc.; (ii) increase the number of water supply sources and provide alternative sources to satisfy present and future water needs; (iii) protect the water eco-systems by reducing the amount of freshwater extracted so that the dilution capacity of bodies of water is not reduced (a response to the quantities of nutrients and other toxic contaminants found in water); (iv) reduce the need for water control structures, such as dams and reservoirs; (v) comply with environmental legislation by means of improved management of water and of wastewater.

5.1 Water Recycling

In Colombia, recycled wastewater with little or no treatment has been used mainly for crop irrigation (Silva, 2008; Silva et al., 2008). Technical feasibility studies have been developed and proposals for wastewater recycling have been made since 1998 (Vanegas Gálvez et al., 2001; Osorio, 2006) thus demonstrating that the recycling option (Valencia, 1998; Madera et al., 2003) is viable in terms of availability and of reducing the environmental harm to the receptor waterbodies in which wastewater is deposited.

For the recycling of wastewater to be promoted, an integrated water management system should be adopted; therefore legislation and regulations must be given an integrating focus that takes into account the characteristics of wastewater, its treatment, the quality needed of the recycled water and the area's natural conditions (Manga et al., 2001). Also, the concept of recycling has been difficult to understand in certain regions of Colombia (Madariaga et al., 2005).

Valencia et al. (2010) proposed a methodology for recycling domestic wastewater, which serves as a navigation map for the implementation of recycling projects, and in 2012 they carried out a study to determine the potencial of recycling the outflow of the Wastewater Treatment Plant (WTP) at Nátaga in the Huila department. The authors concluded that the area in question (that suffers from an insufficient water during most of the year) could use recycled water to irrigate the local cacao crops, but not before the effects of the treated water on the soil, the cacao plant and on public health had been evaluated.

Jaramillo (2010) evaluated the potencial of recycling domestic wastewater as a way to control the contamination caused by wastewater in the Cauca River valley. This study formed part of the SWITCH[1] project, a joint research project financed by the European Commission (SWITCH, 2013). The study concluded that 2 out of 26 municipalities in the area made direct use of recycled wastewater (planned usage) (treated wastewater used for a specific purpose) and the others made indirect or unplanned, use of recycled wastewater (untreated wastewater

1. http://www.switchurbanwater.eu/

outflow used without having any specific purpose). The study's principal conclusion was that the use of recycled water depends on multiple factors that have to be evaluated on the local level.

The Pontificia Javeriana University (Spanish initials PUJB) developed a proposal to recycle the outflow of the El Salitre Wastewater Treatment Plant in Bogotá. The main thrust of the proposal was that the treated outflow be used for crop irrigation, given that the La Ramada Irrigation District (with a surface area of more than 23,000 ha) is located near to the El Salitre Wastewater Treatment Plant. A situation analysis was carried out on the irrigation area at that time and it was found that the treated outflow could be used as a complement to the surface water used to irrigate the existing and also the extended areas. Parallel to this analysis, other possible uses were evaluated–industrial, landscape and recharge foraquifers–bearing in mind the quality of the Wastewater Treatment Plant outflow in the secondary system, treatment of the water with disinfectant, the potential market in the city of Bogotá and the cost of implementation. It was concluded that of the above uses, the most viable is industrial use of treated wastewater. This conclusion was reached based on a survey carried out among the industries located near to the WTP, though the main barrier to implementation were the costs of wastewater distribution; regarding the other uses analyzed, it was found that additional treatment was required to improve the treated wastewater's quality. The principal conclusion, however, was that the treated wastewater use with the greatest potential was agricultural irrigation, given that greater volumes could be used and that the cost was acceptable to farmers when compared with the amount they paid for water of a lower quality (Campos et al., 2011).

Lasso and Ramírez (2011) studied the recycling of wastewater from the regulatory, hydro-climatological and environmental point of view for irrigating sugar cane and palm oil crops for the production of biofuels. The authors concluded that recycling wastewater was in the economic interests of the producers, given that the practice of using fertilizer and the cost of water would be reduced. It was also established that if recycling wastewater was to be implemented, integrated management policies and mechanisms had to be developed that take into account the characteristics of wastewater as well as its treatment and the required quality.

Echeverri et al. (2012) evaluated the quality of the treated water produced by the Cali WTP and used for irrigation purposes, and they compared it with the quality of the groundwater in a well. This study was the first step towards launching a plan to recycle domestic wastewater to irrigate sugar cane crops in the Cauca River basin.

Regarding the policies and regulations related to wastewater recycling in Colombia, Law 373, passed in 1997, encourages the use of treated wastewater as a low-cost alternative that should be valued. (MAVDT and the National Planning Department Spanish initials DNP, 2004). Decree 3930, passed in 2010 by the Ministry of the Environment, Housing and Land Development, that substituted Decree 1594 (1984) of the Ministry of Health, (excepting Articles 20 and 21) contemplates, among others, a review of current water uses with a view to the MAVDT updating the water quality criteria for its different uses and the dumping regulations to guarantee these criteria. Its transitory Article 76 states that while the MAVDT is responsible for regulating water usage and providing the quality criteria for each of its uses, Articles 37 to 48 of Decree 1594 (1984) are still in effect. These articles define the quality criteria for human and domestic consumption, for agricultural, livestock, and recreational uses through primary and secondary contact, and for aesthetic and industrial uses.

Based on Decree 3100 of 2003 (regulation of compensatory rates), Decree 3440 of 2004 (an amendment to Decree 3100) and Resolution 1433 (2004) (regulations for Article 12 of Decree 3100 (2003), and on the Plan for Sanitation and Waste Deposit, the autonomous regional corporations of Colombia have developed other definitions of the water quality in watersheds that should be linked to the quality objectives and goals for different water uses.

Box 1

Vision and Integrated Water Management

Proposal for an Integrated Water Management Model

The main problem faced in supplying water in Colombia is quality rather than quantity. The institutional and administrative system, in other words, water governance, is also a significant factor in this problem. The Integral Water Management model consists of four steps:

First step: Recovering and protecting the affected basins

The majority of the basins supplying the municipal aqueducts have been affected for several decades by various man-related activities. Principal man-related activities affecting water quality:

- Contamination by domestic wastewater.
- Contamination by industrial wastewater.
- Contamination by fertilizers and pesticides.
- Inadequate waste disposal.
- Alluvial and artisanal mining activities.
- Animals decomposing in the open.
- Crops on hillsides and close to water sources and courses.
- Livestock grazing close to water sources and courses.
- Sediment dragging caused by road building, quarry mining and other engineering works that involve modifying the landscape.
- Modification of the courses (meander cut-offs, obstruction of connection to lagoons, among others).
- Construction of engineering works that modify the dynamics and course of current (bridges, dams, water diversions, among others).
- Burning and cutting down of forests.

Second step: Educating the community on efficient water use and saving

Recommended actions for efficient water use:

- Repair defective faucets.
- Check pipes for breakdowns.
- Check bathroom tank for leaks.
- Reduce the volume of toilet tank.
- Take short showers.
- Wait until washing machine is full before using it.
- Turn off the tap while brushing teeth.
- Water fields and gardens using only the necessary water.
- Do not use the hose to wash the front of the house or the street.
- Raise awareness among all family members regarding water saving.
- Immediately report leaks in pipes on public roads.
- Promote wastewater treatment in factories; this can result in savings of up to 70%.
- Do not think that you can use all the water that you wish, just because you can pay for it. Others need this water.
- Water fields and gardens in the morning.

Box 1

Third step: Recovering and managing wastewater

Most commonly used wastewater treatment systems.

- Activated sludge.
- Physiochemical treatments.
- Oxidation ponds.
- Channels planted with aquatic plants.
- Wetlands.
- Microfiltration using modern nanotechnology.

Fourth step: Recovering and managing riverbanks. Linear ecological parks

Once the wastewater has been recovered, the currents flowing through each municipality will regain their physiochemical and bacteriological properties. In these circumstances, the population will have the opportunity to use them for fishing and leisure, and nearby land will become parks for the community's recreation activities.

- Walking and relaxing.
- Children's play
- Family relaxation.
- Artistic activities.
- Enjoying Nature and the landscape.
- Communing with Nature.
- Engaging in cultural traditions.
- Integrating urban with environmental development.
- In short, this means **Quality of Life.**

5.2 Recycling urban run-off water and the use of rainwater

Around the world, the use of rainwater is seen as an efficient use of water and as a basic pre-requisite for ensuring more sustainable cities. Use of rainwater in cities is considered to be a multi-purpose strategy for controlling flooding; at the same time, it helps to reduce potable water consumption, to lessen the demands heavy rainfall makes on the drainage system (European Environment Agency –EEA–, 2012), and to reduce and, in some cases, to resolve water shortage problems and those related to the contamination of surface and groundwater; such usage is especially helpful to local populations when the price of potable water rises. Using rainwater could also play a key role in increasing evapotranspiration as an additional way of addressing the problem of global warming, together with policies aimed at preventing carbon dioxide emissions.

Use of rainwater in Colombia is part of the Program for the Conservation and the Efficient Use of Water established by Law 373 in 1997, that states that the public agencies responsible for granting water concessions must offer consumers, as per the previous studies, the use of rainwater and put in place the necessary technology so that its use is a viable option at the right price.

Collecting rainwater that falls on the tiled roofs of houses is currently carried out using traditional means such as bottles, pots and hand-dug wells; this water is given non-potable use in shopping malls, service centers, office buildings and apartment blocks (Ramírez-Fonseca, 2009; Castañeda, 2010). For example, as per the direct observations made by the authors in the outskirts of Bogotá since 2002, several families are currently making use of untreated

Box 2

Succesful project for Water Recovery in Colombia

Domestic and industrial wastewater management has always been a challenging problem. The costs and significant investments involved in treatment plants for purifying water before pouring it into ravines or rivers have been one of the principal obstacles to satisfactorily solving this problem.

The aquatic plant biotechnology has been developed as an alternative system for treating wastewater which, in small communities and industries, has efficiently removed a wide range of substances, including organic matter and nutrients.

This biological water purification system is a recent innovation in the fight against pollution and an ecological and economic option for treating wastewater in tropical and subtropical regions worldwide.

Panoramic view of canals planted with water hyacinths (*Eichhornia crassipes*)

- 1.2 hectares are required to treat 680 m³/ day of wastewater for a population of 5,000 inhabitants.
- Length of canals: 500 m
- Layout of canals: 50 m long x 6.0 m wide x 0.20 - 0.80 m deep
- Approximate discharge rate: 8 to 10 liters/sec.
- Water retention time: 14 to 21 days
- Only one workman is required to maintain them (plant and sludge removal).
- Removal of saturated (yellowing) plants: every 4 to 5 weeks.
- One hectare of hyacinths produces: 16 to 32 tons/day of biomass; 90 to 180 m³ of methane gas and 0.5 tons/day of fertilizer.

For more information about this experience, please visit:
http://www.ianas.org/index.php/books
http://www.ianas.org/books/books_2015/water_lines.pdf

surface rainwater collected from roofs (including human consumption). This practice is therefore linked to substantial health risks, especially in terms of its collection, storage and distribution methods. In spite of this risk, there is little scientific study on or analysis of the quality of rainwater in Colombia (Lara et al., 2007; Castañeda, 2010; Buitrago y Camacho, 2012; Torres et al., 2013), or complementary themes such as its volume, collection or storage (Torres et al., 2012). Research on this subject is therefore required, as is an evaluation of the volume of contaminants to receptor waterbodies, and new rainwater treatment systems must be designed.

6. Water and Health in Colombia

According to information provided by the office of the Attorney-General, the Government has allocated a total of $117 billion pesos (approximately $53 billion dollars) over the last ten years, of which $7.2 billion pesos (approximately $3 billion dollars) were assigned for the potable water sector; however, the morbility and mortality rates caused by water transmitted bacteria. Chronic diarrhea is the most common disease, in spite of the investment by the General Subsidy Scheme (Spanish initials SGP), donations and other sources.

According to information provided by Sánchez-Triana et al. (2006), 7.2% of infant deaths are attributable to diarrhea-related illnesses; prevalence of two-week diarrhea in children under the age of 5 is 2.9%, with 90% of the cases and subsequent hospitalizations being attributed to poor water quality, poor sanitation services and hygiene.

The National Political and Economic Council (Spanish initials CONPES) 3343 has established that the average cost of public health due to "inadequate, unhygienic water supply and sanitation services reaches $1.96 billion pesos (approximately $890 million dollars)".

The Ministry of Health and Social Protection informed that Colombia was one of the 20 nations that convened in Bogotá to evaluate, analyze and be updated on the situation regarding yellow fever, cases of which have not been reported in Colombia since 2010. This meeting was an important event in terms of public health monitoring. Table 4 shows diseases most frequently caused by poor water quality.

7. Climate Variability and its Impact on the Water Supply

The reduction in surface waters at times of lowest water levels related to long-term climate trends orextreme climate conditions is one of the greatest threats to integrated water management of watersheds that supply the demand from large urban centers. This situation is especially alarming in mountain basins that supply water to the aqueduct systems in several cities in the Andean region. Large cities located in Colombia's mountainous regions such as Bogotá, Medellín, Manizales and Bucaramanga, whose populations make up a large proportion of the country's urban dwellers, could face significant water supply challenges to their domestic, commercial and industrial needs in the medium and long term. The net decrease in surface waters combined with a disproportionate increase in demand and poor water quality makes it urgent that planning organizations and decision-makers to design appropriate strategies and actions that ensure the continual supply of high quality potable water. Capacity expansion projects, together with water conservation and efficient usage programs are the usual strategies adopted by the public service companies and planning authorities when faced with the problem of an increase in water consumption in urban areas. These initiatives have materialized in parallel with water business proposals and policy guidelines that consider this resource to be a structural axis. Proposals for citizen training and sensitization regarding water as well as for the restructuring of the organization responsible for managing the water resources have also accompanied these proposals and have allowed that these improvements affect the daily lives of the urban population more rapidly.

Apart from the concerns about the increase in demand, certain conflicts of interest are currently arising in Colombia regarding the presentation of projects at the sources of water basins that have been at times interpreted as being a threat to optimal water quality and volume. Such projects, which many of the members of urban communities have

Table 4. Most frequent diseases in Colombia

Type of illness	Cases reported	Mortality cases
Acute Diarrhea illness (Spanish initials EDA)	605,497	26
Malaria	15,000	1
Hepatitis A	1,237	220
Dengue	1,010	29
Leptospirosis	718	12
Typhoid fever	104	0
Cholera	57	0
Poliomyelitis	1	0
Yellow fever	0	0

Several sources INS, SIVIGILA, DANE

demonstratedto bein conflict with their proposals for the integrated watershed management of the basins that supply their potable water, emphasize the need for the environmental authorities and environmental licensing agencies to work more closely and prioritize the different proposals.

8. Rainwater and Flooding Problems

The problem of managing rainwater is linked to the disproportionate growth of the urban population. This growth requires that more impermeable areas be constructed and constant renovation be made to the drainage systems that are such important features in modern life. In addition to the above, and due to the way climate change affects the hydrological cycle, changes in rainfall patterns, including in some cases an increase in the frequency of extremely intensive rainfall have been observed. Such rapid change in land use together with urbanization bring about a change in the flow of matter and energy in the hydrological cycle –changes in micro-climates– (Araujo and González, 2010), causing the infiltration rate to decrease drastically; this modifies the concentration times, causing an increase in the amount of surface runnoff. This increase in the volume of and flow of surface waters causes more sediment transport, which could be an environmental threat to the receptor waterbody.

8.1 Flooding in cities

Flooding in cities is one of the problems caused by urbanization that has a high impact on the population and its lifestyle, given that floods affect densely populated areas that, generally speaking, are the locations of vital important infrastructure. Between 2001 and 2010, this was the most common type of natural disaster around the world and floods were responsible for at least half of the victims of such natural disasters and for related financial losses estimated to be $185 billion dollars (International Disaster Database, 2011. http://www.emdat.be/).

In 2010 and 2011, Colombia experienced an unprecedented historical rainy season. During that period of 14 months, 1,734 floods were reported, the equivalent of 45% of those occurring between

Figure 6. The effects of flooding in the Sabana de Bogotá (October, 2011)

1998 and 2008. This number of floods in such a short period of time had unheard of consequences: hundreds of deaths and more than three million affected inhabitants (National Unit for Disaster Risk Management, Spanish initials, UNGRD, 1998-2011; Hoyos et al,. 2013)

Regarding the research on this subject carried out in Colombia, it is important to point out the work on urban hydrology done by the del Norte University (Colombian Caribbean) in the basins of the streams in the city of Barranquilla (Ávila et al., 2012; Ávila and Díaz, 2012; Ávila and Sisa, 2012; Sisa and Ávila, 2012). Of similar importance is the analysis of the relationship between rainwater and runnoff in basins in the urban area of Lorica carried out by the Pontificia Bolivariana University, Córdoba campus (Salgado and Dickson, 2012). In the valley of Cauca, the Water Supply, Environmental Sanitation and Water Conservation Institute of Research and Development (Spanish initials, CINARA) of the University del Valle has done some outstanding work in the application of simplified models in urban hydrology, hydrodynamic modeling of the urban drainage systems of the city of Cali, and in the analysis of the challenges presented by climate change in urban centers (Galvis et al., 1987; Galvis et al., 2007; and Carvajal, 2007). In Bogotá, recent work on an urban watershed by Hernández and Cubillos (2102) also stands out; they proposed and successfully implemented a methodology to evaluate the public risk from flooding caused by rain in the basin of the Salitre River. There is, however, very little research on the effects of flooding caused by rain on sewage systems (Sandoval et al., 2012) and its interaction with other parts of the system such as water treatment plants or rivers.

For predicting flash floods, early warning systems are applied which have been recognized as the most advanced system in the world (Quintero et al., 2012). Colombia has made little progress in this sense (Rogelis and Ardila, 2012). The PUJB (university) has carried out work on basins in the city of Bogotá related to the subject of technology, particularly on the importance of installing meteorological radar system (Copete et al., 2012); there is also a study on the distribution of rain over Bogotá (Vargas et al., 2010; Santos, 2011; Vargas et al., 2011; Rada Ariza and Torres, 2011). In addition to the work mentioned above, the National University (Manizales campus) has analyzed the spatial-temporal variability in rainfall in the city of Manizales (Botero, 2009; Botero and Cortés, 2010; Cortés, 2010), the rainwater-runoff conversion process in the urban basin of the San Luis ravine (Suárez, 2008) , and they have made an estimate of the variability in times of concentration in this urban micro-basin (Vélez and Botero, 2011), using an installed urban meteorological network for these purposes. Another project, developed by the National University, Medellin Campus with the assistance of professors from the National University, Bogotá Campus (Vélez et al., 2010) and carried out by the Public Companies of Medellin (Spanish initials EPM), aimed at launching urban hydrology research in EPM is the pilot hydro-meteorological information network for the Valley of Aburrá (Jiménez et al., 2008), in the SIATA (the early warning system of Medellín, which is actually the first in the country)[2] and also the analysis of the urban watershed of the La Picacha stream. The research projects to date underline the fact that studying rainfall in Colombian cities is a more complex process than in other countries. This is due to the cities' extension, the landscape, and the limitations of the instruments installed, making it difficult to understand local rainfall patterns and forecasts. It is therefore necessary that meteorologists and climatologists work together in Colombia and continue to develop in-depth research projects on urban hydro-meteorology.

8.2 New solutions

The understanding of the environmental impact of urbanization has brought about a new focus aimed at improving the management of the urban water resources. This focus contemplates the concept of sustainable drainage that includes long term environmental and social factors in drainage projects; they seek to maintain the ecological, environmental and hydrological integrity of a location relatedto the natural condition prior to urbanization by means of controlling floods and by collecting, storing and improving the water quality of runoffand minimizing the impact of infrastructure and human activity on water quality.

2. http://www.siata.gov.co/newpage/index.php

However, given that the urban drainage system is complex and interacts in many ways with social, economic and ecological aspects, the challenge lies not only in the question of technology or in the uncertainty of climate change, but also in a consideration of the whole mega-urban water system and how its different parts inter-relate with each other and with sub-systems. It is therefore necessary to evaluate the traditional urban drainage system that is becoming increasingly out of line with society's environmental values and makes progressing in the search of more sustainable urban environments difficult. To the two traditional objectives of urban drainage, which are (i) to protect and maintain the security and health of the community, ensuring that floods do not interfere with the city's activities and eliminating human waste in order to ensure a healthy environment; and (ii) to protect the natural surroundings, maintaining environmental standards and complying with the pollution limits of waterbodies and of the environment, a third that seeks the sustainability of the system should be added. This implies taking into account the long term consequences of drainage practices in general.

8.3 Structural and non-structural solutions

Sustainable urban drainage systems (SUDS) are classified into two large groups: structural and non-structural. Non-structural types consist of a variety of institutional and educational practices commonly known as << control at source or the prevention of contamination>> that seek to reduce or stop contaminants from coming into contact with rainwater. These practices do not eliminate contaminants entirely, but they can make the structural controls more effective by reducing the amounts of contaminants these controls can manage.

Non-structural SUDS are the following: (i) reduction of consumption; (ii) good practices at home and in industry; (iii) preventative maintenance of the drainage systems; (iv) prevention of point source discharges; (v) education of the community.

SUDS of the structural kind are systems that increase infiltration, minimize the volume of surface runoff, temporarily hold back urban runoff or treatment before it reaches the receptor bodies of water. Examples of these systems are retention ponds, permeable paved surfaces, canals with vegetation and constructed wetlands, among others (Durrans, 2003).

Compared to conventional drainage systems, which are created to collect, channel and discharge surface runoff as quickly and efficiently as possible, but that do not take into account large volumes of urban runoff and their impact on surface waterbodies, SUDS seek to preserve the hydrological conditions of the location in place before urbanization and minimizing the impact. The inclusion of the SUDS in urban design seeks to produce low impact on the location whichconserves and improves locations with high environmental value in order to adapt them to the new urban conditions; this implies the use of permeable materials in hard zones and a reduction in these impermeable areas, thus making the most of green areas (gardens, public parks, traffic circles and street separators) designed from the point of view of hydrology (Fernández, 2011).

In order to replicate the natural processes of urban watersheds,the use of a "management train" is being proposed. This concept consists of considering the following techniques, in hierarchical order. (i) Prevention. Use good designs and apply maintenance measures in the locations in order to prevent run-off and contamination, and design and implement measures for the use or of recycling of rainwater; (ii) Control at the source. Control runoff water that lies closest to the impermeable areas that create them (by means of infiltration and retention); (iii) Control at the locations. Manage the water in local areas (direct the water from rooftops, from car parks into large retention tanks or infiltration systems; (iv) Regional control. Manage the water from different local areas.

The implementation of SUDS in Colombia is relatively recent and has great potential for improving water management in urban centers. SUDS are not used nationwide, and even less so as means of reducing contamination.

In Bogotá in 2008, the City Council agreed to create the Unique Sustainable Construction Standard in Bogota´s building Code (Agreement 323, 2008) in order to be able to evaluate the reduction in the environmental impact of a construction. In 2011, the Ministry of the Environment passed Resolution No.

5926 designed to create and regulate the Recognition of ECO-efficient Buildings Program (Spanish initials PRECO). This program seeks to promote eco-efficient, environmentally friendly construction projects that encourage the use of new technologies in favor of environmental sustainability.

In Medellín an environmental management manual was developed for construction that seeks to reduce the environmental impact of construction, and the Colegio Mayor de Antioquia (Upper College of Antioquia) and the National University currently offer post-graduate courses in sustainable construction.

The experience nationwide are considering studies on the technical feasibility of SUDS (Galarza and Garzón, 2005) and on the benefits of reducing peak volumes of urban runoff (Ávila and Díaz, 2012). Modeling has been developed for the location of SUDS (Díaz-Granados et al., 2009), as have simulations and experiments in scale models in a laboratory setting (Gómez et al., 2010; Torres et al., 2011; León and Avellaneda, 2012; Álvarez and Celedón, 2012; Devia et al., 2012; Torres et al., 2012).

In practice are the construction of productive greenroofs built in low-income areas of Bogotá (Forero et al., 2011) and constructed wetlands have been created alongside natural wetlands with a view in controlling the contamination of urban runoff (Lara-Borero, 2010). However these systems have not been monitored on a continuous basis so the degree to which they provide hydric attenuation and amounts of contaminants, among others, has not been determined. Also, in 2013, the PUJB (university) built a constructed wetland/regulating tank in order to treat runoff water coming from a car park building for its subsequent re-use. This system will be monitored in order to understand how the system works from the hydraulic point of view and to see whether it improves water quality (Galarza-Molina et al., 2013).

Regarding the green roofs, monitoring and modeling studies of these systems have to be developed, as follows: the effects of the vegetation on thermal flows; the rate of evotranspiration through the soil and the vegetation; the transference of heat; the balances of energy for the vegetation and the substratum as well as the economic benefits obtained from these green roofs as applicable to the country's main cities.

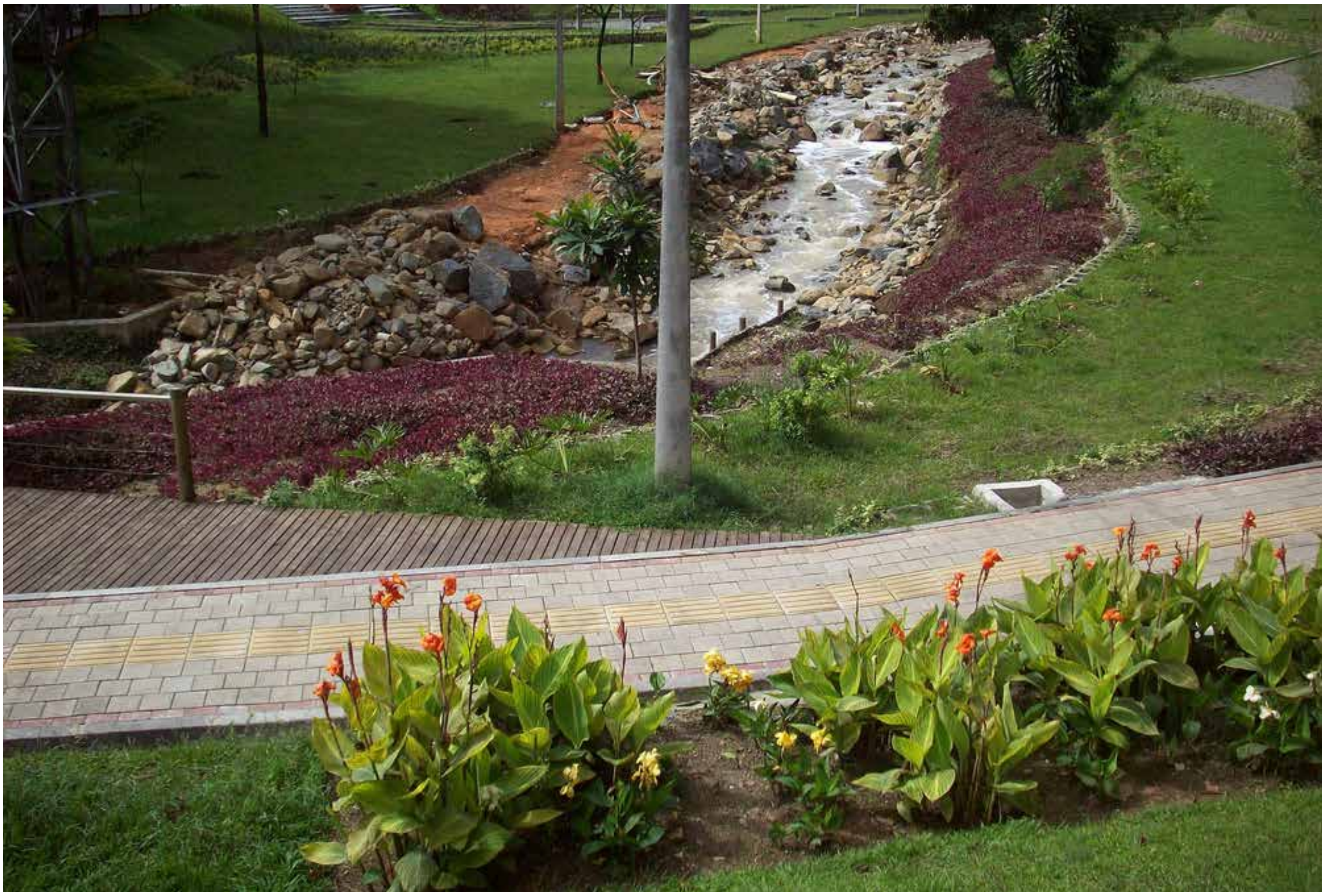
Progress has been made in Colombia in the area of environmental architecture since the '90's, but it has been during the last decade that projects at institutions, universities, family compensation funds (caja de compensación familiar), schools, hotels and industry have joined in the global environmental movement and the paradigm of sustainable development in cities such as Bogotá, Medellín and the medium-sized cites of Pereira and Palmira.

Similarly, environmental solutions such as linear parks (Figure 7) have been implemented in Colombia that contain measures that reduce the risk of flooding and erosion. These provide natural flooding control along rivers or streams and bring about savings in investment in more complex structures. They conserve the land, natural resources and the landscape. They conserve and improve urban living conditions. They make up a migratory corridor for plants, birds and fish found in the immediate surroundings. They allow for the proliferation of the wildlife. They conserve and protect water quality. They improve and protect the quality of air given that they serve as a contaminant filter. They serve as an integrating factor that allows for a balance between environmental conservation, economic improvement and community participation. And although they have different names in different countries, they are an alternative that improve individual mobility and the quality of life in our cities and towns, and they represent a valuable contribution to the achieving sustainability in our communities.

Six of these linear parks have been developed in Medellín: Bermejala Linear Park, La Presidenta Linear Park, Los Sentidos, Linear Park, La Hueso Linear Park, La India Linear Park, La Herrera Linear Park, and a competition to design and create the Medellín River Linear Park has just been announced.

Although there is in some cases a high number of green areas in urban centers in Colombia, many parks or recreational areas are considered of low value; urbanization has intruded into the spaces taken by streams and has adopted a type of vegetation that is more aesthetic than ecological and is thus limited in its potential to carry out all the functions of urban vegetation.

Figure 7. La Presidenta Linear Park in Medellín



If there is to be an integrated approach to environmental management based around the development of water resources, conflicts in the use of rural areas must be reduced and agricultural, ranching and agroforestry activities must be carried out in their appropriate areas. With these sorts of activities asthe development of linear parks, habitats for flora and fauna can be protected in strategic ecosystems, thus restoring the natural landscape surroundings, preserving the soil and diversifying the forest environments for all inhabitants of the watersheds in general.

Also, with the purpose of functionally linking existing public green areas in urban centers to the fragments of natural vegetation in nearby rural areas, it is important to have an ecological network that includes ecological restoration activities in protected areas. This provides a tool for urban green area planning and for the recovery, restoration and conservation of natural resources. This also prompts the establishment of a closer relationship between the city and nature, and better enjoyment and appreciation of natural areas resulting in the community taking better care for these spaces.

The country is becoming aware of the need to implement an urban planning process that analyzes the problems and potential of watersheds in all their components. Scenario planning and interaction with the community and the municipal agencies have determined that a likely and desirable scenario is the one whose short-term goal is to create conditions that are favorable for finding integrated solutions to the socio-economic as well as the environmental problems in the river basins.

9. Conclusions

- Colombia is one of the countries with the largest availability of water resources in the world, but they are not uniformly distributed across the country.
- The area with the heaviest rainfall is the Pacific coast that receives up to 12,000 mm per year.
- Close to 90% of the population is located in the Andean range of mountains with a high population density that affects the quantity and quality of the water resources. Also contamination originated in homes, agriculture, industry and deforestation greatly limits the use of water.
- The greatest problem is that most of the wastewater is not treated, making recycling impossible. It is estimated that only 3% of wastewater is properly treated.
- Colombia's water problem is not the quantity, but rather its improper use. Also rubbish and garbage that is deposited directly into the water sources or along their banks or shores is a frequent source of pollution in many areas of the country.
- To summarize, quality and quantity problems of water resources are more a question of educating the public in its use and management, and improving the deficiencies of governance and non-application of the existing laws.

10. Recommendations

- The first priority to plan the use of the watersheds andmicro-basins in order to guarantee a sufficient quantity of good quality water.
- For this to happen, deforestation and the use of pesticides and fertilizers has to be controlled, and promote sustainable agriculture.
- Wastewater treatment plants must be built in all cities and towns in order to prevent the water sources from becoming contaminated and thus allow for the reutilization of treated water.
- Organize technical management and recovery of garbage that allows for a high percentage of recycling.
- Adopt a vision of integrated use and management of water that takes into consideration the basin as the source of water; that educates the public in the rational use and conservation of water, and makes the municipal authorities responsible for the treatment of wastewater.

Box 3

Linear Ecological Parks

Colombia has seen the development of numerous linear park projects, designed principally to meet the leisure, educational, environmental, health, sport and transport requirements of the communities living in an urban environment undergoing significant changes.

The municipal government of Medellín in the state of Antioquia has designed a concrete and decisive program to recover the withdrawals of urban water flows, and this mainly by implementing green corridors and linear parks. These linear parks are a strategy that complies with the investment guidelines established by the municipal government. These spaces have also responded to the environmental, social and economic needs of the basins developed. Consequently, they have been created together with plans for the organization and management of these basins, coordination initiatives with the communities living in the basin, and the application of the relevant Colombian norms.

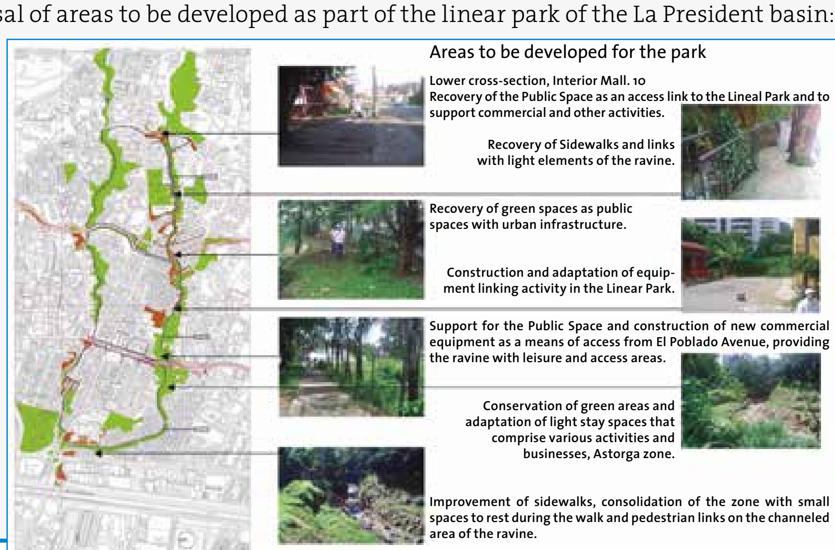
The linear park of the La Presidenta ravine is a good illustration of the environmental, social and economic services that this space provides for citizens. The project is described below.

The Linear Park project was designed to link the public space of the center of the El Poblado neighborhood to the pedestrian areas network and the withdrawal and protection borders of the La Presidenta ravine. It thus became one of the pilot actions of the Integral Organization and Management Plan for this microbasin, and a model for other initiatives in the region.

Furthermore, the project aimed to recover a natural corridor that contributed to maintaining the area's fauna and flora, making it an element of urban quality of life. It also envisaged linking it with other nearby natural spaces, configuring an environmental network across the entire zone, and contributing to designing a peripheral pedestrian ring around the center of the El Poblado neighborhood. In later years this would be complemented by recovering the edges of the La Poblada ravine, the principal affluent of the La Presidenta ravine and the development of public spaces.

The design of the Park maintained the existing vegetation as far as possible, in order for green to predominate over gray. It aimed to provide the community with a fresh, friendly, tranquil environment with attractive, pleasant-smelling trees, bushes and gardens, and home to a great diversity of wild animals, which could find food and nesting places in this area. The embellishment of the landscape had an ecological purpose, as in addition to its pleasing appearance for pedestrians it also strengthened the environmental conditions of this area as a biological corridor for fauna and flora, and as a space to mitigate the region's flood risk.

Proposal of areas to be developed as part of the linear park of the La President basin:



Box 3

The architectural design of the stretch to be developed is displayed below

Current view of the linear park of the microbasin of the La Presidenta ravine in Medellín (Antioquia - Colombia)

Box 4

Water Footprint

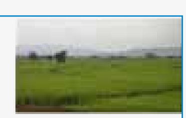
The water footprint indicator was developed by two researchers, A. Hoekstra and A. Chapagain, in 2003. It is based on two previously proposed ideas, the first being the concept of virtual water put forth by J.A. Allan in 1993, the second being M. Falkenmark's idea of green water proposed 1995. These two concepts are the primary components of the conceptual and methodological basis of the water footprint. The Water Footprint Network (WFN) led the standardization of the concept, its quantification methodology and the guidelines for undertaking an evaluation at the international level.

The water footprint makes it possible to consider the use of water hidden in the production chain of consumer goods and services, providing information on the effects on water of the habits or people or populations, guilds and firms. This multidimensional indicator shows water consumption according to its origin and the volume required to absorb the pollution generated. The components of the water footprint geographically and time specific.

There are a number of applications for the water footprint, including the perspective of consumption and production, for a single person or a group of people, a farmer or a group of farmers, a product or group of products and a geographically limited area such as a water basin.

The water footprint is made up of three components:

The green water footprint
refers to the consumption of groundwater stored from rainfall that maintains vegetation without irrigation. It meets a need without requiring human intervention.

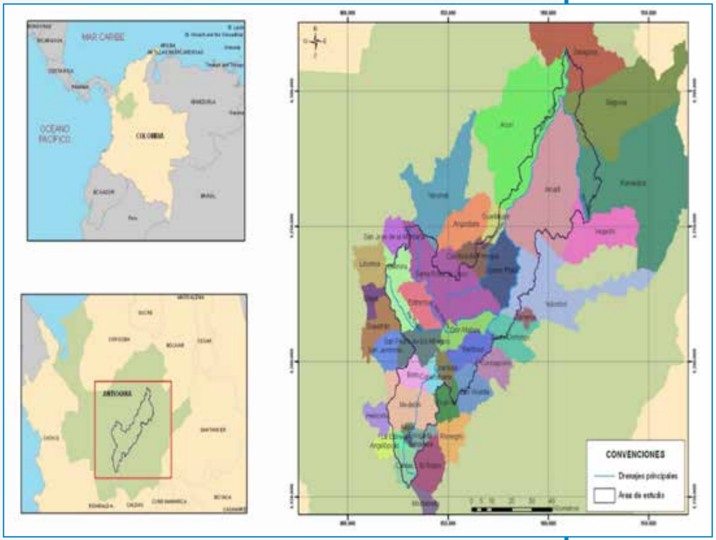


The blue water footprint
refers to the consumption of water extracted from surface or underground to meet the needs of a process. It measures the loss of available water (evaporation, change of watershed, product incorporation) due to specific consumption. It requires human intervention.

The grey water footprint
is defined as the amount of fresh water required to absorb the amount of pollution in a body of water, taking into account the environmental quality norms and limits established for quality for both the environment and people.

Box 4

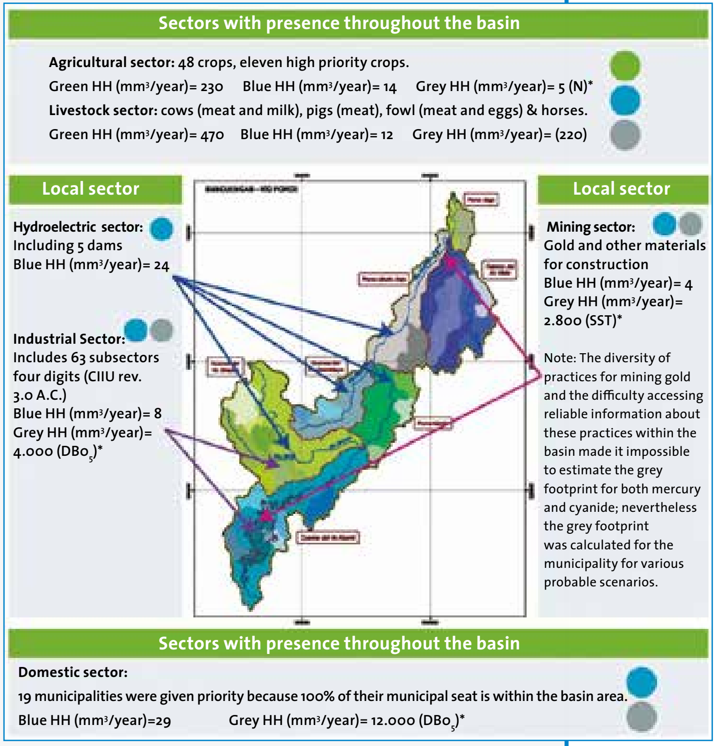
A number of countries, economic sectors and businesses have begun to incorporate a water footprint evaluation into their environmental sustainability plans. In the Americas, Colombia has made the greatest progress in this respect. The water footprint for Colombia's agricultural sector was established in 2010 and since then, more than ten large corporations have assessed their water footprint, and scrupulously followed the methodology established by the Water Footprint Network to evaluate the Porce river basin. To date, this evaluation is unique, not only in the Americas, but also across the globe. Knowledge of the water footprint in Colombia has advanced to such an extent that this year it was decided that the National Water Study, the most widely consulted document on water and the basis for the country's water-related decision-making, should include the concept of water footprint. Some results from the water footprint assessment of the Porce River basin are included.



Geographical Characteristics:

The Porce River basin covers 5,248 km² and is located in the area of Antioquia along the Colombian Central Mountain range. Its main channel is off the Aburra River, which rises in the Alto de San Miguel in the municipality of Caldas. It runs for 252 km before joining the Nechi River in the municipality of Zaragoza. The basin's topography is irregular and on an incline, with elevations of between 80 and 3340 masl. The political-administrative division of the basin includes 29 municipalities that are either totally or partially included within the basin area.

The study of the basin covered six economic sectors: the agricultural sector, including 48 large products within the basin; the livestock sector, including cattle, horses, pigs and poultry; the energy sector, with an analysis of the five reservoirs within the basin responsible for 16% of the country's power; the industrial sector, with the 56 most important subsectors and Colombia's three most heavily industrialized municipalities; the domestic sector, including the population of the country's second largest city; and the mining sector, sine the lower regions of this basin is the site of extensive mining activity, both formal and informal. The analyses yielded the following results:



During the final stage, a gradual, collective process of construction of the actions necessary to solve the problems identified in the Porce River basin through the water footprint

Box 4

The three water footprints obtained during the quantification process (sectoral and multi-sectoral analyses) were compared to the characteristics of the land associated with the significance of each footprint in different current, possible and ideal scenarios. According to the Water Basin Development and Management Plans and the environmental conservation and protection goals established for rivers and streams by the Environmental Authorities for the basin. Through these means, more than 100 important geographical and temporal points were identified and can now be used to inform an effective, concrete decision with regards to space and time.

Workshop for formulated response strategies and policy guidelines

evaluation. Various public, academic, economic, communal and non-governmental organizations contributed their knowledge and experience to the process, producing policy guidelines and defining top-priority projects to be implemented in the basin and reduce its water footprint.

One of the project's main achievements grew was the multi-disciplinary and inter-institutional approach that involved the participation of public and private entities and the leading social stakeholders within the area of the river basin. These stakeholders included environmental and land authorities with jurisdiction over the basin, businesses and cooperatives that provide public services, universities, non-government organizations, private citizens and communities who voluntarily joined forces and collectively worked to construct and develop a project to obtain a shared result and a multi-sectoral perspective on water use (alteration of availability in terms of quantity and quality).

The water footprint evaluation project for the Porce River basin is presented as a tool for informing the decision-making process for integrated water management. According to the authors of this study, it also contributes to the state of the art of water footprint evaluation. It was developed through a participatory work approach involving those who make decisions on the basin, both as regards operational development and the design and formulation of strategies to reduce the water footprint.

The water footprint has proved to be a robust tool for conveying comprehensible results to all the sectors and stakeholders present in the basin. The results and conclusions of the study (at the basin level) show that they are complementary to the results obtained through other applications of the water footprint evaluation (corporate, national and global applications). They are on the verge of becoming a tool to support other indicators designed for integral water resource management in both the local and national context.

One recommendation made during the development of the project and the ensuing

Box 4

discussions was to maintain the focus on the basin as a basic unit of analysis for the water footprint. It should be regarded as a basic study that complements and is complemented by other water footprint applications at the micro (business and production) and the macro (national and large-scale geographic) levels. Specifically with regard to corporate applications, emphasis was placed on the fact that businesses should reflect on and contextualize their water footprints and guide their responses, as proactive actors within the basin. They must maintain awareness of the space that creates an impact due to its water use, transferring the benefits of water use to communities and the land where they engage in their economic activity and including the stakeholders present in them, with whom they share resources, risks and the challenges of sustainability.

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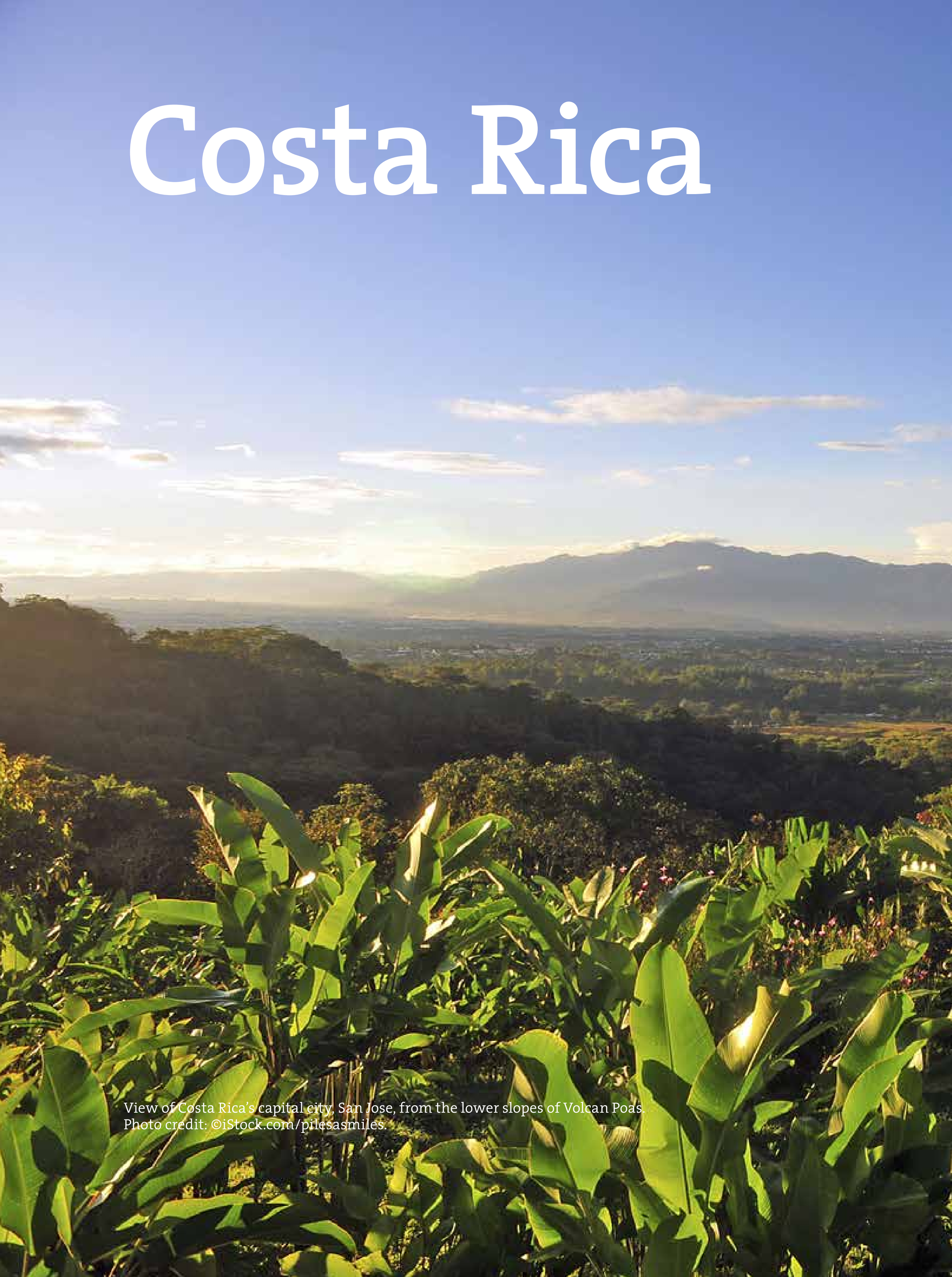
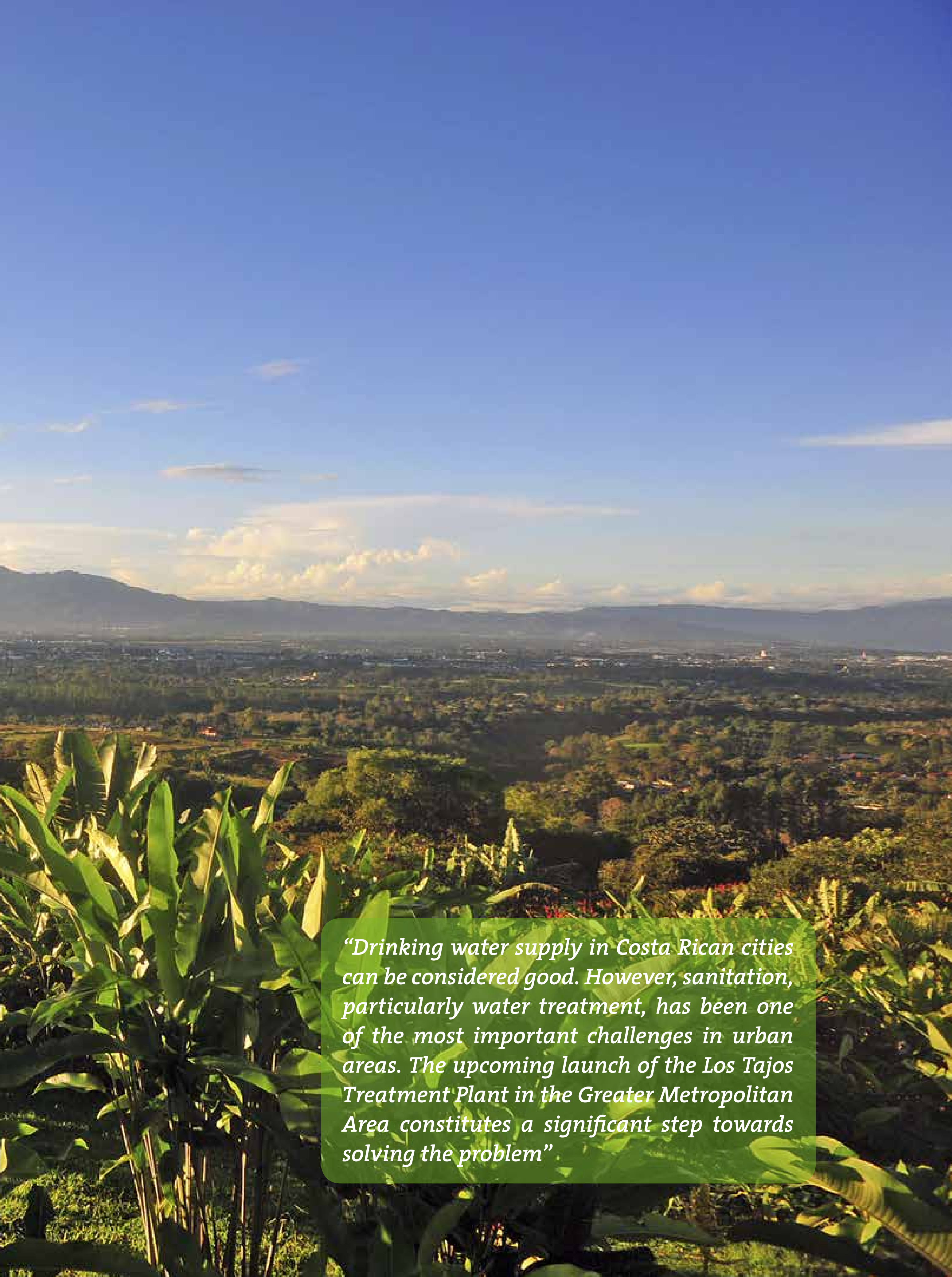


View of Costa Rica's capital city, San Jose, from the lower slopes of Volcan Poas.
Photo credit: ©iStock.com/pilesasmiles.



"Drinking water supply in Costa Rican cities can be considered good. However, sanitation, particularly water treatment, has been one of the most important challenges in urban areas. The upcoming launch of the Los Tajos Treatment Plant in the Greater Metropolitan Area constitutes a significant step towards solving the problem"

Urban Waters in Costa Rica

Hugo G. Hidalgo León, Carolina Herrero Madriz, Eric J. Alfaro Martínez, Ángel G. Muñoz, Natalie P. Mora Sandí, Darner A. Mora Alvarado and Víctor H. Chacón Salazar

Summary

This chapter provides a summary of the main issues related to urban water such as supply, sanitation, health, physical and human dimensions, floods and climate variability and change affecting cities. In general, it was found that except for some cities that have problems, water supply in Costa Rica is fairly good. However, sanitation (especially related to sewage treatment) is an issue that is only just beginning to be addressed. In 2000, sewerage coverage in urban areas was 96%, comprising 34% with sewerage facilities and 62% with septic tank availability. In 2009, the amount of urban water collected and treated remained below 4%. As for health, much of the explanation for the relatively positive indicators in this regard is linked to the integral social health system, although credit must also be given to the effect of the widespread availability of potable water in the majority of urban areas. In Costa Rica, progress has been extremely satisfactory, with 98% coverage of indoor piped water and 99% of improved drinking water sources being achieved in 2012.

Costa Rica is influenced by several large-scale natural climate phenomena such as El Niño-Southern Oscillation, Atlantic climatic variations, the influence of the Intertropical Convergence Zone and the Caribbean Low Level Jet. Likewise, in recent decades, Central America has experienced changes in hydrometeorological variables that suggest anthropogenic origins. Temperature trends towards hotter nights and days are fairly consistent, while precipitation trends (rain) have been less consistent and clear (in some locations there have been positive trends and, in others, negative ones). Moreover, in the capitals of Costa Rica (San José) and Honduras (Tegucigalpa), significant reductions in surface runoff have been found from the 1980s onwards, possibly associated with increased evapotranspiration

losses due to temperature increases. Projections with models point to a drier Central America at the end of the century, especially in the northern part (with runoff reductions of about 30%), and less so in the south (with 10% reductions in runoff). These changes become more significant when examined in light of the socioeconomic differences between northern and southern Central America, and when the vulnerabilities characteristics of countries in the region are considered, such as dependence on subsistence agriculture in some regions or society's vulnerability to extreme hydro-climatic events. Analysis and forecasting systems can help reduce these risks.

1. Introduction

Although Costa Rica has a fairly good potable water supply in general, Costa Rican cities have the problems typical of major Latin American cities, such as: a water supply deficit in specific regions, river pollution and floods. In Costa Rica, water is a relatively abundant resource, since it is a country with generally low water stress. These national figures mask the problem of water availability in some areas, however, especially in the western region of the Greater Metropolitan Area (GMA), which includes San José and the surrounding cities (Hidalgo, 2012). River pollution is a worrying aspect linked to urban sanitation, since rivers in the GMA have concentrations of pollutants several orders of magnitude above recommended levels. Many of these problems have persisted over time, and it has been difficult to make improvements in the system due to lack of funding and the costs that would be involved in its modernization. It is important, however, to highlight positive aspects, such as the low incidence of diseases caused by contaminated water and certain efforts being made, such as the construction of a treatment plant in the GMA.

This study will address some of these issues, as well as evaluating the potential effects of climate change on the future of cities. It also includes a section stating the need to comprehensively assess physical and social aspects in order to determine the vulnerability of populations to climate variability and change.

2. Water Sources in Urban Areas and the Impacts of Urbanization

Drinking Water Service in Urban Zones

The water service provided by the Costa Rican Institute of Aqueducts and Sewers (AyA), the government body responsible for water supply and sanitation, can generally be regarded as good. For example, the specific case of urban coverage, with values of approximately 99%, is an indicator that confirms this condition. Some of the positive health indices, in comparison with other countries in the region, may be partly attributed to the availability of drinking water. Aqueduct infrastructure and technology is generally good, particularly as regards capture and production systems.

Drinking water quality is monitored throughout the process by AyA through the National Water Laboratory (NWL), reaching significant levels of purification (AyA, 2002). Although the percentage of coverage of the water distribution network of drinking water is high, however, there is little confidence in the system in some areas (AyA, 2002). This is paradoxical given that, on average, Costa Rica has low water stress, but these supply problems exist at a local level (Hidalgo, 2012). For example, although in the Metropolitan Area of San José (the capital) water production was slightly lower than demand in 2002, this deficit has grown over time and mainly affects the upper parts of the city (AyA, 2002). These problems are accentuated in certain cities where production capacity is very close to or below demand, as a result of which they already have serious problems during the dry season. As part of the solution, the outlet valves of tanks have been closed overnight and their use rationed (AyA, 2002). This proves that the water supply is insufficient in some sectors, there are significant leaks or that there are insufficient reserve tanks.

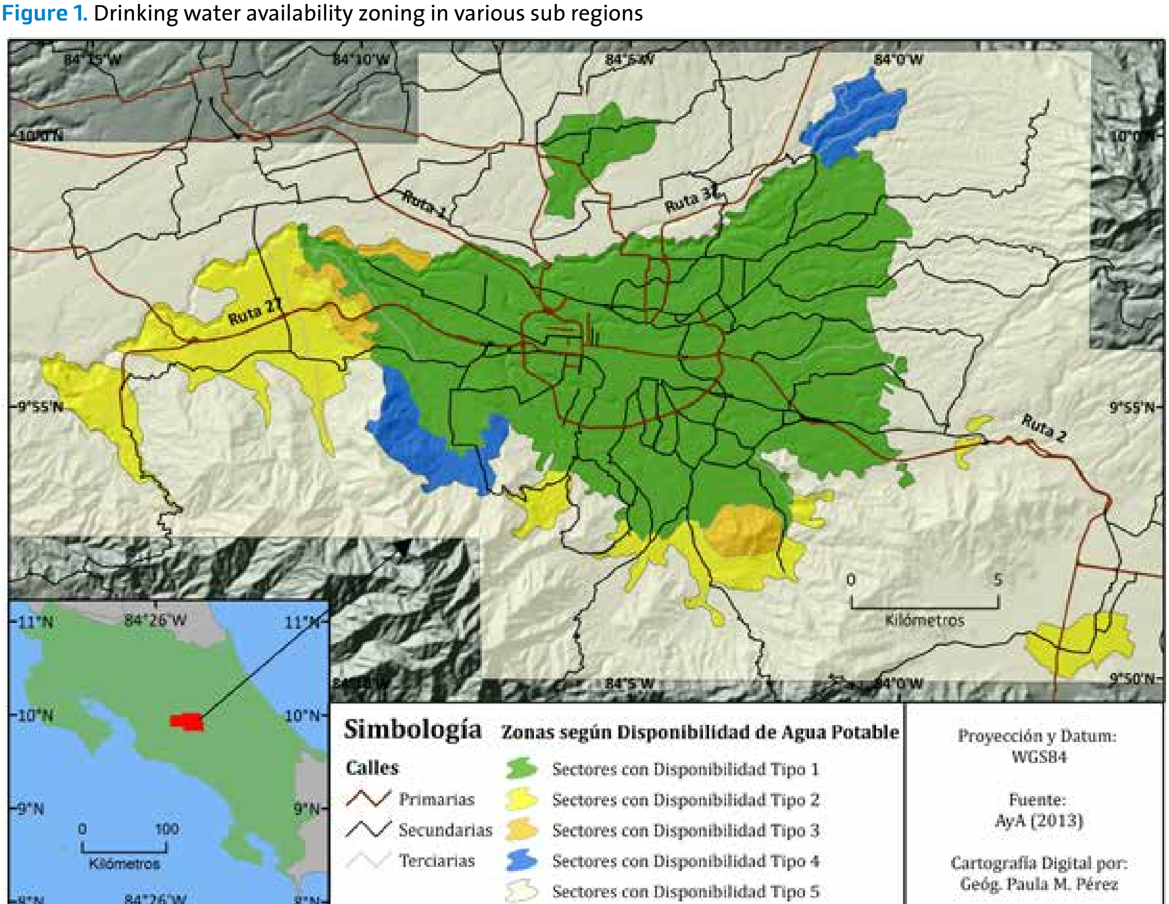
AyA (2002) mentions that one of the main shortcomings of the service is not the water supply per se, but the distribution system, as borne out by the high level of unaccounted for water, estimated at approximately 59% for the San José Metropolitan Aqueduct (and at 50% for the country as whole). Of this 59%, it is estimated that commercial losses are in the order of 29%, divided into cadastral deficiencies (unregistered connections) accounting for about 13%, lack of metering (unmetered connections) in the region of 7% and micrometering deficiencies (unrecorded consumption in meters) totaling approximately 7% (AyA, 2002). In short, the system's shortcomings are caused by several aspects such as deficiencies in the structure of the networks due to their type and age, visible leaks in the networks and connections, invisible leaks, network operation management, reserve tank overflow coupled with the lack of a register of users and networks, micrometering, and pressure control (AyA, 2002). As will be seen later, Costa Rica fares less well as regards sanitation than water supply; public sewerage coverage is relatively low, relying heavily on septic tanks, while wastewater treatment is virtually non-existent.

Table 1. Urban coverage of water and sanitation services, 2013

Area	Services	Population Served (Thousands of inhab.)	Coverage (%)
AyA Urban Area*	Aqueducts	950	99.00%**
	Sewerage	97	6.80%**
Urban Water Municipalities and ESPH	Aqueducts	N.D.	N.D.
	Sewerage	N.D.	N.D.

*AyA: Costa Rican Institute of Aqueducts and Sewers. Only the population with available water service is considered through a connection to public supply systems or aqueducts. Source: Jorge Aguilar Barboza, AyA (personal communication, 2014). ** Data from Peripheral Systems

Figure 1. Drinking water availability zoning in various sub regions



In Costa Rica, by 2000, water coverage at the urban level (an area served by the AyA and Heredia Public Service Company (ESPH) was approximately 98.5% (AyA, 2004), reaching 99.5% in 2009 (Arias, 2010). In 2000, sanitation coverage in urban areas was 96%, comprising 34% with sewerage facilities and 62% with septic tanks (AyA, 2004). The treatment rate for urban waters of under 4% (Arias, 2010) remained constant in 2009. In terms of the total population (urban plus rural), in Costa Rica, only 25% have sewerage, with 80% using septic tanks or latrines (Arias, 2010). Table 1 shows aqueduct and sewerage coverage for urban regions in 2013. As one can see, in Costa Rica, water supply coverage in urban areas is high, while sewerage coverage is low. Moreover, the problem of using septic tanks is more serious than one would think, since there are operating problems linked to soil type (such as low permeability), climate, the characteristics of the water to be treated and water volume (Arias, 2010).

The production system barely covers demand in some seasons and in some cases, fails to do so. However, attempts to secure major investments in infrastructure to increase the production capacity of aqueducts could be challenged by international lending agencies, unless losses are reduced to acceptable levels (AyA, 2002).

In order to plan the development of new buildings, the AyA has proposed zoning based on the availability of drinking water in several GMA subregions (Figure 1) (AyA, 2013). The various areas in Figure 1 are listed below (see also AyA, 2013):

- Availability Type 1: Supply Sectors of the Metropolitan Aqueduct without restrictions for new services, housing developments, residential condominiums, commercial condominiums, apartment buildings, shopping malls, schools, hotels and housing developments. Infrastructure installation or additional improvements by developers or stakeholders may be required.
- Availability Type 2: Supply Sectors for the Metropolitan Aqueduct, which, due to their location and topographic elevation, and the lack of sufficient infrastructure for drinking water production, storage and distribution, do not permit the development of housing developments, residential condominiums, commercial condominiums, apartment buildings, shopping centers, schools or hotels. They only permit the vegetative growth of individual new services allowed for single-family residential housing or new subdivisions with six or fewer lots, with public road frontage, and piped drinking water, supplied by AyA. For these cases, infrastructure installation or additional improvements by developers or stakeholders may be necessary.
- Availability Type 3: Sectors currently supplied with drinking water by the Metropolitan Aqueduct, which, due to the lack of sufficient infrastructure for drinking water production, storage and distribution, do not accept individual applications for new services or new housing developments, residential condominiums, commercial condominiums, apartment buildings, shopping centers, schools or hotels.
- Availability Type 4: Areas with water supply restrictions as stated in the AyA Board Agreement from 2005-1012, and subsequent modifications. Drinking water availability will only be provided for residential, single-family housing on existing plots of land or in new housing developments with existing public frontage, which also have piped water. Drinking water will not be supplied to housing developments without public road frontage, or condominiums, urban developments or apartment buildings.
- Availability Type 5: Areas outside the boundaries of the Metropolitan Aqueduct supply, where there are water supply systems administered by the Aqueduct and Sewerage Administrators' Associations (ASADAS), municipal aqueducts, other associations or EPSH. According to the latest data for 2013, there were a total of 163 ASADAS with an average flow rate of 769.6 liters per second

Service delivery in the GMA can be divided into two types of sources: springs and wells (Table 2). There are also 19 water treatment plants. Moreover, the urban area contains three water supply treatment plants in Tarbaca, San Gabriel Aserrí and Higuito de San Miguel de Desamparados, where private wastewater operating regulations have been established.

Table 2. Total annual production for 2013 for various water sources in the Greater Metropolitan Area

Production System	Production Source	Source Type	AyA Classification	Total Production (m³)
Planta Potabilizadora Tres Ríos	Tres Ríos	Surface	Plant	61,660,874
Planta Potabilizadora Tres Ríos	Pozo Mc. Gregor 2 (Registro)	Well	Well	642,159
Planta Potabilizadora Tres Ríos	Pozo Mc. Gregor 1 (Periféricos)	Well	Well	944,269
Planta Potabilizadora Tres Ríos	Pozo Vesco	Well	Well	246,154
Planta Potabilizadora Tres Ríos	Pozo Las Monjas	Well	Well	58,450
Planta Potabilizadora Guadalupe	Guadalupe	Surface	Plant	9,087,921
Planta Potabilizadora Los Sitios	Los Sitios	Surface	Plant	6,809,485
Planta Potabilizadora Los Sitios	Pozo La Florida	Well	Well	1,330,768
Planta Potabilizadora San Juan de Dios	San Juan de Dios Desamparados	Surface	Plant	1,936,634
Planta Potabilizadora San Juan de Dios	Pozo Veracruz	Well	Well	60,267
Planta Potabilizadora San Antonio de Escazú	San Antonio Escazú	Surface	Plant	2,551,857
Planta Potabilizadora Los Cuadros	Los Cuadros	Surface	Plant	2,229,067
Planta Potabilizadora Salitral	Salitral	Surface	Plant	1,829,319
Planta Potabilizadora San Rafael de Coronado	San Rafael Coronado	Surface	Plant	843,644
Planta Potabilizadora San Jerónimo de Moravia	San Jerónimo Moravia	Surface	Plant	652,653
Planta Potabilizadora Quitirrisí	Quitirrisí (1)	Surface	Plant	516,447
Planta Potabilizadora Alajuelita	Alajuelita	Surface	Plant	343,047
Planta Potabilizadora Mata de Plátano	Mata de Plátano	Surface	Plant	313,285
Planta Potabilizadora Guatuso Patarrá	Guatuso Patarrá	Surface	Plant	373,399
Planta Potabilizadora El Llano de Alajuelita	El Llano de Alajuelita	Surface	Plant	180,328
Planta El Tejar del Guarco	Acueducto El Tejar del Guarco			1,342,196
Bombeo Tejar del Guarco	Acueducto El Tejar del Guarco			1,025,620
Sistema de Puente Mulas	Puente Mulas	Well	Well	28,750,137
Sistema de Puente Mulas	Bombeo Intel	Well	Well	518,058
Sistema de Puente Mulas	Pozo La Rivera (Intel)	Well	Well	661,671
Sistema de Pozos La Valencia	La Valencia	Well	Well	27,868,898
Sistema de Pozos San Pablo	Pozo RIncón de Ricardo #1(Pequeño)	Well	Well	N.D.
Sistema de Pozos San Pablo	Pozo RIncón de Ricardo #2 (Grande)	Well	Well	1,749,699
Sistema de Pozos San Pablo	Pozo San Pablo # 1	Well	Well	785,482
Sistema de Pozos San Pablo	Pozo La Meseta	Well	Well	1,627,461
Sistema Potrerillos San Antono	Booster Matra	Well	Well	5,219,019
Sistema Potrerillos San Antono	Pozo Zoológico	Well	Well	178,558
Sistema Potrerillos San Antono	Pozo Brasil de Mora	Well	Well	102,259
Sistema Potrerillos San Antono	Potrerillos-Lindora	Well	Well	1,050,565
Manantiales la Libertad	Bombeo La Libertad	Well	Well	2,754,916
Manantiales de Padre Carazo	Manantiales Padre Carazo	Spring	Spring	2,009,196
Manantiales de Pizote	Manantiales Pizote	Spring	Spring	766,836
Manantiales de Vista de Mar	Manantiales Vista de Mar	Spring	Spring	211,446
Manantiales de Chiverrales	Chiverrales	Spring	Spring	1,321,920
Manantiales de Lajas	Lajas (Fuentes no medidas)	Spring	Spring	N.D.
Planta Barrio España	PP Barrio España	Surface	Surface	183,086
Captaciones Matinilla	Matinilla (Fuentes no medidas)	Surface	Surface	N.D.
Captaciones al Sur de Alajuelita	Sur Alajuelita (Fuentes no medidas)	Spring	Spring	N.D.
Captaciones Sur de Escazú	Pozo Bebedero	Well	Well	34,388
Captaciones Sur de Escazú	Sur de Escazú (Fuentes no medidas)	Various	Surface	0
Captaciones Ticufres	Fuentes Ticufres	Spring	Spring	31,476
Total				170,802,915
Systems whose production is not injected into the Metropolitan Aqueduct:				
Cartago (3)		Plants		10,074,490
Quitirrisí (2)		Plants		1,815,546

ND=Not available. (1) Ciudad Colón, (2) Puriscal-Central West Region, (3) Plant operated by the Metropolitan Region to supply Cartago and Paraíso.
Source: Jorge Aguilar Barboza, AyA (personal communication, 2014)

As can be seen from Table 2, installed capacity in springs is approximately 4.3 million m^3 per year, whereas in wells, it is in the order of 74.5 million m^3 per year, Heredia being one of the provinces with most groundwater contributions (AyA, 2013). In the GMA, groundwater therefore constitutes 68% of drinking water sources, with surface water accounting for 32% (AyA, 2002). The most important aquifers in the country are: Colima Superior, Colima Inferior, Barba, Liberia, Bagaces, Barranca, La Bomba (Limón), Zapandí and the coastal aquifers: Jacó, Playas del Coco, Brasilito and Flamingo. With regard to surface water, Hidalgo (2012) provides a table showing the characteristics of the main rivers.

Water Treatment in Cities

The cities with sewerage networks are San José, Liberia, Nicoya, Santa Cruz, Cañas, San Isidro de El General, Puntarenas, Limón, Heredia, Cartago and Alajuela, which together account for 33.8% coverage in the urban area. The only ones providing treatment through stabilization are the cities of Liberia, Nicoya, Santa Cruz, Cañas and San Isidro de El General, while a portion of the water collected in Puntarenas is treated at an activated sludge plant. It is estimated that only 4% of the wastewater generated by the urban population with sewerage (AyA, 2002; Arias, 2010) is treated.

If the country wishes to redress the imbalance in water and sewerage coverage, it must be prepared to make major investments in the urban area (AyA, 2002). It was estimated that the amount of investment required in 2002 to build a treatment plant for the GMA was approximately $289 million USD and at some point it was thought that the project could be implemented through a concession (AyA, 2002). In 2014, costs were revised and is now estimated that the final figure would be $344 million USD (*La Nación*, 2014). On September 12, 2012, a contract was signed with the Spanish company Acciona Agua, responsible for developing the Los Tajos treatment plant in La Uruca, which will receive wastewater from 11 cantons in the GMA, serving 1,070,000 inhabitants. The contract with the Spanish company stipulates that a master plan will be designed for the first, intermediate and second stages of the plant but only the first one will be built. AyA is seeking funding sources for secondary treatment. The plant is currently under construction (in February 2014, the plant was 10.65% complete) and is scheduled to begin operating in May 2015 (*La Nación*, 2014). Half of the cost will be covered by the Japan International Cooperation Agency (JICA). The Los Tajos Wastewater Treatment Plant is a component of the Project for the Environmental Improvement of the Metropolitan Area of San José, which incorporated the construction of a sewerage facility that will collect the water to be treated (EF, 2012). Over the next 14 years, other plants are to be built in the provinces of Heredia and Cartago (*La Nación*, 2014).

At present, 96% of urban wastewater collected by sewerage facilities is discharged untreated into rivers. Two of the country's major basins, those of the Grande de Tárcoles and Reventazón rivers, inhabited by approximately 70% of the population, receive raw sewage from the cities of San José, Heredia, Alajuela and Cartago (AyA, 2002). Hidalgo (2012) shows some of the average concentrations of certain water quality indicators in two of the most polluted rivers in the Greater Metropolitan Area (GMA) (San José and the surrounding cities) such as the Tárcoles River and Virilla River (a tributary of the Río Grande de Tarcoles). This situation shows how concentrations of pollutants far exceed recommended concentrations.

The degradation of the country's environment and water bodies, particularly in the GMA, over the past three decades, has become increasingly costly in human and economic terms. In fact, it has been estimated that the annual cost of pollution in terms of lost productivity and the treatment of associated diseases totals approximately $325 million USD, divided into $122 million USD in the areas of cities connected to the sewerage system and $203 million USD in areas with septic tanks (Moreno Díaz, 2009). Table 3 shows the characteristics of the AyA and ESPH (the company responsible for the water supply and sewerage in the province of Heredia) sewerage systems.

3. Water and Health in Cities

Overall health rates for the country reflect good progress in the global context. Life expectancy at birth rose from 76.7 in 1990 to 80.0 in 2012 (World Bank, 2014). During the same period, the infant mortality rate (death in the first year of life) fell from 15.3 to 8.5 (INEC, 2013). These rates were achieved through the country's effective health policies, where the integral social security health system has played a major role, while drinking water (or in many cases clean water) coverage has undeniably had a major impact. The 2012 infant mortality rate of 8.5 per thousand live births is low in comparison with other countries in the region, since the percentage of infant deaths from infectious diseases, particularly intestinal and acute respiratory infections, is relatively low (INEC, 2013). For example, the percentage of causes of death in infants due to infectious and parasitic diseases is 1.6% and to respiratory infections is 4.3% (INEC, 2013). In contrast, most infants' deaths occur in the perinatal period (48.4%) and as a result of congenital malformations (37.2%) (INEC, 2013). The situation is different with regard to diarrhea, since rates have steadily increased from 1996 to 2000, meaning that there may well be a direct link with the problem of the lack of wastewater collection systems in urban areas and environmental sanitation in general, which jeopardizes the quality of water for human consumption (AyA, 2002). Health indicators are presumably influenced by the scant attention paid to the problem of wastewater in urban areas, where ditches, streams and rivers are used to discharge pollutants (AyA, 2002). However, digestive system diseases are rarely fatal in childhood. For example, in 2011, the percentage of deaths of children under five years due to these causes was 0.01 per thousand, compared with the mortality rate of 2.21 per thousand obtained by adding all kinds of causes of death for that age range (Ministry of Health, 2011).

Drinking water is public service par excellence in which preservation of the population's health is based on providing hygiene and adequate means of disposing of excreta and other solid waste (AyA,

Table 3. Sewerage infrastructure characteristics of AyA and Heredia Public Service Company

Region / System	Rates	No. of Services	Type of Treatment	Disposal Final
AyA Metropolitan Region				
San José	U	0	N	R
AyA Huetar Atlantic Region				
Limón	U	7811	EPA+Em	M
Brunca Region				
San Isidro de Pérez Zeledón	U	3153	LE	R
Boruca, Buenos Aires	U	112	PT	Q
Lomas, Buenos Aires	U	86	LE	Q
AyA Chorotega Region				
Liberia	U	3435	LE	R
Cañas	U	1691	LE	R
Santa Cruz	U	1367	LE	R
Nicoya	U	1461	LE	R
AyA Central Pacific Region				
Puntarenas	U	8127	PT	M
West Central Region				
Ciudad Hacienda los Reyes	U	184	PT	Q
Villa Verano	U	125	PT	R
Santa Cecilia de Puriscal	U	40	PT	Q
ESPH				
Heredia	U	0	N	R

Notes: Type of treatment: PT-Treatment Plant, LE-Stabilization Pond, N-None, Disposal point: S-Stream, R-River, M-Sea. The service number is up to 30/6/2001, except for Puntarenas, which is up to 31/8/2001; In Heredia, ESPH has two small extended aeration and activated sludge plants operating and which treat a small portion of the sewerage effluents with a regular yield.
Source: Internal Commercial System, Datmart Comercial, 2014

Table 4. Cases and rates of incidence (in parentheses) of diseases related to water and sewerage

Disease	1996	1997	1998	1999	2000
Cholera	36 (1.05)	1 (0.003)	0 (0.00)	0 (0.00)	0 (0.00)
Dengue	2294 (66.62)	14279 (406.74)	2628 (69.73)	2628 (68.15)	4908 (124.47)
Diarrhea	99967 (2903.22)	113772 (3240.78)	132995 (3528.75)	140092 (3632.91)	164629 (4175.01)
Streptococcal Disease	62463 (1814.03)	58292 (1660.44)	75124 (1993.26)	91099 (2362.91)	No hay dato
Viral encephalitis	14 (0.41)	22 (0.63)	37 (0.98)	28 (0.73)	17 (0.43)
Typhoid Fever	19 (0.55)	16 (0.46)	10 (0.27)	8 (0.21)	8 (0.20)
All forms of hepatitis	868 (25.21)	1191 (33.93)	1483 (39.35)	2132 (55.29)	1739 (44.10)
Meningococcal Infection	34 (0.99)	23 (0.66)	24 (0.64)	16 (0.41)	19 (0.48)
Leptospirosis	29 (0.84)	27 (0.77)	26 (0.69)	312 (8.10)	156 (3.96)
All forms of meningitis	470 (13.65)	446 (12.70)	458 (12.15)	615 (15.95)	514 (13.04)
Salmonellosis	28 (0.81)	37 (1.05)	15 (0.40)	34 (0.88)	89 (2.26)
Shigellosis	73 (2.12)	40 (1.14)	45 (1.19)	38 (0.99)	89 (2.26)

Source: AyA (2002) using data from the Statistical Unit of the Ministry of Health. Rates per 100,000 inhabitants

2002). The link between drinking-water and health has been proven, since without this service, society cannot develop healthily. Since colonial times, Costa Rica has been concerned with providing this service to all areas. This element is also essential to development, since there can be no development without drinking water (AyA, 2002).

Lack of potable water and sewerage infrastructure or the deterioration thereof, has undoubtedly led to the presence of communicable diseases in certain parts of the country, such as cholera, typhoid fever, salmonellosis, shighelosis, amebiasis, giardisis, other intestinal infections and viral hepatitis (AyA, 2002). Diseases related to water that have been detected in the country include the following: amoebic dysentery, bacillary dysentery, diarrhea (including the previous two), cholera, hepatitis A, typhoid and paratyphoid fever, polio, schistosomiasis, dengue and malaria. Table 4 shows the incidence rates of diseases related to water and sanitation (AyA, 2002).

In practice, monitoring is used to control supply systems, as intensive health surveillance programs are no longer implemented, even though the authorities are aware of the high vulnerability of sources, particularly surface ones. Nor are there any programs to ensure the sustainability of the quality of water used for human consumption, incorporating reforestation, land use, etc. (AyA, 2002). In fact, the lack of a land use plan has been mentioned as one of the most pressing problems in Costa Rica, especially for urban areas (Hidalgo, 2012).

The recent "WHO/UNICEF Report 2014: Progress in Drinking Water and Sanitation" provides data and conclusions on the progress of Goal 10 of the Millennium Development Goals (MDGs) to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015 compared to 1990.

The Joint Monitoring Programme (JMP) established the new concept of "Improved Drinking Water Sources" (IDWS), for the purpose of measuring progress in drinking water by implementing this initiative. An improved drinking water source is one which, due to its type of construction, adequately protects water from outside contamination, particularly fecal matter and includes access to water through piping located indoors or in the patio, a standpipe, borehole or spring 1 km from the house, or even rainwater collection. This concept does not take either water quality or service quality (quantity, continuity, quality, coverage and costs) into account.

Within the framework of this weak concept, "great progress" has been observed worldwide, such as the fact that IDWS coverage rose from 76% in 1990 to 89% in 2012. In this context, it is important to note that this progress has been concentrated in rural communities, with an increase of almost 20% between those years, since it rose from 62% to 82%; However, in urban areas, access to IDWS decreased because the piped water supply fell by 1% in comparison with the 81% reported in 1990 to 80%.

In general, 23 out of the 222 countries evaluated have seen a decline in access to piped water, among which some African and Asian countries. In the Americas, coverage in the United States dropped from 100% to 99% and in Dominican Republic from 95% to 74%. During the 22 years of the study, in most of these countries, the decrease in access to improved drinking water sources is due to economic decline and poverty, migration of the rural population to urban cities and the consumption of packaged water, to the detriment of supply systems. This means that many countries have achieved MDGs within the concept of IDWS, setting standpipes or using water from wells and springs, rather than building aqueducts as has happened in most Central American countries.

Costa Rica has achieved highly satisfactory progress, including 98% water coverage of indoor piping and 99% coverage of IDWS in 2012. However, it is necessary to address water service quality and the universalization of potable water in order for these services to reach the most marginalized villages in the country.

4. Climate Variability

Costa Rica's climate is influenced by natural factors, such as the following: El Niño-Southern Oscillation (ENSO), latitudinal movements of the Intertropical Convergence Zone, the Caribbean Low Level Jet, the Mid-Summer Drought, tropical storms and hurricanes, the influence of the Atlantic and cold fronts. Valle Central de San José, where large urban centers are located, has a climatology typical of the Pacific region, with a dry season from December to April and a rainy season from May to November, with a secondary minimum in July known as Mid-Summer Drought (Figure 2). Average monthly temperature changes very little throughout the year.

High precipitation extremes cause severe flooding and damage to infrastructure in urban areas. The problem is not only caused by possible positive trends in storm intensity (see section on climate change below), but is compounded by constructions near unstable slopes or river beds, lack of maintenance of storm sewers and channels, and rapidly increasing urbanization in some areas. Frequent flooding in much of the country, such as during 2010 (classified as a La Niña year), serve as a reminder that it is essential to make efforts in other areas such as road and sewer maintenance, river care and cleaning, the conservation and strengthening of the network of hydrometeorological observations, the establishment of design standards for slopes incorporating hydrometeorological criteria, the need to update and respect land use planning and investment in education and training at all levels. These actions to ensure the maintenance, planning and development of civil protection systems are less expensive in the long run than the cost of lost infrastructure and human lives after a disaster (Hidalgo, 2010).

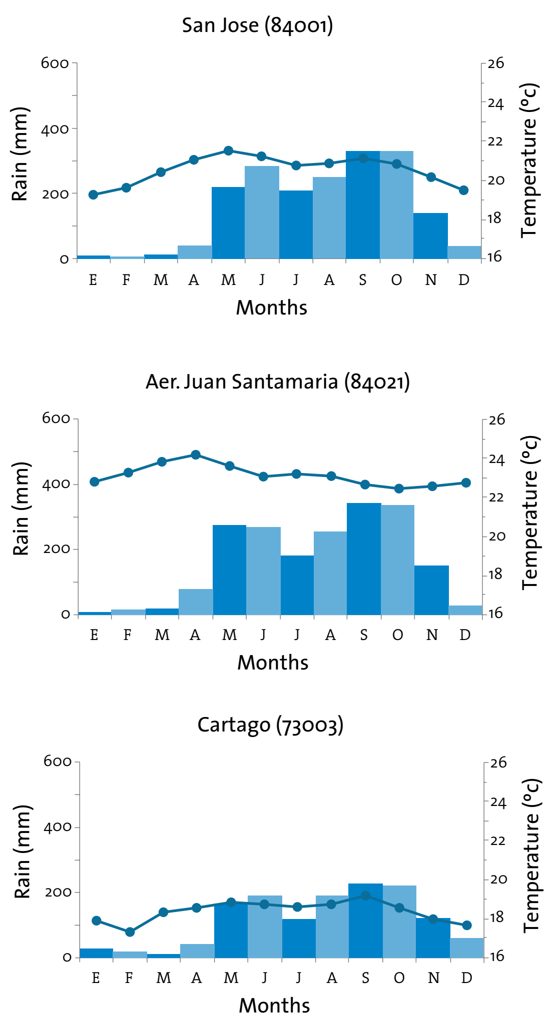
Urban Flooding, Some Case Studies

Urbanization triggered by population growth impacts on watersheds, causing: an increase in water discharge peaks and runoff and its frequency, increased verticality of channel walls, increased sediment in basins and the erosion and degradation of rivers when a basin is already well waterproofed.

This phenomenon has occurred in the basins of the cantons south of Heredia, which have been severely affected over the past 30 years. On 15 April, 2005 the Constitutional Court (the legal body responsible for issuing rulings linked to the interpretation of the Constitution) issued Resolution 2005-04050 in which the following public institutions were convicted of issuing building permits and the mismanagement of municipal water and storm sewers, within the watersheds of Quebrada Seca and the Burío River: the Ministry of Environment and Energy, Costa Rican Institute of Aqueducts and Sewers, Central Region of the Ministry of Health, Heredia Public Services Company, Municipality of San Rafael de Heredia, Municipality of San Antonio de Belen, Municipality of Heredia, Municipality of Barva, and Municipality of Flores.

The report concludes that environmental damage has been caused and obliges these institutions to prepare a joint interim report together with the actions taken to solve the above problems. The situations encountered in these streams include overflowing during intense periods of rain, direct discharge of sewage into these rivers and the disposal of garbage in their waters, resulting in unpleasant odors, a decline in fauna and flora, damage to housing and industries, and frequent evacuation of population centers. Quebrada Seca and the Bermúdez River comprise a major hydrological network in these cantons. They are basins that have historically provided one of the

Figure 2. Climatology of three seasons in three major cities in Valle Central in Costa Rica



Source: Online atlas of the Instituto Meteorológico Nacional (http:www.imn.ac.car/).

greatest hydrogeological potentials for the GMA and have been heavily exploited for water supply, not only for the region but also for other provinces throughout the country.

The problems identified have mainly been caused by the exponential, uncontrolled growth of the municipalities in question, without the implementation of any mitigation measures to avoid increasing runoff and its pollution at the time. Intensive urban growth has also increased the aquifer exploitation in the upper part of these basins, with a consequent decrease in the base flow of the channels. This has impacted the environment, since during the dry season, the flow significantly decreases, thereby preventing the wastewater (often without any form of treatment) discharged directly into rivers, from being diluted by the flow of the latter. The situation is not unique to the aforementioned cantons, since it occurs increasingly frequently at the national level. To date, however, no plan or project has been submitted to propose an effective solution to this problem.

Most of the country's municipalities with strong urban development have focused on asking builders to provide rain compensation lagoons for the various housing developments or works with significant areas, without there being any standardized methodology for the design and/or supervision of the construction of these lagoons. The vast majority of these lagoons are designed without considering a full hydrograph of the basin, with different return periods and parameters without any form of calibration.

Preliminary research undertaken on this subject showed that the Municipality of San Antonio de Belén and the National University are virtually the only two entities working on a solution to this problem. Nevertheless, the Municipality of San Antonio de Belén is attempting to solve to its particular problem rather than provide an integral solution.

Urban areas require that drainage systems achieve multiple objectives, such as the following: improved water quality, groundwater recharge, recreational facilities, the creation of a habitat for flora and fauna, and ponds or swamps, landscape protection, erosion control and sediment disposal and the design of open spaces. Therefore, whenever possible, it is always recommended that existing systems be used. Urban development in areas without adequate drainage provision multiplies public spending, since the problems caused must subsequently be solved using taxpayers' money. The southeast of San José also presents problems of urban flooding, particularly in the cantons of Desamparados Aserrí and Curridabat.

5. Climate Change

Observations of Climate Change in Records of Recent Decades

In Central America, the average annual temperature increased by approximately 1°C during the period from 1900 to 2010, with the number of hot days and nights growing by 2.5% and 1.7% per decade, while the number of cold nights and days has declined by 2.2% and 2.4% respectively (Corrales, 2010). Temperature extremes show an increase of between 0.2 and 0.3°C per decade (Corrales, 2010). These trends are consistent with the results of the temperature and precipitation extremes encountered by Alexander et al. (2006) in a set of approximately 600 stations across the world. According to this study's maps of Central America, reductions from 1951 to 2003 in the number of cold nights (below the 10th percentile, TN10) total approximately 3-6 days per decade. Hot nights (above the 90th percentile, TN90) have increased from 4 to 8 days per decade, cold days (TX10) have decreased by 0 to 3 days per decade, while hot days (TX90) have increased from 4 to 8 days per decade. Trends in extreme temperature events (TN10, TN90, TX10 and TX90) are consistent with the study by Aguilar et al. (2005) using stations in Central America and the Alianza, Clima y Desarrollo (2012). However, this same report indicates that trends observed in heat waves show a wide spatial variation (with increases in some areas and reductions in others).

Temperature and precipitation analysis reveals a variety of changes over the past 40 years in Central America and northern South America. While this is true for both variables, temperature changes have a greater degree of coherence. This is not surprising, since precipitation in the region varies more than temperature (Aguilar et al., 2005). In the Central American region, there are no significant trends in overall annual precipitation (Figure 9 in Aguilar et al., 2005). In general, trends in average rainfall rates and extremes show no sign coherence in Central America. In other words, some of the precipitation stations show positive trends and others negative ones, most of which are insignificant (Aguilar et al., 2005; Alianza, Clima y Desarrollo, 2012). However, at least one study (Neelin et al., 2006) found negative trends in the northern part of Central America using station (1950-2002) and satellite (1979-2003) data. Corrales (2010) and Aguilar et al. (2005) mention that although there is significant spatial variability, precipitation indices indicate that while there have not been significant increases in the amount of precipitation, there has been an intensification of the latter. This means that rainfall patterns have changed so that now it rains more intensely in a shorter time. Some regions have seen an increased proportion of very severe storms since 1970, which is much higher than that recorded in the simulation using current models for this period. The frequency of occurrence of extreme weather and climate phenomena is likely to increase in the future, together with the frequency and intensity of hurricanes in the Caribbean Basin (Corrales, 2010). This last statement should be viewed with caution, however, since, although some modeling studies have shown there is likely to be an increase in the number of intense hurricanes in the future (Kerr, 2010), there is evidence that historically, there have not been significant increases in the number of tropical cyclones and hurricanes (Alfaro, 2007; Alfaro et al., 2010;. Alfaro and Quesada, 2010).

Hidalgo et al. (2013) changed the scale for the precipitation and temperature data from the NCEP-NCAR Reanalysis (Kalnay et al., 1996), using it as input in a hydrological model for two sites in Central America: Tegucigalpa (Honduras) and San José (Costa Rica), and thereby obtain annual runoff estimates. The results show significant negative trends in annual runoff from 1980 to 2012. These "observed" trends are relatively stronger in the case of San José (south of the isthmus) than in Tegucigalpa (northern part of the isthmus). These trends are consistent with studies in other parts of the world, which have found that in the 1980s, there were particularly significant climate changes in hydrometeorological variables (Barnett et al., 2008 and Meehl et al., 2007). However, other reports on the trends in dryness observed are varied and inconsistent (Alianza, Clima y Desarrollo, 2012).

In the particular case of Costa Rica, the differences between the climate from 1961 to 1990 and from 1991 to 2005 in weather station data show some changes in the North Pacific (with trends towards a drier climate), the Central Pacific (with trends towards more humid climates) and the Southern Caribbean (with trends towards more humid climates) (MINAET, 2009). In particular, the North Pacific area has experienced a significant decrease in rainfall from May to September. Some of these changes may partly be due to natural climate changes, since, for example, phenomena such as the El Niño-Southern Oscillation (ENSO) have changed in recent years toward higher frequencies of warm events and fewer cold events. Although it is difficult to know whether these changes are a response to anthropogenic climate change, there are large-scale, low-frequency natural phenomena, such as the Pacific Decadal Oscillation (PDO; Mantua et al., 1997) that can modulate the frequency of ENSO.

Hydro-Climatic Projections for Central America and Costa Rica

Climate projections are generally based on General Circulation Models (GCMs) or Global Climate Models. These models are mathematical representations of the factors and processes that govern the Earth's climate, considering various forcings such as solar and volcanic influence and greenhouse gases. There are several series of runs of these models, the most recent being the Coupled Model Intercomparison Project 5 (CMIP5). However, because they are relatively new, CMIP5 model runs have yet to be evaluated in great detail as regards their ability to model large-scale climate factors affecting the climate in Central America. Moreover, there are very few published studies with projections of these models. For this reason, the most recent results mentioned here are based on CMIP3 runs. There are limitations in the CMIP3 models, but they usually approximately reproduce some weather patterns associated with the Central American climate (Pierce et al., 2008 and 2009; Delworth et al., 2012; Hirota et al., 2011; Liu et al., 2012; Rauscher et al., 2008; Martin and Schumacher, 2011; Jiang et al., 2012; Hidalgo and Alfaro, 2012).

For annual temperature, the average warming in the Central American region projected for the late 21st century is approximately 2.5 to 3.5°C depending on the location (Hidalgo and Alfaro, 2012), although projections for southern Central America can be as high as 4.5°C in some months. The GCM consensus on the CMIP3 is that Central America will experience a reduction in rainfall in the order of 10-20% and of runoff by 20-40% by the end of the century (see Figures 3.3 and 3.5 respectively from the IPCC report, 2007). End of the century projections in the models, using the A2/A1B emission scenarios, indicate that warmer days are likely to increase, while cold days are likely to decrease. Hot nights are likely to rise and cold nights to fall. There will probably be heat waves and longer, more frequent and/or more intense periods in most of the region. Heavy precipitation trends are inconsistent, and there will be an increase in dryness, with less confidence in the trend in the southern end of the region (Alianza, Clima y Desarrollo, 2012). Using a regional model, Karmalkar et al. (2011) found significant reductions in future rainfall in the dry season in Central America in the A2 emissions scenario. Neelin et al. (2006) found an agreement between the models, showing a dry pattern over the Central American and Caribbean region at the end of the century (2077-2099). Using 17 GCMs, Rausher et al. (2008) cite a decrease in precipitation in summer (JJA), an intensification of "Mid-Summer Drought" or "veranillo" and a shift towards the south of Inter-Tropical Convergence Zone (ITCZ) in the Tropical Eastern Pacific as responses to climate change in the region. Using a vegetation model (rather than a hydrological one), Imbach et al. (2012) studied changes in vegetation and runoff in Central America using 136 GCM runs. These authors concluded that runoff will decrease since higher temperatures encourage evapotranspiration. Hidalgo et al. (2013) confirmed the projections for the northern part of Central America in particular, reductions at the end of the century were found of approximately 30% in some months during the summer. Hidalgo et al. also (2013) confirmed a trend towards a more pronounced Mid-Summer Drought, previously mentioned in Rausher et al. (2008). There is a significant trend (especially in the northern part of Central America) toward greater prevalence of extreme drought (years when runoff is less than the 10th percentile from 1950 to 1999) at the end of the century, and although there is a high degree of variability between the models regarding the magnitude of the predominance of the percentage of dry areas, it is clear that there will be a significant increase in the future (Hidalgo et al., 2013).

MINAET (2012) and Alvarado et al. (2011 and 2012) state that Costa Rica in particular and Central America in general are the most prominent "hot spots" in the Tropics as regards the issue of climate change due to the decrease in rainfall in JJA, consistent with results found in other previously mentioned studies (see, for example, Hidalgo et al., 2013 and Imbach et al., 2012) as well as historical records and the results of 20 global models using different emission scenarios (Neelin et al., 2006; Trenberth et al., 2007).

Although the results of many studies imply a general decrease in precipitation and runoff in Costa Rica, according to MINAET (2012), the climate in Costa Rica is not expected to respond uniformly but rather to be subjected to wet and dry extremes. Thus, projections for a high emissions scenario indicate that for the period from 2011 to 2040 in the Caribbean, increases in precipitation are estimated in the order of 35-75% for the period from May to July due to the reduced activity of cold fronts during winter. On the Pacific slope and the Northern Zone, the model estimates less precipitation than at present, and an intensified Mid-Summer Drought, which is consistent with Hidalgo et al. (2013) and Rauscher et al. (2008).

Table 8.2 of the "Second National Communication to the United Nations Framework Convention on Climate Change" (MINAET, 2009) contains a list of references related to climate change studies in Costa Rica, while Table 1.3 of this document lists recent evidence of climate change in Costa Rica. In this study, expected changes in precipitation at the end of the century (2071-2100) relative to the baseline scenario (1961-1990), obtained through the PRECIS model forced with the HadAM3P model in the A2 low emissions scenario, are negative on the Pacific coast with reductions of up to -56% in the Nicoya Peninsula, and positive on the Caribbean slope, with increases of up to 49% on the north coast of Limón city. The maximum temperature will increase from 2.4 to 7.9°C depending on location, while the minimum temperature will rise by 1.4 to 3.8°C depending on location. Similar conclusions are reached in Alvarado et al. (2012) with respect to precipitation, although the authors show regions of the South Caribbean where temperatures will fall.

Seasonal Climate Forecast in Central America for Urban Areas, Including Physical and Human Dimensions

Recent analyses in Central America show that trends associated with the annual number of impacts and disasters related to hydrometeorological events cannot solely be explained by climate trends. This means that other variables, such as those associated with socioeconomic aspects, should be included in this type of analysis to explain these variations and their associated impacts (e.g. Alfaro et al., 2010).

For example, an analysis for Central America of the annual precipitation signal indicates that 84% of the total variability is associated with interannual variations, whereas 14% is related to decadal variations (Figure 3). Assuming that climate change models are correct (which they may not be) and that scenarios with increased susceptibility to drought can therefore be expected, they may also increase or decrease in the region by decadal (10-30 years) or interannual (a few years) episodes, associated with the natural variability of the climate system (Becker et al., 2014 and Greene et al., 2011).

Moreover, Hidalgo and Alfaro (2012) found that the current north-south socioeconomic contrast between countries, in which those in the south -Panama and Costa Rica- have better living conditions than the rest of the region, will not decrease over time and may instead increase, according to some climate and future social scenarios developed by the Economic Commission for Latin America (ECLA). Moreover, Panama and Costa Rica are the only countries with better living conditions at the end of the century to take into account, for example, the positive effect on increasing GDP.

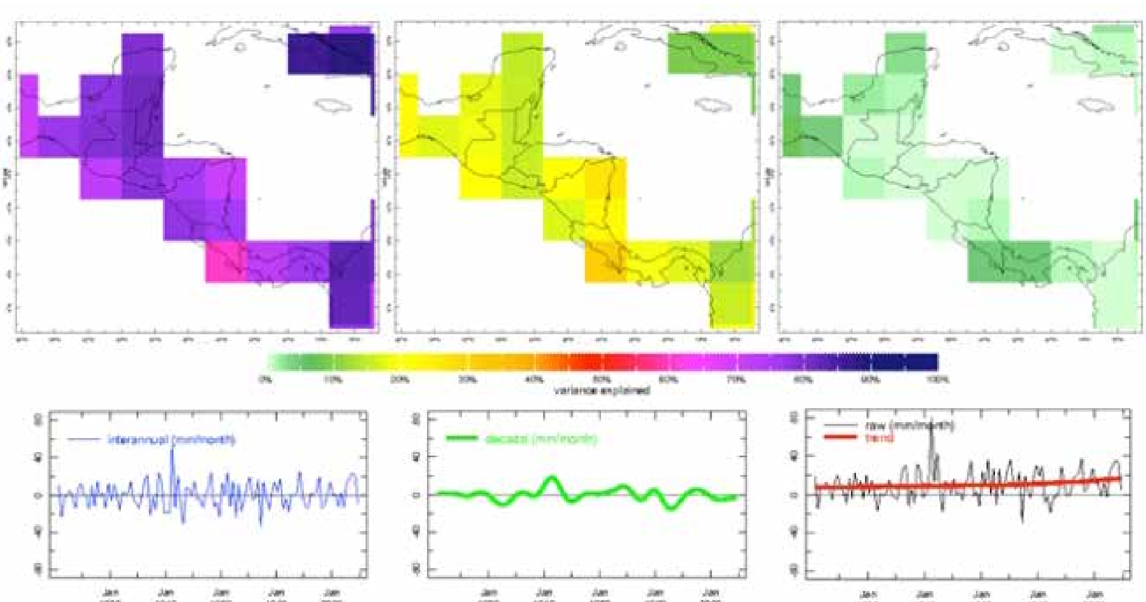
Consequently, north-south differences in living standards will probably increase in the region, meaning that attention should be paid to both the physical and socioeconomic effects which could play an important role in increasing these differences (Hidalgo and Alfaro, 2012).

Given the scenario mentioned above, seasonal climate prediction for urban areas would play a crucial role, especially in the fields of watershed planning and integrated management. These predictions should not only cover matters related to the measures of a central tendency of a particular variable, but also aspects of their variability and extreme events. An important factor to consider when studying extreme events in urban areas is land use (such as territorial planning associated with urbanization), including the maintenance of hydraulic structures in relation to the influence of climatic aspects and their impacts such as flooding and/or landslides. All these aspects should be considered when designing a system of individual forecasting for cities.

Since 1997, various parts of Latin America have organized Regional Climate Outlook Forums (RCOFs), in an effort to produce climate prediction products (IRI, 2001). They have been funded by several international agencies with the assistance of various entities such as the Regional Committee for Water Resources (CRRH) in Central America (Donoso and Ramírez, 2001; García-Solera and Ramírez, 2012) as one of the committees affiliated to the Central American Integration System, SICA, which also participates in other regional initiatives such as the Latin American Observatory of Extraordinary Events, OLE[2] (Muñoz et al., 2010; Muñoz et al., 2012).

Alfaro et al. (2003) add that these forums usually bring together representatives of meteorological and hydrological services and members of the scientific and academic community, who work with the development of local and regional climate perspectives. The purpose of these forums is to use national climate experience to develop a climate perspective with a regional consensus, usually on precipitation in the coming months, to present it

Figure 3. Total annual precipitation in Central American region



Time breakdown of annual rainfall in inter-annual scales (left), decadal (center) and long-term trend (right). The upper panels show the spatial distribution of the total explained variance by each scale in relation to the total variance, while the lower ones show the time series associated with the corresponding time scale for the entire spatial domain considered. The explained variances for each scale are 84%, 14% and 2% respectively. Spatial resolution is 0.5%, using CRUV 3.21. For details, see Greene et al. (2011).

Figure 4. Spatial distribution for SPI values in different seasons in Costa Rica for time scales of a) 6 b) 12 and c) 36 months.

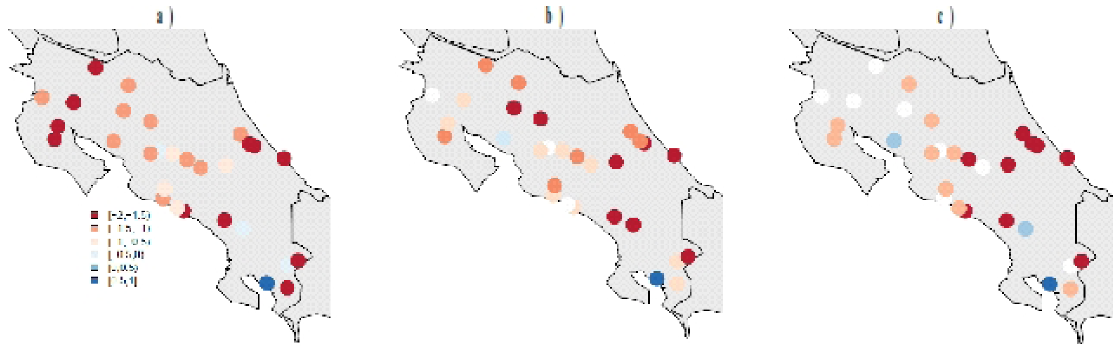
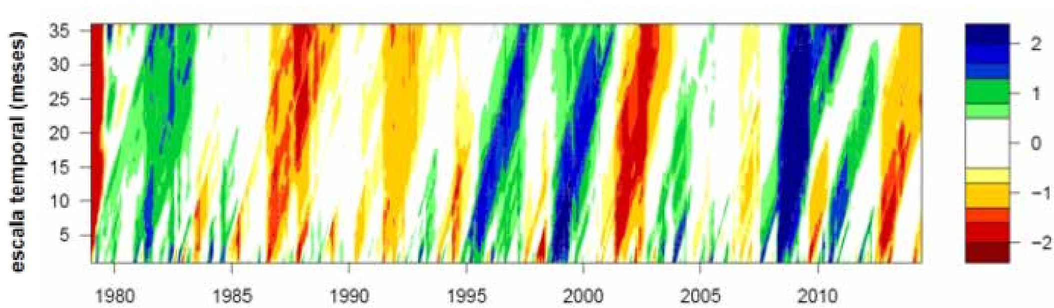


Figure 5. SPI values for the season located in CIGEFI.UCR (9° 56' 10'' N, 84° 2' 42'' W, 1236 masl, San José, Costa Rica)



in a useful way for the various agencies involved. The recommended methodology is simple and this perspective is then integrated regionally to help the various meteorological services with their activities, as well as the decision-makers and stakeholders involved.

Maldonado et al. (2013) reported that Climate Applications Forums were recently held, after the Central America RCOFs, to translate the potential impacts associated with climate predictions for users and to compensate for the fact that this information is not necessarily used by decision-makers. Feedback from these meetings raised the need for seasonal predictions on aspects related to extreme events and days with precipitation (in other words, how it rains in addition to how much it rains). These issues may be addressed using different variables, tools and scale tuning techniques (Maldonado and Alfaro, 2011; Amador and Alfaro, 2009; Alfaro et al., 1998). However, Alfaro and Pérez-Briceño (2014) and Maldonado et al. (2013) in an analysis of the seasonal geographical distribution of reports of disasters, found that it is not necessarily consistent with the geographical distribution of extreme precipitation events, reinforcing the ideas presented earlier that social variables such as population vulnerability, should be included in the analysis of the impacts of extreme events, highlighting the need to include aspects related to the seasonal prediction of extreme events and their variability in urban areas of Central America.

The use of a standardized precipitation index (SPI) has recently been suggested as a way to address the need for the monitoring or surveillance and forecasting of extreme events (WMO, 2012).

Figure 4 shows the SPI values for various weather stations in Costa Rica, by comparing periods of 6, 12 and 36 months working backwards from June 2014. Several of these weather stations are located in major urban areas such as San José, Alajuela, Cartago, Limón and Liberia. Note that in Figure 4, precipitation deficit conditions have prevailed for over six months and up to three years in some stations, such as the urban area of Limón and the

Box 5

The Environmental Service Payment Program (ESPP) in Costa Rica

by Mary Luz Moreno Díaz*

The ESPP process responded to the problem of deforestation that emerged in the mid-50s in Costa Rica. Deforestation in Costa Rica rose from 46,500 ha/year in 1950 to approximately 16,000 ha/year in 1997 (De Camino, Segura, Arias and Pérez, 2000). It began with a series of forestry incentives and evolved into the ESPP.

Costa Rica established the basis of an ESPP as a policy instrument to "strengthen the development of the natural resources sector" (Art. 46) through the Forestry Act No. 7575 (1996). Environmental services are defined in Article 3, section k of the Forest Act as "those provided by forests and forest plantations, which directly affect the protection and improvement of the environment. The following environmental services are recognized: mitigation of greenhouse gas emissions (fixation, reduction, sequestration, storage and absorption), protection of water for urban, rural or hydroelectric use, protection of biodiversity to conserve it and sustainable, scientific and pharmaceutical use, research and genetic improvement, protection of ecosystems, livelihoods and natural scenic beauty for tourism and scientific purposes (Act No.7575, 1996, Art.3, section k) .

ESP stakeholders can be classified into two categories: public and private. Actors in the public sphere representing various state and non-state organizations that have direct influence on ESP (National System of Conservation Areas-SINAC, National Forestry Financing Fund-FONAFIFO, among others).

Stakeholders in the non-public area include mostly private organizations such as non-governmental organizations (NGOs), County Agricultural Centers (CAC), associations and private companies, which perform activities directed towards the development and benefit of the owners of the forest resource receiving ESP. They also comprise the owners of forest resources, which in turn include private owners and indigenous territories.

The main sources of financing for ESPP have come from the 3.5% tax on fuel, loans from International Bank for Reconstruction and Development (IBRD), financial support from the German KfW Bank, the water use canon and contributions from companies and organizations. In total, the ESPP paid $27.2 million USD in its various modalities during the period from 1997 to 2012.

Since its inception in 1997 and until 2012, the ESPP contracted 934.274.60 hectares nationwide in the categories of: forest protection (89.7%), reforestation (6.1%), forest management (3.1%), natural regeneration (1%) and established plantations (0.1%). The last three modalities have been intermittently used during this period. In 2003, the Agroforestry System was established, whereby owners were compensated according to the number of trees recognized; the total number of trees recognized by 2012 being 4,677.135 (Fonafifo, 2014).

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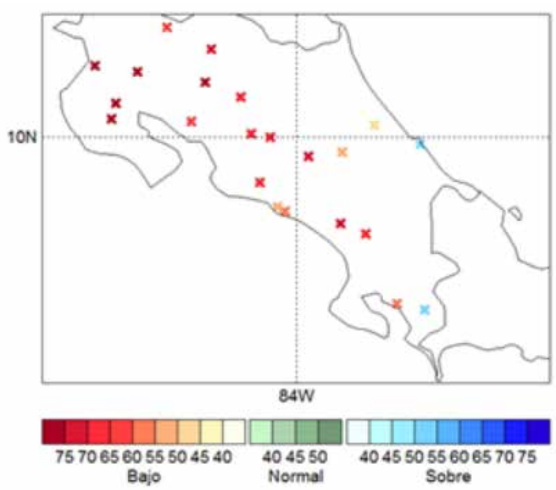
* Research fellow. International Center for Economic Policy for Sustainable Development (CINPE) Universidad Nacional, Costa Rica (mmoreno@una.cr).

capital, San José. The cumulative effect of droughts, such as the one mentioned here, generally entails significant adverse impacts on decision makers in various sectors. However, the advantage of this type of event is that since they occur more slowly than other climate events, their occurrence, spatial distribution and intensity can often be predicted sufficiently ahead of time.

Figure 5 shows the particular case of the station located at the Center for Geophysical Research of the University of Costa Rica in San José. Note that this index can be used not only for monitoring rainfall deficit conditions (2002-2003, etc.), but also for situations in which periods may be considered humid or very humid. This is the case for the period from 2007 to 2010, for example. This figure can also be used to analyze the cumulative effect of drought on different time scales (vertical axis), giving an idea of their severity and type: prolonged periods in red indicate long durations, while red tones extending over multiple time scales (vertical axis) indicate droughts that have evolved from droughts (lasting a few months), to agricultural or hydrological droughts (several months).

Another advantage of this index is that it can be used in seasonal forecasting. Figure 6 shows the SPI forecast for the quarter from July to October 2014. One can infer from this figure that the most likely scenario is the persistence of precipitation deficit conditions over the next four months, especially on the Pacific Slope of Costa Rica. In conjunction with the fact that the deficit can be traced backwards in some regions, months or years, the above could affect key socioeconomic issues in urban areas, such as drinking water supply or hydroelectric power generation, since this aspect experiences a dry spell during the boreal winter (Alfaro, 2002).

Figure 6. SPI Probabilistic seasonal climate forecast for the July-August-September-October 2014 period



SPI probabilistic seasonal climate forecast for the July-August-September-October 2014 Period. Using a canonical correlation statistical model based on the CPT tool. (see http://iri.columbia.edu/our-expertise/climate/tools/cpt/). As a predictive field, the anomalies of the sea surface temperature for the month of June were used [60°N-10°S; 150°E-30°W] together with the persistence of the seasons in May and June. The period of the calibration was from 1979 to 2013, with a maximum of 15 modes.

Authors of sections of this chapter from Costa Rica

H.G. Hidalgo: Summary, Introduction, Conclusions, Recommendations and subchapter 1,2,3 and 4.
V.H. Chacón participation in Subchapter 2.
D.A. Mora participation in Subchapter 3
C.Herrero participation in Subchapter 4.
E.J. Alfaro, A.G. Muñoz and N.P. Mora: Subchapter 5

6. Conclusions

Drinking water coverage in Costa Rica's major cities is generally quite high. In certain cities, however, water is rationed in the dry season. Although over-exploitation of water resources in some regions is the main cause of the problem, water availability could be improved if the amount of losses in the supply system were reduced. Water losses are quite significant and limit the amount of credit that can be obtained to improve the system from financial institutions that demand the reduction of these losses as a pre-requisite. It has also been argued that there is a need to create land use plans to protect surface and groundwater sources.

The greatest challenge in terms of water supply and sanitation in the country, however, involves the low sewerage coverage, particularly the low percentage of water treated before being discharged into rivers. The construction of a new treatment plant in the GMA is a step in the right direction towards increasing this percentage. However, much remains to be done. Septic tanks are widely used in the country, albeit less so in urban areas. Their use has been criticized, since in many cases, they are not given proper maintenance, and sometimes these tanks have been constructed with drains into soils with low permeability. There is also a lack of studies measuring the contamination of aquifers used for water supply by this type of tank.

The lack of potable water and sewerage infrastructure or the deterioration thereof, has undoubtedly led to the presence of communicable diseases in certain parts of the country, such as cholera, typhoid fever, salmonellosis, shighelosis, amebiasis, giardisis, other intestinal infections and viral hepatitis (AyA, 2002). Diseases related to water that have been detected in the country include the following: amoebic dysentery, bacillary dysentery, diarrhoeal diseases (including the previous two), cholera, hepatitis A, paratyphoid fever and typhoid, polio, schistosomiasis, dengue and malaria. Variability and climate change as well as land use changes, such as urbanization, have resulted in severe flooding in the country's major cities. In fact, the Constitutional Court has ruled in relation to the need to seek a solution to some of the most serious problems of flooding in certain cities.

Recent studies have indicated that runoff reductions are expected in Costa Rica in the coming decades. It is worth noting, however, that these climatic reductions could paradoxically be accompanied by a trend toward larger, positive extreme events. This is because runoff reductions occur in monthly or annual time scales, whereas weather events are in the order of hours or days.

Urban flooding in Costa Rica is related to three origin factors: 1) inadequate capacity of stormwater works and rivers, 2) changes in land use (e.g. urbanization), and 3) climate change (e.g. increase in extreme events). It is essential to determine the relative contribution of these factors.

7. Recommendations

Greater awareness of the problem of sewage treatment is required and more resources must be invested in treatment plants in urban areas. Urban river pollution is perhaps the most serious problem related to urban water.

As for urban flooding, more studies are required to determine the solution to these problems. Each basin has specific characteristics, making it difficult to find a "one size fits all" solution. In some places, builders of new housing developments are being obliged to provide a system for rainwater disposal. This is usually done through infiltration lagoons. Unfortunately, there have been cases where the lagoons are abandoned once the building permits have been approved, meaning that better control is required through municipalities and ministries to ensure the correct functioning of these lagoons.

It is essential to incorporate aspects related to projected climate change into water planning. Due to the uncertainty of climate change, it is essential to have a planning mechanism that includes adaptive water management, in which long-term climate projections will guide shorter term planning and after a number of years, short-term climate projections and planning must be reviewed in order to move forward.

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9. Acronyms

ASADAS: Aqueduct and Sewerage Administrators' Associations
AyA: Costa Rican Institute of Aqueducts and Sewers.
ECLA: Economic Commission for Latin America
CMIP3: Coupled Model Intercomparison Project 3.
CMIP5: Coupled Model Intercomparison Project 5.
GMA: Greater Metropolitan Area.
EF: El Financiero (Newspaper).
ENSO: El Niño-Southern Oscillation.
ESPH: Heredia Public Service Company
IDWS Improved drinking water sources.
INEC: National Institute of Statistics and Censuses.
IPCC: Intergovernmental Climate Change Panel.
IRI: International Research Institute for Climate and Society.
JICA: Japan International Cooperation Agency.
LNA: National Water Laboratory.
GCM: General Circulation (climate) Models
MINAET: Costa Rican Ministry of Environment, Energy and Seas
NCEP-NCAR Reanalysis: Meteorological database of the US National Center for Environmental Prediction/ National Center for Atmospheric Research.
PDO: Pacific Decadal Oscillation
OLE: Latin American Observatory of Extraordinary Events.
WMO: World Meteorological Organization
WHO: World Health Organization.
PCM: Joint Monitoring Programme.
RCOF Regional Climate Outlook Fora.
SPI: Standardized precipitation index.
TN10: Number of cold nights (below the 10th percentile).
TN90: Number of warm nights (above the 90th percentile).
TX10: Number of cold days.
TX90: Number of hot days.
UNICEF: United Nations International Children's Emergency Fund.
ITCZ: Intertropical Convergence Zone.

Contributors

Roberto Villalobos Herrera
Student, Escuela de Ingeniería Civil, Universidad de Costa Rica
rvillaloboscr88@gmail.com

Jorge Aguilar Barboza
Unidad de Gestión de Información, Instituto Costarricense de Acueductos y Alcantarillados
jaguilar@aya.go.cr

Javier Valverde Hernández
Systems Management Subsystem, GMA, Instituto Costarricense de Acueductos y Alcantarillados
jvalverde@aya.go.cr

Marcos Quesada Sanabria
Systems Management Subsystem, GMA, Instituto Costarricense de Acueductos y Alcantarillados
maquesada@aya.go.cr

Ana L. Arias Zúñiga
Environmental Engineering, Instituto Tecnológico de Costa Rica
ana.lorena@itcr.ac.cr

Alejandra Rojas González
School of Agricultural Engineering, Universidad de Costa Rica
alejandra.rojasgonzales@ucr.ac.cr

Matías A. Chaves Herrera
School of Agricultural Engineering, Universidad de Costa Rica
alejandra.rojasgonzales@ucr.ac.cr

Cuba

Panoramic view over Havana. Down to the left it is possible to see the chamber of the groundwater grid, used to impede the entrance of objects and sands into the siphon through the tunnel which crosses the bay from one side to the other. Photo credit: ©iStock.com/FrankvandenBergh


“The principal threats to the inland water system and water quality in island territories in the Gulf of Mexico and the Caribbean are associated with the rise in sea level. In general, processes associated with climate change represent an important threat to life and livelihoods in communities in Cuba and all regions of the world”

Singularities of Island Aquifer Management in the Humid Tropics: the Urban Water Cycle in Havana, Cuba

Coordinator
Daniela de las Mercedes Arellano Acosta

Authors
L.F. Molerio-León
Ma. I. González González
E.O. Planos Gutiérrez

Summary

This chapter explores the geological environment giving rise to the terrestrial phase of water cycle development in the islands of the Gulf of Mexico and the Caribbean. We review the status of water resources in this geographical region, using Cuba, and specifically Cuba's capital, Havana, as our example, and include information on the status of waterborne illnesses in Cuba. Because of the usefulness of the subject, particularly for new generations of Cubans dedicated to water management and conservation, we present a history of Cuba's water distribution system and problems related to Havana's water supply and sanitation systems from their creation in 1516 to the present day; keeping in mind that the city center's sewer system, completed in 1915, has been in operation for almost one hundred years. As a final note, the authors summarize situations associated with principal threats to ground water regime and quality in insular territories of the Gulf of Mexico and the Caribbean.

1. Introduction

Problems inherent to the proper management of urban hydrology on islands and small islands in Wet Tropical zones are directly related to the physical-geographical environment, natural threats arising from geographical position, water supply infrastructure, rainwater and wastewater drainage, vulnerabilities brought about or increased by social and economic inequalities, as well as the cultural and socio-economic standards, distribution and composition of the population.

These determining factors are manifested in the following ways in the Gulf of Mexico and the Caribbean:

- The predominance of coastal cities.
- The growth of some large cities.
- Social vulnerability.
- Lack of water supply in and around cities.
- Deficiencies in the household water supply system; and the evacuation and disposal of rainwater and human waste.
- Population concentration, pressure from internal migration; and local and international tourism.
- Endemic threats from natural events such as hurricanes, earthquakes, volcanic activity, landslides, floods, drought, land subsidence, erosion, etc.
- Antiquated and poorly functioning potable water supply and drainage systems.
- Insufficient liquid and solid waste treatment.
- Deficiencies in land management and physical planning.
- Non-compliance with or absence of municipal or national ordinances regarding urban drainage system administration.

These issues increase in complexity as worldwide environmental problems alter the urban water cycle. High on the list of problems are threats stemming from climate change, particularly from the rise in sea level and collateral effects such as inland incursion of sea water, increased soil salinity, modifications to current coastlines, increased internal migration, among others.

We tackle these questions in general terms, in the context of the islands of the Gulf of Mexico and the Caribbean. This particular geologic setting determines how the land phase of the hydrologic cycle develops. Island cities in this area of the Wet Tropics possess not only important local populations, constantly growing due to internal migration; but an enormous floating population as well, linked to the service sector, and tourists which support this sector of the economy. We review the situation of water deterioration and sustained scarcity in this geographic region using Cuba and its capital, Havana, as an example. We discuss the principal consequences of negative effects of island city growth in terms of urban hydrology and the manner in which urban drainage is currently managed. In the case of Havana, founded half a millennium ago, the population reaches almost 2.5 million inhabitants concentrated in an area no greater than 730 km^2. Havana receives an influx of nearly 1 million tourists, primarily during the dry (low water) season, supported by aqueducts and sewer systems built in 1925, whose last major modification was carried out more than fifty years ago. This system now supplies services to prodigious consumers of water, such as hotels, restaurants, housing and room rentals, and urban agriculture. Continual efforts to supply the demands of a developing city, growing at the cost of importing water from sources at distances increasingly remote requires a change in paradigm in order to guarantee sustainability based on the best science currently available to us.

2. Physical environment and hydrology of small and very small islands

According to the United Nations Education, Science and Culture Organization (UNESCO), small islands are conventionally considered to be those with an area no greater than 2 thousand km^2, and a breadth of up to 10 km (Falkland, 1991). Depending on an island's geological and hydrological characteristics, and the way in which subterranean water flow is organized, small island classification can include land areas up to 10 thousand km^2.

Very small islands are considered to be those whose area is no greater than 100 km², with a breadth no greater than 3 km. In the Gulf of Mexico and Caribbean regions there are hundreds of islands within these limits comprising island states (Figure 1). These islands represent two geological extremes –carbonate and volcanic– each extreme having it's own particular topography which provides the conditions for structuring superficial and subterranean runoff on the islands.

Carbonate islands have experienced important cave and karst development processes which have controlled the development of diffuse flow, epigenetic and syngenetic karst systems, meaning subterranean waters form locally discontinuous flow systems with highly variable density, short run, small volume and scarce reserves. The aquifers' natural replenishment zones (recharge zones) are linked to small ridges and furrows. These are generally dolines caused by corrosion or collapse (in many cases, ancient blueholes) towards which rainwater circulates and recharges the mantle aquifer.

These depressions are sometimes filled with debri, earth or rubble as a consequence of poor land use practices and deficient solid waste management. The waters that reach these depressions suffer deterioration in quality and as a result, contaminated water infiltrates the aquifer. The inland intrusion of tidal water also affects water quality. For this reason, water and sludge disposal sites must be carefully evaluated to prevent negative impacts on a site's environmental quality. A monitoring system for water management and quality is indispensible for guaranteeing the sustainability of any development project.

Local cave development, dependent on varying sea levels during the last glacial periods, has established zones with varying foundation capacity which can result in differential settling. The scale of construction of projected civil works and the necessary earth excavation and removal requires detailed knowledge of the geotechnical properties of the construction materials and terrain in these sites. Of special importance is the often overlooked fact that these civil works projects and paving of land surfaces, etc., substantially reduce the aquifers' natural recharge capacity.

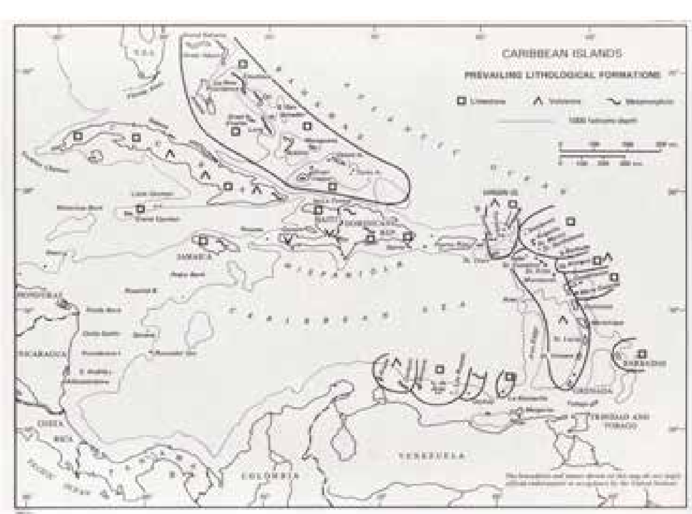
Some superficial water storage can be found in *maars* within volcanic cones on volcanic islands (such as the Grand Etang *maar* in Grenada), however the dominant mountainous topography presents serious limitations for the development of a subterranean aquifer system. In some cases one finds a well developed, short-run river network forming very narrow and elongated basins.

The rapidly concentrated flow, steep gradient and geographical substrate place substantial restrictions on the development of important coastal aquifers, although some subterranean water, basically interflow or hypodermic flow, and bank storage can be found in the lower third of these basins. In addition, the rapid response to torrential rains occasions the formation of flash floods carrying great quantities of sediments which are usually carried out to sea rather than being deposited along the flat sections of the basins.

Sustained erosion acceleration along riverbeds also affects fluvial terrace growth, subsequently reducing the possibility of increasing the quantity of available water; erosion hinders the development of cumulative terraces and causes constant loss of agricultural soil. This process can be mitigated only through engineering improvement methods that contribute to the recuperation of soil lost to erosion.

The prevailing aggressive erosion and meager river basin development are also limiting factors

Figure 1. Fundamental lithologies of the small islands of the Caribbean (taken from United Nations (1976): Ground Water in the Western Hemisphere. Natural Resources, Water Series No. 4. Dep- Econ. Soc. Affairs, New York, 337.)



for building retention structures for superficial runoff and artificial recharging of subterranean waters. In the case of the former, the accumulation of residue, debris and sediment within engineering work, such as dams, dikes and barriers, occurs with great rapidity, and in the case of the latter, there is practically no aquifer to recharge.

At the same time, strong fluctuations in river flow during the course of the year, including even shorter periods, results in substantial inland penetration of sea water, above all at high tide, increasing the salinity of inland waters. Prevailing wind velocity and direction is an additional cause of soil salinity and consequently, of inland waters through the penetration of aerosols. Measurements made by Molerio (1992) have shown aerosol penetration up to 50 kilometers inland. As none of the small islands reach that magnitude in breadth, the entire territory is covered by the aerosols.

The territory is exposed to tropical hurricanes as well as drought conditions. Thus, vulnerability to hurricanes is a topic to be considered in detail in the planning and building design phase of water supply and sanitation civil works projects; damage from winds and torrential rains must be minimized and mitigations measures made available to reduce response and repair costs to a minimum following these extreme events. Volcanic activity and earthquakes are also permanent threats profoundly complicating not only water resources management but the proper administration of the territories themselves. Small and very small island hydrology in the Gulf of Mexico and the Caribbean is tremendously complex, encompassing extremely fragile and vulnerable tropical ecosystems. Their inland water resources are always scant and difficult to manage for the following reasons:

a. Fresh water availability depends on the abundance and distribution of rain and on subterranean storage capacity – generally quite limited and dependent on island topography and geological makeup. In fact, rain distribution throughout the territory is highly variable. In Guadalupe, for example, the western slopes of its mountains receive between 2.5 thousand and 10 thousand mm annually, while in the rest of the country, average annual rainfall is around 1.4 thousand mm. Lower annual rainfall averages are recorded in the Bahamas (with minimum annual rainfall on the order of 600 mm) and in some areas of the interior of Hispaniola (Haiti and the Dominican Republic).
b. Superficial runoff tends to be weakly organized and generally present only on mountainous islands –the only islands exhibiting some possibility of artificial runoff regulation. However, on small volcanic islands the majority of rainfall escapes to the sea through superficial runoff.
c. Discharge of subterranean waters occurs through a precarious equilibrium with sea water; the intrusion of sea water directly affects the quantity and quality of subterranean freshwater resources. This is, without a doubt, the principal problem limiting the development and full use of subterranean water resources on the islands and coastal zones, and this problem will grow in coming years as a consequence of the rise in sea levels associated with climate change.
d. Due to the small size of the islands, problems associated with superficial and subterranean water contamination tend to be extremely serious and costly to repair. The proximity of subterranean waters to the surface, and consequently, the narrow width of the non-saturated zone make this zone an inefficient barrier against the flow of contaminants from the surface to the aquifers. At the same time, the existence of numerous housing settlements on the higher slopes of the valleys, and the release of virtually untreated wastewater into the ground and superficial waterways pose a continual threat of deteriorating superficial water quality.
e. The prevailing lithology is one of the major controlling factors over the distribution of superficial and subterranean water resources on small islands. Two basic lithologies are recognized in the formation of the islands' geological structure: one being essentially carbonate, in which karstic processes take place; and the other, volcanic, in which sand and gravel aquifers and fractured-rock aquifers are equally prevalent. In the Greater Antilles (Cuba, Hispaniola, Puerto Rico and Jamaica) both lithologies are present with karstic carbonate aquifers predominating.
f. The economies of these small islands –many of them island states– tend to be based on

Table 1. Variation in potential water resources in Caribbean countries (Planos 2000 & 2001)

Country	Potential Water Resources Prior to 1961-1990 (10^6 m^3)	Potential Water Resource 1961-1990 (10^6 m^3)
Cuba	38150	30067
Haití	11000	9603
Dominican Republic	22505	16559

Tabla 2. Potential Water Balance 1961-1990

Region	Area Km²	T °C	P mm	Eo mm	E mm	Q mm
Caribbean	4160000	26.8	1880	1633	1208	2797.3
Cuba	184000	24.9	1326	1540	989	62.0
Belize	22500	27.1	2368	1677	1337	23.2
Jamaica	45000	28.3	1868	1751	1252	27.7
Española	100000	24.8	1469	1534	1042	42.7
Lesser Antilles	360000	27.1	2368	1677	1337	371.0

T: temperature (°C); P: precipitation (mm); Eo: potential evaporation (mm); E: evaporation (mm), Q: volume of runoff (mm)
Source: Llanes et al., 2012.

services oriented primarily toward the tourism industry, an extremely high and increasingly demanding (but frequently poorly administrated) consumer of good quality water. Additionally, small islands suffer from other economic and demographic problems due to the scarcity of natural resources, such as the limited availability of cultivatable land, minerals and conventional sources of energy,[1] The isolation of many of the islands and their exposure to the most destructive natural events such as hurricanes, typhoons, earthquakes, volcanic eruptions and tsunamis contribute to difficulties in hydrologic resource management. High population density, which comes close to 800 inhabitants per sq. km. in New Providence, Bahamas, also conspires against the availability of good quality water as it continually increases demand and the ensuing danger of contamination.

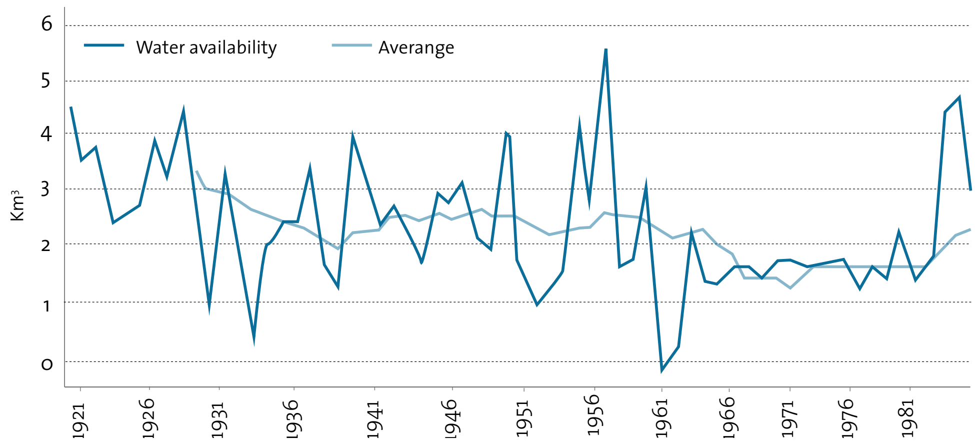
g. Extreme rainfall events associated with torrential rains and hurricanes constitute one of the elements of greatest risk for natural resources and society; droughts tend to exert disastrous effects on supply among the population in these regions, characterized by a persistent shortage of water.

The availability of water resources in the region has also been dwindling, corresponding to changes observed in the climate. Planos et al. (2000), and Planos and Rodriguez (2004) confirmed this in Cuba, the Dominican Republic and Haiti when comparing potential water resources evaluated for these countries prior to 1970 against the period 1961 to 1990 (Table 1). In the last few decades, identical behavior has been seen in runoff, reflecting a negative tendency, in the case of Cuba, Jamaica and the Dominican Republic.

Variability and observed changes in the Caribbean climate since the 1970's and the manner in which these changes are manifested through water availability was corroborated by Shiklomanov (1998). By analyzing the dynamic of water availability in Mesoamerica and the Caribbean between 1921 and 1985, Shiklomanov discovered a negative tendency in the time series beginning in the 1960's in which statistical homogeneity was broken around the year 1970 (Figure 2). In a report on the potential hydrologic balance, estimated by Llanes et al. (2012) for CEPAL, the investigators analyze annual precipitation during the period 1931-2000, which shows a tendency toward a decrease in precipitation in many areas of the Caribbean region (Table 2). Figure 3 shows the prevalence of the tendency toward decreasing annual precipitation in almost the entire area.

1. Cases such as Trinidad and Tobago, with abundant availability of petroleum and gas, are a notable exception.

Figura 2. Dynamic of water availability in Mesoamerican and the Caribbean



3. Water and Environmental Health

In the last two decades, access to potable water and basic sanitation increased in Latin America and the Caribbean, principally within urban zones. Access to basic sanitary conditions was also greater in urban zones. Between 2002 and 2010, the proportion of the urban population benefiting from adequate solid waste collection services surpassed the urban population growth. Nevertheless, these achievements were not spread uniformly across all countries or even within a given country. Progress was also made in terms of specific legislation including guidelines for water and sanitation policies supported by an evaluation of services provided in urban zones. Of note is the challenge in providing services to marginal neighborhoods with low quality housing, lack of access to basic services and wastewater treatment, as well as monitoring chemical contamination of the water supply. Discharge of untreated urban waste into basins and springs is an emerging topic in various countries (PAHO, 2013).

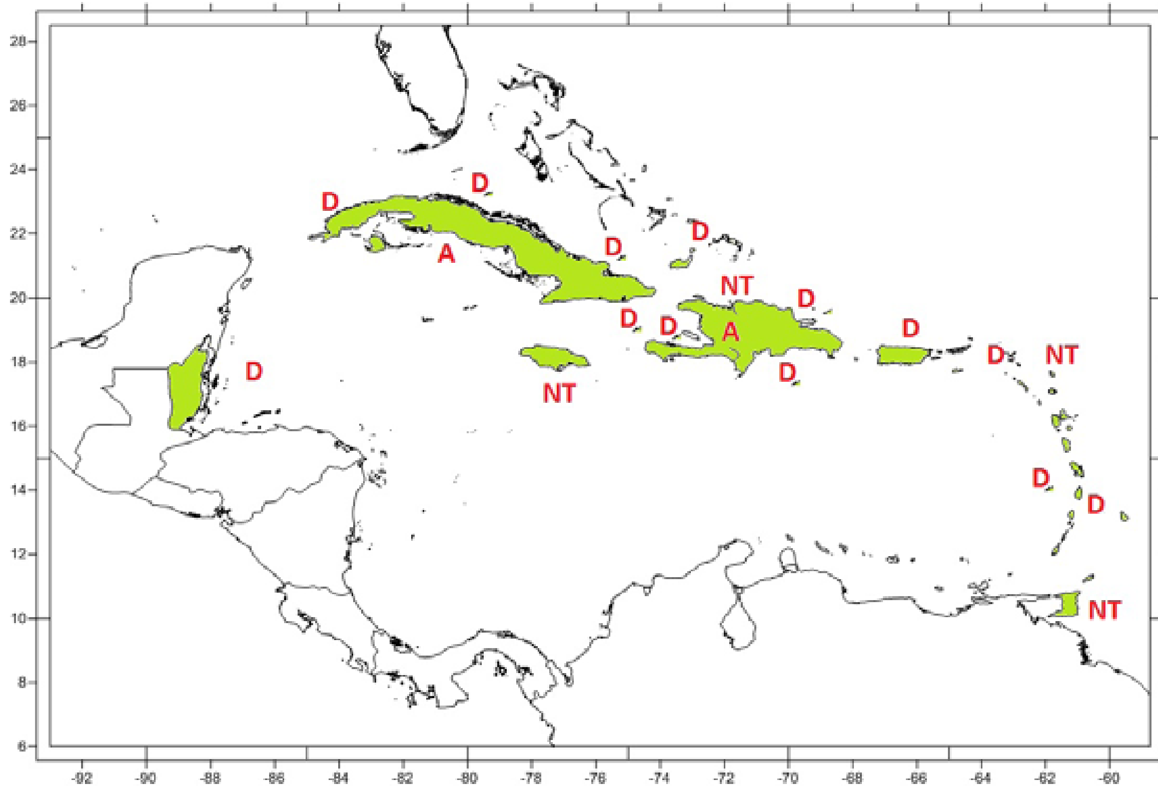
Half of the world's population now lives in cities; and within two decades, almost 60% of the world's population will live in urban centers. Urban growth is greater in developing countries where the cities gain an average of five million inhabitants each month. The urban growth explosion brings with it unprecedented challenges, the lack of water and sanitation services being the most urgent and damaging among them (PAHO, 2010).

Overexploitation of water resources is increasing. Thus, with the rapid pace of urbanization, cities are facing increasing demand for water and sanitation services. According the United Nations (2010), 77% of the Latin America's population is urban and urbanization rates continue to increase, affecting access to safe potable water and sanitation in some countries. At the same time, contamination of rivers and oceans is a critical problem affecting coastal cities where more than 60% of this region's population lives.

Classification of Water Related Illnesses

In terms of illnesses associated with water and sanitation, water related illnesses are seen as the most extensive. These illnesses are defined as any significant or widely distributed adverse effect on human health, such as incapacity, illness or suffering, directly or indirectly caused by the condition of, or changes in, the quantity and quality of water. Three essential components exist for classification purposes: pathogens and other agents involved in water related illness; type of water exposure; and the degree of probability that the illness is water related. Host factors, such as nutritional status,

Figura 3. Tendency of annual precipitation in the Caribbean region for the period 1931-2000



D: Decreasing; A: Increasing; NT, Tendency Not Significant (according to Llanes et al., 2012).

are important in terms of the details and priority required for surveillance systems in countries with high levels of malnutrition, immunodeficiency or significant mortality resulting from waterborne pathogens (Stanwell-Smith, 2009).

Status of Water Related Illnesses in Cuba. Health Statistics

Cubans enjoy a high life expectancy at birth (77.97 years); infectious disease incidence and mortality are low; and the infant mortality rate is very low (4.5/1,000 live births). Fifteen infectious diseases have been eliminated from Cuba and another eight appear so infrequently as to preclude public health problems (less than 0.1/100,000 inhabitants). All State and social sectors participate in environmental protection and improvement, including the health sector, through comprehensive programs that span water, protection and care of oceans, soils and woodlands, air and noise quality, liquid and solid waste (especially biological waste) and public health surveillance (PAHO, 2012).

The health status of the Cuban population improved between 2006 and 2010. Fundamental aspects of public health in Cuba include the accelerated rate of population aging; low levels of fertility and generation replacement; low infant and young child mortality rates with mortality trending more toward advanced age; and elevated life expectancy. Infectious diseases have been eliminated or controlled to the point where they no longer represent public health problems, although environmental conditions and risky lifestyles in terms of the introduction and spread of disease still persist. The vaccination program protects the population from respiratory infections, and acute diarrhea infections are the primary reasons for medical consultations (PAHO, 2012).

The Cuban population numbers 11,210,064, distributed throughout 15 provinces and 168 municipalities; the male to female ratio is 995 men to 1,000 women; the percentage of urbanization is 76.8%; and 18.3% of the population is 60 years old or older (Statistical Yearbook, 2013).

A total of 92,270 deaths were reported in 2013; 2,898 more than in 2012. The increase in mortality occurs primarily in those 65 years of age and older. The general (crude) mortality rate is 8.3/1000, an increase of 4.8% over 2012; the age-adjusted mortality rate remains at 4.5/1000. The greatest increase in mortality during the five year period between 2009 and 2013 occurred between 2009 and 2010 with 4,125 additional deaths; then, between 2010 and 2011, deaths decreased by 4,021; in 2012, deaths increased by 2,328 and by 2,898 in 2013. The increase in deaths in 2013 is 30% less than the maximum increase recorded during the five year period previously mentioned. Fluctuations such as these correspond to variations in mortality, and to the country's demographic profile of illness and death. According to classification into three large mortality groups, the mortality rate for non-infectious chronic diseases is the highest (680.7 deaths/100,000), followed by deaths from infectious diseases and maternal, perinatal and nutritional causes (72.0/100,000) and death from external causes (66.8/100,000). The mortality rates for these three groups have increased compared to 2012 (National Health Statistics and Medical Records Bureau, 2013).

The vaccination program protects against thirteen illnesses with almost 100% vaccination coverage for children less than one year old. Fourteen infectious diseases and another nine non-infectious diseases represent no health problems for the country because the incidence rate is less than 0.1/100,000 inhabitants. Acute diarrheal infections increased in the beginning and the end of the summer season. Cases of illness caused by *V. cholerae* biotype eltor serogroup O1, with Ogawa as the prevalent serotype, were reported and controlled. Coordinated actions were directed towards reducing *Aedes aegypti* infestations, resulting in a 17% reduction compared to 2012 (Statistical Yearbook 2013).

The 2013 Annual Report of the Pan American Health Organization/World Health Organization (PAHO/WHO) presents all alerts and epidemiology updates published throughout the year regarding public health events occurring in the Americas and other parts of the world which had or could have had international public health repercussions in the region. Referring to cholera outbreaks in the region, the report recommends that member States put into action their preparation and response plans, and strengthen their cholera surveillance systems. PAHO/WHO also exhorts countries to accelerate their work to improve water quality and sanitation (PAHO/WHO, 2013).

A study of water quality within the homes of Old Havana's urban population, and the possible relationship to waterborne diseases between November 2010 and December 2012 shows that water is untreated in 57.6% of homes; 34.6% boil their water; 6.2% filter it; and 1.2% use chlorine. Some 98.8% of this population relies on an erratic or intermittent water supply. The microbiological study finds that 51.8% of samples contained heat-tolerant coliform bacteria and 66% of homes had water with chlorine levels below the limit established by the potable water safety standard. Among those presenting with diarrhea in the last thirty days, 63.6% did not treat their potable water in any way. This reveals a statistically significant association between water treatment and the occurrence of diarrhea during the last thirty days (Concepcion et al., 2013).

Cholera in Cuba

The first cases of a cholera outbreak on the island of Cuba were reported in July 2012. The total number of confirmed cases of cholera during that year was around 500. Only three deaths occurred from cholera as reported in the Epidemiology Alert of July 31, 2012. After the passage of Hurricane Sandy through the country's eastern provinces in October 2012, isolated cases of cholera were reported in the provinces of Santiago de Cuba, Camagüey and Guantanamo. A total of 47 cases were confirmed in these three provinces. No additional cases were detected after December 15, 2012. Among the control methods applied by national authorities were reinforcement of environmental sanitation and hygiene methods; guarantees of potable water supplies; strict control over the populace's food and sanitation education with an emphasis on hand washing, safe food consumption and potable water ingestion (PAHO/WHO, 2013).

After having detected cholera in Manzanillo in 2012, with 417 cases and three deaths, Cuba's Health Ministry registered two other outbreaks:

the previously mentioned outbreak following Hurricane Sandy in October, 2012; and another at the beginning of 2013 in the province of Havana, with 51 confirmed cases. In 2013, the National Focal Point for International Health Regulations (CNE) reported that beginning on January 6 there had been an increase in the number of acute diarrheal infections in the municipality of Cerro and in other municipalities of Havana. Samples were taken from suspected cases of cholera, which were analyzed by the Pedro Kouri Tropical Medicine Institute. By January 14, 2013, a total of 51 cases of cholera had been confirmed, all characterized as *V. cholerae* biotype eltor serogroup O1 enterotoxigenic serotype Ogawa. The outbreak in Havana occurred as a result of improper food handling. As a result, Cuban authorities reinforced sanitary education among the populace with an emphasis on hand washing, safe food and potable water consumption. They simultaneously continued taking measures to guarantee the supply of potable water and strict food control. Active and strict clinical-epidemiological surveillance of acute diarrheal infection was also maintained and all detected cases were treated as possible cases of cholera.

The most recent Pan American Health Organization Alert Bulletin reported that in Cuba, between epidemiological week (EW) 35 of 2013 and EW 8 of 2014, suspicious cases were investigated, and 23 additional cases of cholera were confirmed. Including this data, the total number of confirmed cases of cholera in Cuba since the beginning of the outbreak in EW 27 of 2012 until EW 8 of 2014 came to 701, including three deaths. National authorities are maintaining the clinical-epidemiological surveillance system operational and are regularly investigating suspected cases of cholera. Hygiene measures have been intensified, especially those related to hand washing, water chlorination and cleaning, as well as proper food handling and cooking (PAHO/WHO, 2014).

Challenges related to water will increase significantly in the coming years. Continued population growth and an increase in income will bring with them an enormous increase in water consumption and the generation of waste. Urban populations in developing countries will grow at an alarming rate, generating an increase in demand beyond the capacity of services, the water supply and sanitation infrastructure, already insufficient. According to the United Nations report on water resources development throughout the world, at least one out of every four persons in 2050 will live in a country with chronic and recurring water shortage (WHO, 2015).

4. Hydrological characteristics and sources of water in Havana

Cuba's inland waters have their origin in rainfall. Identical problems confront the exploitation of superficial and subterranean waters participating in the urban water cycle, including pipeline leaks, loss of water quality, dwindling resources and an increase in the water footprint. These problems grow in areas related to sanitation; the disposal and collection of urban wastewater are carried out through insufficient networks of sewage systems that require the use of latrines and septic tanks accompanied by treatment systems using stabilization ponds, and compact (and traditional) water treatment plants. Rainwater is channeled into rivers, streams and superficial waterways in general, which circulate through urban zones, as well as through storm drains, with the particular difficulties presented by each, and which are common in urban zones.

Havana, the capital of the Republic of Cuba, with 2,168,255 inhabitants, has suffered since its founding in 1516 from persistent water supply and urban drainage problems which have become more serious with time due to systemic structural deformation and the disproportionate concentration of the population in the last few decades. In 1545, Joanes de Avila was already making it known in a letter to the King of Spain that "*in this village of "Avana" there is great need of water to be brought by the ships which arrive here...*".[2] Two years later, His Majesty stated in the Royal Charter of February 11, 1547 that "*I command you to arrange with the person or persons whom you deem appropriate to bring you said water to said village...*".[3] In fact, the city was built around

2. Letter from Joanes de Ávila to the King, May 31, 1545 (Eguren, 1986).

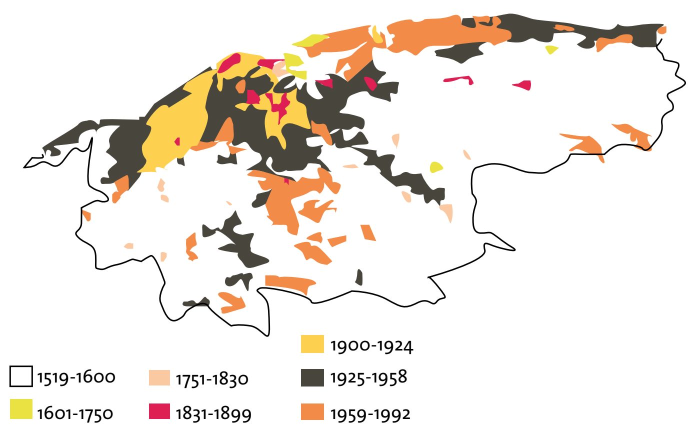
3. Royal Charter of February 11, 1547.

wetlands and springs which were drained, where the Cathedral Plaza is found today for example. The urban topography provides evidence of an ancient and now inexistent drainage system in streets such as Monte, Lagunas, Manglar, Cienaga, Cardenas (previously called Basurero), El Chorro and Zanja.

Havana (Figure 4) is a coastal city that has grown in its current location (it has moved at least twice in 1515 and 1516, prior to its current position) around a "pocket bay" into which drain three rivers from small basins (Luyanó, Martin Pérez and Arroyo Tadeo). For only a short time in the epoch of its founding did these basins supply potable water, limited to very small communities which also relied on subterranean waters, as in the cases of the Cisterna de la Cienaga (Swamp Cistern), situated in the current Cathedral Plaza; and the Pozo de la Anoria (Anoria Well) very close to where Parque de la Fraternidad (Brotherhood Park) is located today. In general, the city was founded on the coast but eventually grew inland on rocky soil with low aquifer productivity, which forced the inhabitants to seek reliable sources of water outside of the urban perimeter beginning practically from the city's founding. The Cisterna de la Cienaga, the Pozo de la Anoria and even the Cisterna del Jagüey at the foot of Loma de la Cabaña, on the eastern edge of the bay's channel proved insufficient. At a distance of some 10 km to the west, however, the early population of the city had the waters of the Río Almendares (Almendares River) which supplied the city's second location with water when it moved from the south coast to the north. For some time, water was brought by sea or by land in barrels, from the town known at that time as Pueblo Viejo (Old Town), to the city situated on the edge of the bay, protected from tropical storms and winds, and capable of harboring tens of ships which, beginning in 1540 with the establishment of the shipping fleet system, gathered together to make the return journey to Spain.

The systemic importation of the water supply reached notable levels in the 15th century when in 1566, Calona began construction of the Royal Trench (completed in 1592) which carried 70 thousand m^3/day of water for eleven kilometers westward from the Almendares River to a point close to the current Cathedral Plaza (Figures 5 and 6). Improvements were later introduced –but less than expected– with the construction of the Fernando VII Aqueduct

Figure 4. Stages of urban development in Havana



(Figure 7). At the end of the 19th century, with the construction of the Vento Canal (Figures 8 and 9), an efficient system was created which improved water supply even up to today.

The practice of importing water didn't end, and today the city's water footprint requires the support of a system of aquifers occupying an area close to 2,235 km^2. It consists of various subterranean basins, tens of kilometers distant from the capital city, including the Ariguanabo, Sur, Jaruco-Aguacate, Jaimanitas-Santa Ana, and Vento basins which, in no small measure, has compromised peripheral development in other areas –such as industry and agriculture– by subordinating water resources to the interests of the capital city and its need for potable water.

The city's entire water supply system is centralized into great aqueduct systems that take advantage of subterranean water in very rich karst aquifers. The eastern sector of the city receives support from systems supplying superficial water through a series of dams (La Coca-La Zarza and Bacuranao) incorporated into the water supply system in the 1970's. To a large degree, this systematic increase in the water footprint is associated with deficiencies in the networks and a lack of methodical maintenance over the course of decades.

All subterranean basins supplying water to the city are karstic in nature. Marked karst development has been advantageous as well as disadvantageous for efficient subterranean water resources management. Guaranteeing water supply to the city has required the systematic development of integrated management tools for Tropical Wet karst aquifers, a phenomenon without antecedents in other regions, combining management of coastal and closed inland basins in rural and partially urbanized areas. These partially urbanized areas are accompanied by a systematic process of varied and highly contaminating industrial development, including the sugar industry. The rural areas suffer pressure from a gamut of agricultural activities that

Figure 5. Map of the route of the Royal Trench, created by don José María de la Torreen in 1857, showing branching canals supplying water to “El Chorro“ and “Muelle de Luz”

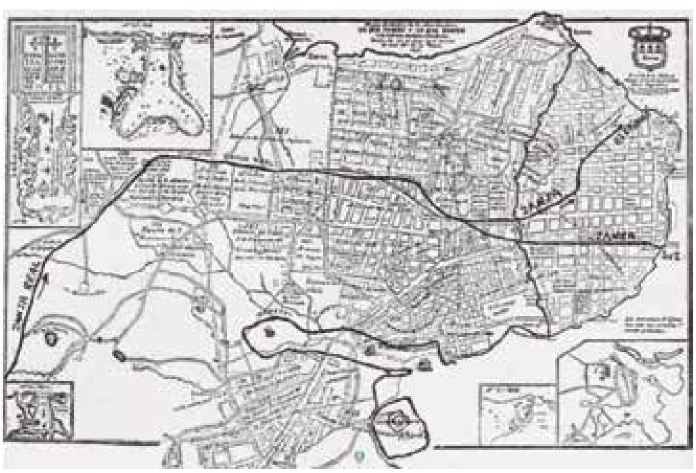


Figure 6. Stone sign in Callejon del Chorro (Chorro Alleyway) on a corner of the Cathedral Plaza in Havana indicating the final destination of the waters brought to the city from the Almendares River, highlighting the name of the governor at that time, Juan de Tejeda, and the year 1592, the year in which construction of the trench was completed

Figure 7. Principal Facade of the Fernando II Aqueduct (Photo taken in 1926)

Figure 8. Construction of the Vento Springs water intake

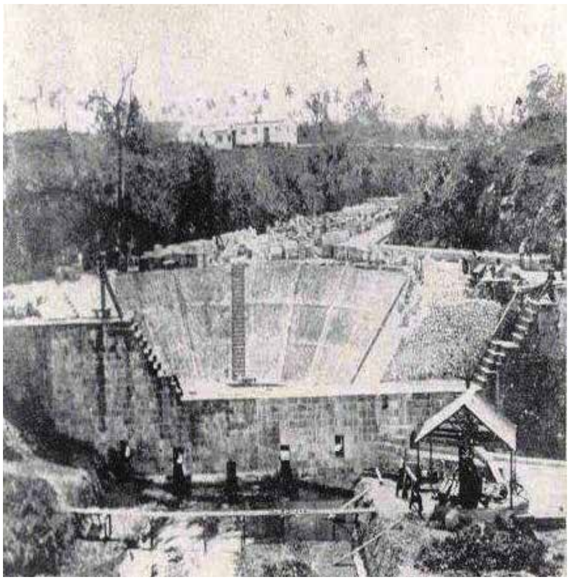


Figure 9. Vento Springs water intake today

demanded the construction of hundreds of wells for local supply and irrigation systems that, with greater or lesser efficiency, made use of, exploited and overexploited water resources in a vast zone surrounding the capital city. Figure 10 shows the aquifer system which supplies the nation's capital with water.

The inland basins (Ariguanabo, Vento, Mampostón-Jaruco and Aguacate) are karst poljes or fields, with varying phases of vertical deepening, surrounded by impermeable rocks creating within them different levels of cave development. They constitute closed basins in the geological sense; that is, they are storage basins in which the packets of karstic carbonate rocks reach up to 350 meters in thickness in the Vento Springs Basin.

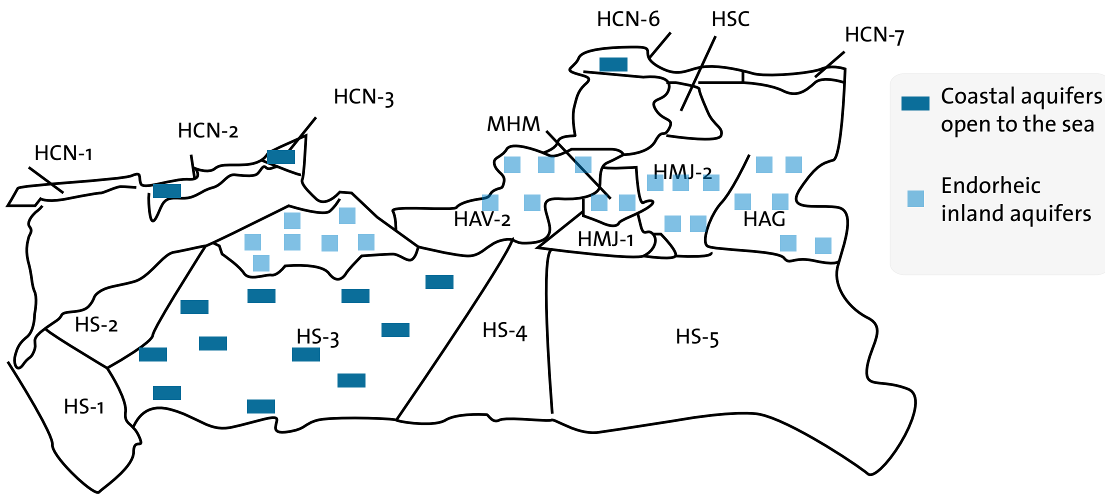
These closed basins basically lack superficial runoff which depends primarily on the poljes' state of hydrologic evolution. In consequence, discharge occurs through one superficial point while the basins themselves form a complex subterranean relationship. This overall situation implies stratification of the different ages of the water (their time in residence) which mandates serious consideration of the exploitation regimen of these waters, to guarantee the sustainability of their usage.

In the city's urban area, flooding is a common phenomenon resulting from the elevated coefficient of runoff and a reduction in water infiltration. But in the case of Havana, flooding has been accentuated by violations of municipal ordinances, building construction and demolition, and an elevated load of sediment associated with a collapse in the networks.

The systematic obstruction or rerouting of superficial runoff routes has created serious urban water problems that have become more serious due to an absolute lack of caution in preventing blockage of sewage and rainwater drains by all manner of debri and rubble. The networks have become almost unusable, contributing to the now common and bothersome problem of sea water intrusion and coastal flooding, systematically aggravated by human activity on top of storm surges and elevated sea levels.

In the end, we have a coastal water system receiving imported water which, through differential treatment, drains to the sea. Waters do not recirculate to resupply the aquifers and the final hydrologic balance is clearly unsustainable.

Figure 10. Map (not to scale) represents aquifer systems currently supplying Havana with water



5. Potable Water System

Access to Potable Water in Cuba

Currently, 95.5% of the population has access to potable water, in both the urban and rural sectors. Access to water in Cuba is provided in the following manner (Cubadebate, 2013; Cubahora, 2014):

- Water piped to the home: 8,401,868 inhabitants, 75.0%
- Water supplied by water tankers: 525,696 inhabitants, 4.7%
- Easy access to water at a distance of 200-300 m: 1,310,014 inhabitants, 11.7%
- Low population density areas: 963,200 inhabitants, 8.6%.

Supply:

- Pumping stations (PS): 3,729 for supplying the population
- From INRH (National Water Resources Institute): 2,592 PS
- Local networks and pipelines: 22,541 km
- Dams: 242, for supply 77
- Water tankers: 1,051 in all institutions
- From INRH: 359, average working 110
- Other institutions: 692

Sanitation:

- With sewer system: 3,980,360 inhabitants
- With 293 systems of stabilization ponds, 534 septic tanks and 10 compact water treatment plants
- With septic tanks and latrines: 6,257,228 inhabitants in 869,829 septic tanks
- Of the total volume of transported wastewater only 34.6% is treated.
- Sewer system networks: 5,310 km
- River and trench cleaning: 3,300 km
- Sewage pit cleaning vehicles: 224
- High water pressure vehicles: 29
- Obstructions: 150,000 per year
- Sewage pit cleaning: 323,000 per year

Within this infrastructure and in compliance with the National Water Policy implementation timeline, works are carried out with an emphasis on indicators that evaluate water supply service quality, prioritizing those that ensure sustainability:

- Maintain elevated coverage in providing public with access to potable water:
- Increase control in hydrometry measurements.

The fundamental problem of access to potable water lies in losses during transport and distribution, advanced age and poor state of water supply systems and the need to rehabilitate these systems, water sources and potable water treatment plants. A large percentage of total water available in the country is employed by the agricultural sector (in which there is an enormous degree of waste) and in industry; and only 20% is employed in aqueducts destined for the State and residential sectors.

The population receives water in three primary ways: 1) water connection in the home; 2) through public water tankers; 3) easily accessible and locally available water within the community through a public faucet or tank, in the case of zones with no existing pipe network or with deteriorated networks. According to Cubahora (2014), National Water Resources Institution (INRH) enterprises serve 8.24 million people; 900 thousand people are supplied water by the Ministry of Agriculture and AZCUBA; approximately another million are supplied by water tankers; and 800 thousand rely on water which they carry for a distance of up to 300 meters. In spite of the high degree of coverage, 200 thousand people in urban zones and 400 thousand in rural zones lack adequate access to water.

Havana is a city with more than 2 million inhabitants (see data from the most recent census). The potable water supply system today is fed by four source groups, with a structure that provides water to 99.7% of the population through a system of aqueducts requiring adequate potable water treatment (99.1%). Because of insufficiency or the poor state of the distribution network, some 40 thousand people receive water services via cistern carrying vehicles (water tankers). Water is provided for an average of 10 to 12 hours per day, every other day, in most sectors of the city, with insufficient pressure, representing a deficiency in services provided.

The city receives water through some 4 thousand km of pipelines and primary local networks, some with more than 100 years of use, such as the Albear Aqueduct. The pipelines between the sources of water and the local networks have an extension of more than 330 km. Only 18.6% of the Vento Springs Basin feeds the Albear Aqueduct supply system through gravity without any energy costs. The rest of the systems do require high volume pumps, some of which are located a little over 50 km from the capital (e.g. El Gato in the Jaruco Basin).

A common characteristic of the city's subterranean supply sources is that in all cases the aquifers are non-confined inland karst aquifers, while one of them (South Basin or Cuenca Sur) is coastal. This characteristic translates into elevated supply system vulnerability to multiple source contamination: industrial, domestic and agricultural.

6. Sewer System

The central sector of the city's sewer system has been in operation for almost 100 years; construction on the system was concluded in 1915. It consists of 1,567 km of pipes including the central sewer system and the local systems on the periphery; two treatment plants; 23 wastewater pumping stations; and fifty stabilization ponds (Table 3). Two more are under construction along the margins of the Luyano River, one of which will treat water that drains from the basins discharging to Havana's bay.

The central sewer system provides services to almost half the city's population. Nevertheless, as the system was constructed for a maximum population of 600 thousand inhabitants, its capacity has been superceded for several decades, resulting in discharges and spillage into streams, rivers, rainwater drains and the coast.

The central network of collection pipes extends 1,130 km in length, divided into local networks, sub-collector pipes and principal collector pipes which transport human waste through physical and mechanical treatment processes prior to being deposited in the ocean via a tunnel submerged to a depth of 10.7 meters at a distance of 147 meters from the coast. Havana's Sewer Tunnel, popularly known as the Playa del Chivo Emissary –one of the Seven Marvels of Cuban engineering– was built between May 1911 and April 1912 with a length of 375 meters, excavated through the rocks under the bay between the old Muelle de Caballeria (Caballeria Wharf) and the Casablanca (Whitehouse) on the eastern side of the bay. The Tunnel drains slightly more than 110 Hm^3/year of wastewater via gravity to a pumping system situated on the eastern side.

Obviously, smaller local systems exist; and in the city's periphery a considerable volume of wastewater is treated in septic tanks using infiltration wells and the Quibu River water treatment system, with a designed capacity of 300 liters per second and which is currently employing only 30% of its capacity.

The disposal and recollection of urban wastewater is carried out through insufficient sewer networks, supported by latrines and a great number of septic tanks, which accompany treatment systems using stabilization ponds and compact (and traditional) water treatment plants. Rainwater is drained to rivers, streams and superficial waterways in general that circulate throughout the urban zones as well as to storm drains.

7. Associated Hydrological and Technical-Economic Problems

Hydrological Problems

In terms of supply basins, the most important hydrological problems consist of the following:

- Sustained increase in the exploitation of subterranean basins supplying water to the city and the extraction of waters with elevated time in residence in the aquifer, to the extent that resources are mined, a portion of which ceases to be renewable.
- Increasing sea water intrusion into coastal aquifers that serve as a source of water for the city, aggravated eventually by the systematic rise in sea level as a consequence of climate change.
- Pressures on some basins caused by urbanization and internal migration.

In terms of the city's hydrological system per se, the city faces a host of eco-hydrological problems of special importance such as (Molerio, 2012):

- Differential settling and subsistence associated with cavern collapse.
- Flooding due to intense rainfall, sea water invasions and storm surges which occur simultaneously under certain weather conditions.
- Landslides.
- Occurrences of waterborne diseases.
- Sedimentation and accumulation of debris in rainwater drains and sewer systems.
- Swamp development in peripheral areas.

Technical-Economic Problems

The most important problems which limit efficient management of Havana's water resources are:

- Loss of water conduction facilities (pipelines, networks of aqueducts and household plumbing) that, according to Kalaff (2013) reaches 58% of flow delivered annually.
- Water recycling.
- Overexploitation of subterranean waters.
- The loss of extended life of the reservoir complex on the east side of the city as well as the accumulation of debris in waterways and long-term exploitation.

8. Conclusions and Recommendations

The principal threats to the inland water system and water quality in island territories in the Gulf of Mexico and the Caribbean are associated with the rise in sea level and consist of the following:

- Progressive intrusion of sea water inland, impacting the fresh water/salt water interface and secondary water mineralization.
- Redistribution of discharge zones of superficial (overflow) and subterranean waters.
- Flooding in low coastal aquifer zones and hydraulic gradient reversal.
- Greater penetration inland of aerosols contributing to soil salinity in higher sectors of the basin and consequently the incorporation of external sources of salinity in superficial and subterranean waters.
- Greater pressure on inland subterranean basins, some of which show evidence over the past 15 years or more of water drainage not pertaining to the actual hydrologic cycle.
- Greater pressure on superficial basins that will shrink in size and become exposed to greater danger of quality loss and alterations in the hydrologic regimen as a consequence of changes in local and regional base levels.
- Deterioration and consequent abandonment of subterranean water supply sources close to the shore.
- Displacement of contamination sites toward other sites near superficial and subterranean basins which can worsen water quality.

Brown (2006) has summarized the following effects of climate change resulting from global warming:

1. The planet's coastal zones will be lashed with storms and flooding of increasing severity, and coastal flooding will displace millions of people.
2. Salt water intrusion due to a rise in sea levels will have repercussions on the quality and availability of fresh water, worsening the world's growing water crisis.
3. As global warming will impact the forests, marshlands and pasture lands, damage to the earth's ecosystem will be far-reaching and irreversible: close to 25% of mammals and 12% of birds could become extinct in the coming decades.
4. The displacement of agricultural soils and the slow advance of desertification will render many zones inutile for cultivation and pasture land.
5. Warming, along with an increase in humidity, can accelerate the incidence of new as well as existing infectious diseases such as malaria and yellow fever.

In general, processes associated with climate change represent an important threat to life and livelihoods in communities in all regions of the world. Yet, without a doubt, small island states are the most vulnerable.

Constantly scarce reserves of superficial and subterranean water resources place these countries in or very close to a state of water stress. Their water resource management tends to be inefficient and they are permanently affected by additional pressures as a consequence of water and soil contamination and exploitation to satisfy growing demand. The intrusion of the seas which advance ever inland as a consequence of the rise in sea levels will be the major cause of a loss in quality and quantity of subterranean fresh water.

Sustainable water management should move forward in the following directions:

- Programs for recharging subterranean waters.
- Improved capacity in artificial regulation of runoff.
- Substitution of treatment technologies in extenso for compact wastewater treatment plants.
- Sewer system improvements.
- Reduction in conduction loss (reduction in leakage in general).
- Implementation of economic incentives against waste and in favor of responsible use.
- Wastewater recycling.

In Havana's case, recommended and approved solutions and perspectives for improving water resources management are incorporated within an engineering and sanitation program in the city and are a component of a policy for pricing readjustment that takes into account the following fundamental elements (Kalaff, 2013):

1. Modifications in State and private sector fees.
2. Rehabilitation of the aqueduct system would include rehabilitating 3.2 thousand km in Havana over 12 years, at a cost of 62.9 million Cuban pesos annually.
3. Recycling 3 m^3/second of wastewater to a filtration field that would permanently recharge the Vento Springs Basin and the Albear Springs is under evaluation; this would provide a constant source of water which would increase the exploitable reserves of this important basin, and increase the possibility of exploiting its waters during normal rainy seasons.

As of today (Kalaff, 2013):

- 691.3 km of local water networks have been rehabilitated with HDPE technology, primarily in zones with deficient supply and low pressure.
- Construction and reparation is pending in Havana for 3.2 thousand km of local water networks and pipelines, including 2,422 km of networks in poor condition and 235 km of amplification.
- In terms of local water networks, 20% of the rehabilitation/amplification of sewer systems will be carried out, for a total of 543 km.
- An 898 km project is planned for the rehabilitation of networks and pipelines.

We highly recommend continued planning and development of more detailed studies on the regime and quality of inland waters (superficial and subterranean) supplying the nation's capital, keeping in mind that we have as the only source the karst aquifers. In terms of management, refinement of the hydrologic surveillance network (including superficial and subterranean waters) provides us with a basic instrument for planning and for the sustainable use of this resource. The incorporation of more rigorous mathematical modeling tools for transportation of mass, momentum and energy is vital for simulating increasingly complex scenarios for interaction between superficial, subterranean and marine waters carrying contaminants differentiated by time, manner and place; with increasing water stress resulting from the demand for water under more adverse climatic conditions and more frequent extreme, prolonged events, it becomes a necessity for small islands and for island states above all.

The incorporation of techniques for intensive water treatment and recuperation, to increase resources through artificial recharge of subterranean aquifers, and/or recirculation and recycling of treated waters primarily from industry and agriculture, is of such importance that it points in the direction of slowly substituting the classic oxidation ponds – which occupy useful lands – for compact water purification and treatment plants accessible to small islands through the transfer of appropriate technology. In the immediate future we must identify and preserve coastal karst areas into which fresh water is discharged, minimizing the salinity of the resultant mixing with marine waters, to reduce the eventual desalination costs that might be incurred in the future. The quality of coastal and marine waters must also be preserved against the high levels of salt and metals extracted by these plants when water with ever increasing levels of salinity are used.

The idea of achieving sustainability of water resources is not just a utopian concept as long as the true magnitude of the complexity of its management, and the need to confront this complexity with the appropriate structural and non-structural measures, is completely understood. Interest groups play more than just an important role in the struggle to achieve sustainability in this area; and this goal is achievable if the government, business sector, population and academia take an active, consensus driven part in the process, fully conscious of the challenge implied in providing safe water for all needs, not in the immediate future, but today, and right now.

"One of the Seven Marvels of Cuban Engineering" Visitors and residents of Havana walk along the city's "malecon", or seawall esplanade, bordering Havana Bay. They enjoy an outing through the city's historic center, transported by a horse-drawn carriage, following the custom of the colonial period. Many are unaware that this grey steel structure to the left disguises a subterranean chamber containing grates which prevent the passage of objects and sand into the siphon. Through a tunnel extending underneath the bay, from one end to the other, waste water from much of the city is removed with the aid of specialized pumps to its ultimate disposal site. Source: Juan de Las Cuevas and Collaborators. Publication of the Office of the Historian of the City of Havana, Cuba, Year 2012, pages 38-56

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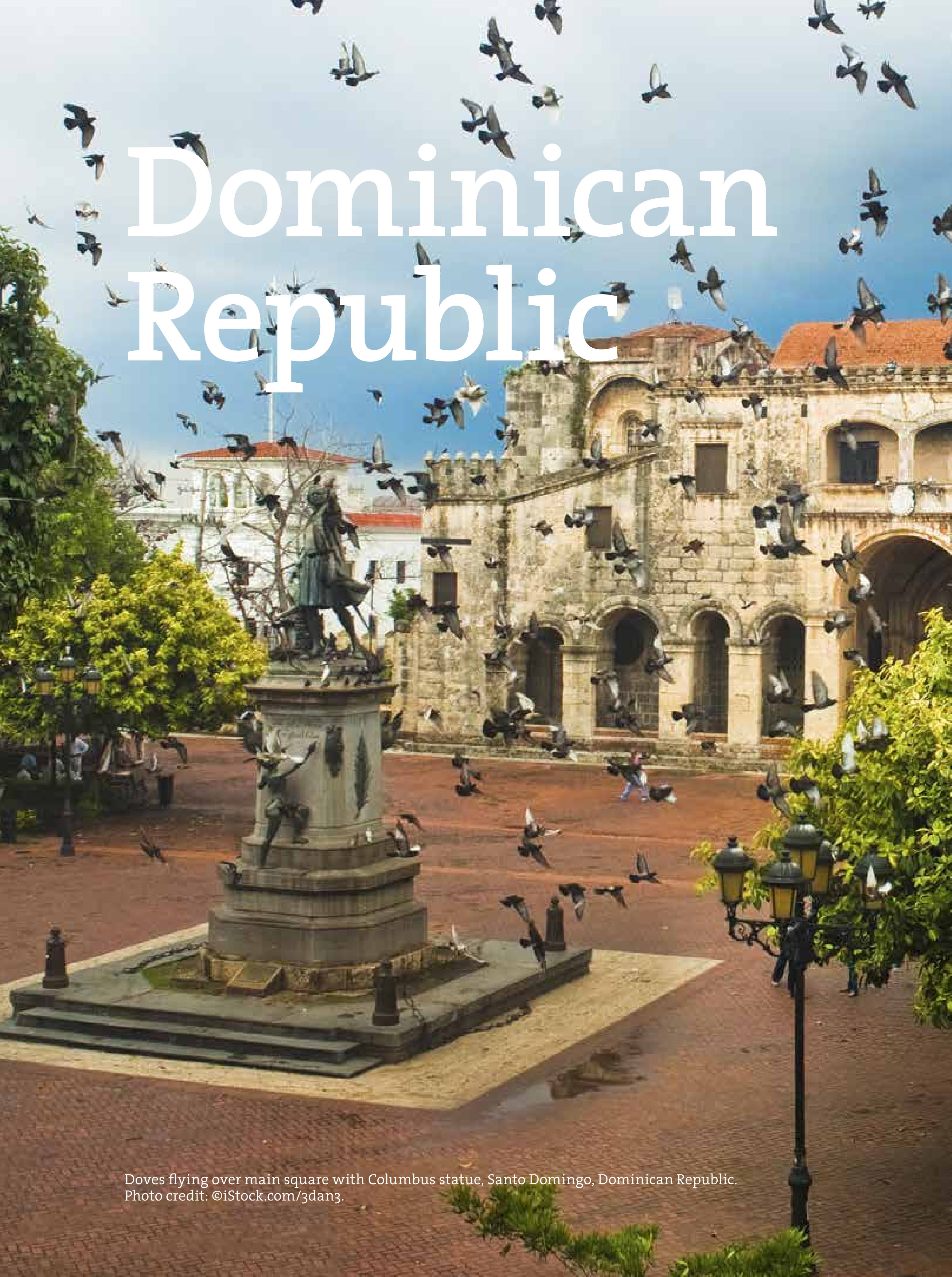
Dominican Republic



Doves flying over main square with Columbus statue, Santo Domingo, Dominican Republic.
Photo credit: ©iStock.com/3dan3.

"The greatest environmental challenge facing the city of Santo Domingo, the first in America, is to clean up the mighty river Ozama, to make it clean, pure and crystalline once again as it was five centuries ago when the colonial city was founded on its shores"

Urban Waters in the Dominican Republic

Rafael Osiris de León

Summary

In the Dominican Republic, towns are expanding, due to population growth exacerbated by the lack of employment opportunities and basic services in rural areas, which forces a sector of rural communities to move to urban areas. Likewise, many inhabitants of neighboring Haiti migrate to the Dominican Republic in search of better living conditions. Both those from rural areas and Haiti, unable to afford to live in urban areas with basic services, settle on the banks of rivers and streams in makeshift shacks, without potable water and basic sanitation, their waste ending up in the adjacent rivers and streams, from which they obtain water that has already been contaminated. We have thereby degraded virtually all our urban water and multiplied waterborne diseases, which mainly affect the poor, who are unable to afford the high cost of treated and purified water.

The periphery of the capital, Santo Domingo, with a population of roughly 3.5 million, concentrated in approximately 350 square kilometers, has grown rapidly, polluting the Ozama, Isabela and Haina rivers, while the lack of an adequate sewerage service has led citizens to dispose of their sewage through vertical filter wells that discharge directly into groundwater, subsequently extracted through adjacent wells to supplement the precarious and intermittent drinking water service. Our cisterns thereby combine drinking water, supplied by pipelines, with raw water directly extracted from the contaminated subsoil, which should be unacceptable in an organized society committed to health and basic sanitation.

The severe problem of urban water pollution has been compounded by an extraordinary drought not seen in the country since the mid-1990s. This drought has caused a severe drinking water crisis, which has forced the water authorities to ration flows for irrigation and prioritize the scarce water available for human consumption. This crisis has been so severe that it has led to inter-municipal conflicts over access to the limited amount of water available.

This should lead the country to redefine its public policies on drinking water and basic sanitation to begin solving old problems accumulated in these two major health-related issues, so that we establish a deadline of not more than 12 years to provide the city of Santo Domingo with adequate sewage service with wastewater treatment plants, relocate poor families living precariously on the banks of rivers and streams, fix leaks in drinking water pipelines, and obtain new sources of water harvesting, all of which must be complemented by new legislation that prioritizes investments in drinking water and sanitation and obliges all new residential projects to be provided with sewage services and treatment plants, while encouraging international agencies and local entrepreneurs to play a more active role in these solutions.

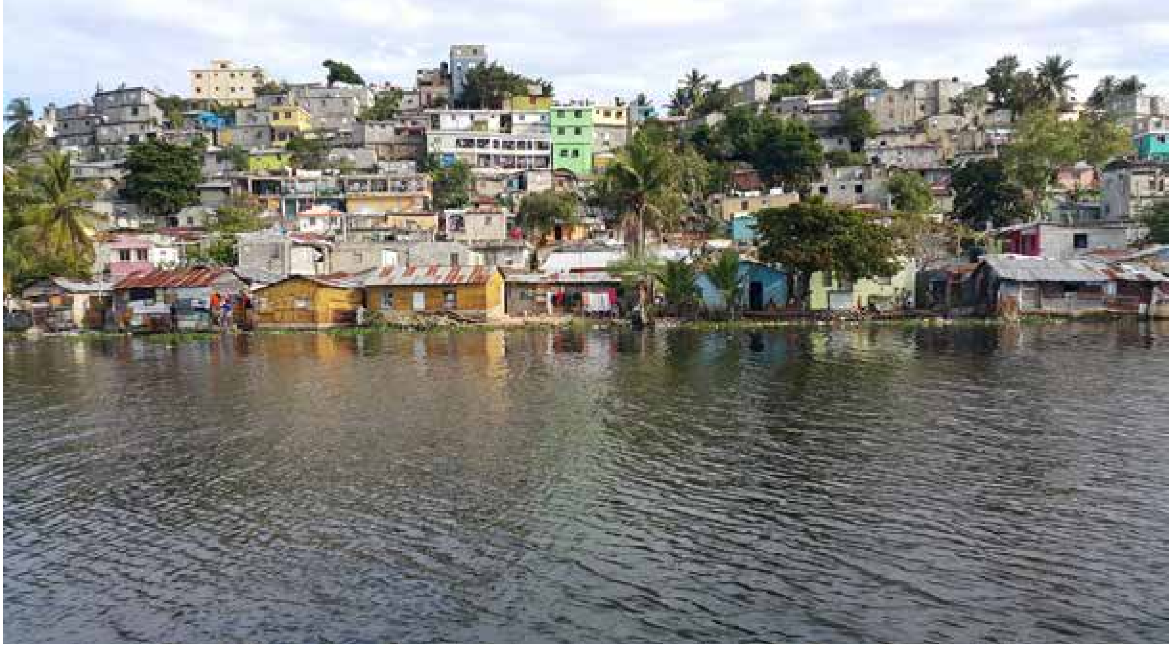
1. Introduction

In the Dominican Republic, as in most Latin American countries, urban waters are synonymous with rivers and streams contaminated by direct discharges from neighboring slums that lack sewers and refuse collection services. Likewise, they have not been connected to the drinking water system nor have they been properly trained to preserve water and ensure basic sanitation. Most urban industries lack wastewater treatment plants, thereby turning the urban rivers of Santo Domingo and the country's major cities into the main recipients of the organic and chemical discharges that damage the quality of the water intended for consumption by the growing population.

The city of Santo Domingo was founded just over 500 years ago, on the banks of the mighty Ozama River, with its crystalline waters, which served as a permanent supply source for drinking water. In the five centuries that have elapsed since its founding, the city has grown westward, northward and then eastward, encompassing a large portion of the banks of the Ozama River and its northwestern tributary, the Isabela River and the west Haina river, now severely polluted by urbanization and industry.

However, the growth experienced by the city of Santo Domingo during the second half of the 20th century led to a swift process of exploiting the groundwater available in the coralline limestone aquifer on which the city was built. This aquifer, whose most effective intake extends E-W for about 1,200 square kilometers, receives an annual net

Photo 1. The Ozama River and its overcrowded buildings make it one of the most polluted urban rivers. Osiris de León.



recharge of approximately 1,200 million cubic meters of water, as well as the direct vertical discharge of almost 90% of the sewage supplied by nearly 3.5 million people who contribute about 7,000 tons per day of excrement, as a result of which this major aquifer, the largest net recharging aquifer in the country, is now severely polluted as are the rivers surrounding the city.

In the Dominican Republic, towns are continuously expanding due to natural population growth, and the fact that the lack of employment opportunities and basic services in rural areas forces a large sector of the people living in rural communities to migrate to urban areas. Since many of them are unable to afford to live in urban segments with basic services, they settle on the banks of rivers and streams, in makeshift shacks, where there is no drinking water service or basic sanitation, and their waste ends up polluting the adjacent rivers and streams, creating an increasingly serious problem.

Clear examples of this situation are published in the national press, such as what happens in the eastern town of Hato Mayor, where the community's refuse, industrial waste and excreta end up in the bed of the Maguá River, as published in the Diario Libre on July 28, 2014.

This situation has degraded our urban waters, both the surface and groundwater of the Eastern Coastal Plain, where the cities of Santo Domingo, Boca Chica, San Pedro de Macorís, La Romana, Higuey and the growing tourist area of Bávaro and Punta Cana are located. It requires urgent attention and a solution, especially since the lack of a regional aqueduct means that the overexploitation of groundwater in the tourist areas of Boca Chica and Bávaro has produced saline intrusion processes of 15 km and 4 km respectively.

But the most worrying thing is that the Dominican Republic has failed to adopt proper drinking water and basic sanitation policies, or invest in the construction of sewers, or wastewater treatment plants, meaning that the wealthiest residential areas in the capital lack sewerage, and all new buildings are allowed to construct vertical filter wells to discharge their waste into the groundwater we extract to supplement the insufficient flow rates received from the main intakes located on the outskirts of the city. There is a tendency to forget that the Santo Domingo aquifer lies on a bed of highly porous coral limestone where hydraulic conductivity is extremely high, and any organic or chemical contaminant spreads rapidly to its surroundings, but mostly from north to south, which is where the hydraulic slope descends seeking the level of the Caribbean Sea located on the south side.

This creates a Dantean situation of extraordinary urban and industrial pollution, in both wealthy neighborhoods and slums. It is exacerbated by an outdated water supply network through which just over half the water is lost, either through leaks in the primary and secondary networks, or informal use, which is either unregistered or not paid for. Coupled with the lack of investment in new water intake works, this means that many sectors of the capital and broad sectors of large cities lack a permanent water supply, forcing many people to purchase tanker trucks for their water supplies, or to protest angrily in an attempt to be noticed by the

Maguá River Choked by Pollution

Diario Libre. Monday July 28, 2014

The Maguá River, which rises seven kilometers away from the farming community of El Manchado in the northern part of Hato Mayor, recorded a high degree of pollution, due to the industrial waste, fats and feces discharged by over a thousand latrines existing on either bank of this water source.

The once mighty river has become a municipal sewer due to the waste thrown into the water, which threatens to eliminate this major tributary.

The waters are covered in filth at source, because the council built a municipal dump a few meters from the start of the runoff that feeds into it.

In the city of Hato Mayor, the Maguá river is affected by the feces and urine discharged by hundreds of toilets, and the red meat waste from animals slaughtered in the municipal slaughterhouse, located about 200 meters from its banks.

The river also receives effluent from the main pipeline in the Hato Mayor sanitation system, which burst open, spilling feces into the waters of the dying river.

Tree felling on the banks of Maguá river has also signaled the death knell of this major local river.

Toxic waste has caused the death of fish, crabs, shrimp, turtles, guabina fish, tilapia and mountain mullet, which have vanished from its waters.

In 2000, the Cattlemen's Association of Hato Mayor, the United Nations Food and Agriculture Organization (FAO) and other national and international agencies announced the clean-up of the Maguá river, but the project was shelved, presumably due to lack of resources and the unwillingness of the government to address the pollution of this key water resource.

authorities responsible for managing the waters that should reach urban centers.

2. Water and the Problems Paused by Urbanization

Under normal conditions, the city of Santo Domingo, the capital of the country, with nearly 3.5 million people, receives about 410 million gallons of water every day, through the Santo Domingo Water and Sewerage Corporation (CAASD) of which 142 million gallons per day are obtained from surface sources in Isa, Mana, Duey, Guananitos, Haina, Isabela and Barrera Salinidad Ozama, 138 million gallons per day are drawn from wells built by CAASD and 130 million gallons a day are provided by the western dam of Valdesia, indicating that the city of Santo Domingo is supplied in almost equal proportions by three sources: a group of surface rivers, an excellent aquifer on coralline limestone, and a large dam which, in addition to providing six cubic meters per second for the aqueduct, supplies 20 cubic meters per second for irrigation channels and 54MW of electrical power, although private wells may be contributing approximately 100 million gallons a day.

The city of Santiago de los Caballeros, the second largest city, with nearly 700,000 inhabitants, obtains 100% of its water from the Tavera and Bao dams, which supply about 125 million gallons per day, and virtually none from groundwater in view of the fact that Santiago is built on impermeable calcareous clays deposited on impermeable clay shales that do not constitute aquifers; the same way that the city of Moca, located east of Santiago, with nearly 100,000 inhabitants, is also supplied by the Tavera and Bao dams, which provide 20 million gallons a day, because since the city of Moca has no surface rivers, it has no significant local catchments, and as it is built on impermeable clays, it cannot rely on groundwater either.

The cities of Central Cibao, such as La Vega, with nearly 400,000 inhabitants; San Francisco de Macorís, with approximately 180,000 inhabitants; Bonao, with about 125,000 inhabitants; and Cotuí, with roughly 75,000 inhabitants, are supplied by the surface waters of the Yuna, Masipedro, Maimón, Camú and Jima rivers and the Hatillo Dam, built on the Yuna River and the Rincón Dam, built on the Jima River, because in this area there is no significant exploitation of groundwater and aquifers are extremely limited and unproductive.

The Northwest Line aqueduct, which supplies the Monción Dam, built on the Mao river, supplies water to approximately 500,000 people in the northwest of the country, from Navarrete, Esperanza, Valverde Mao and Monción to Sabaneta, Villa Vásquez and Monte Cristi, showing that virtually the entire Cibao Valley relies on surface water stored in dams, polluted by urban expansion without sewerage, industrial liquid waste discharged directly into rivers and streams; landfills located on the banks of rivers and streams, agricultural activities using toxic chemicals, livestock activities that dump animal manure into adjacent streams and rivers; and acidic waters, laden with heavy metals from open pit mining operations on sulfurous mineral deposits, without proper government regulation.

The greatest exploitation of groundwater in the Dominican Republic is concentrated in the South, Southeast and Southwest regions, where there are extensive aquifers in recent coralline limestone, tertiary lithographic limestone and alluvial fans of coarse gravels and sands, with the largest underground exploitation being located in Santo Domingo (33% of daily supply), Boca Chica (100%), Punta Cana (100%), Bávaro (100%), San Pedro de Macoris and La Romana (partial delivery), especially the communities of Punta Cana and Bávaro that constitute the main tourist destination in the Caribbean region, where, due to the absence of surface water sources, hotels have been forced to resort to the widespread use of coastal aquifers of recent coralline limestone, and where at the same time, the overexploitation of groundwater has caused saltwater intrusion processes in Bávaro to advance 4 kilometers inland, and 15 kilometers inland in Boca Chica. Coupled with the pollution caused by the proliferation of filter wells that discharge residential and hotel wastewater into the aquifer, and landfills without protective waterproofing, this has seriously damaged groundwater throughout the area, endangering future supplies.

Table 1. Santo Domingo Aqueduct and Sewerage Corporation (CAASD). Monthly production of well fields in millions of gallons per month, 2009 (Source: Santo Domingo Water and Sewerage Corporation. CAASD)

													2009
Systems/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
LECHERIA	140.55	116.29	123.96	103.61	116.21	97.06	110.74	132.62	117.00	137.47	118.30	130.45	1444.26
SECTORAL	79.20	69.74	49.64	55.53	45.47	41.78	43.13	43.83	41.75	31.06	30.55	50.41	582.09
TOTAL NORTHWEST	219.75	186.03	173.60	159.14	161.68	138.84	153.87	1776.45	158.75	168.534	148.85	180.861	2026.36
CAFÉ WELL FIELD	41.27	37.96	42.57	37.56	41.31	38.12	32.38	35.50	35.22	37.44	38.66	38.91	456.90
LAS CAOBAS	116.80	125.85	137.12	108.55	115.36	129.14	133.04	59.07	0.00	0.00	0.00	0.00	924.93
SECTORAL SYSTEMS	186.64	173.45	177.45	157.38	163.49	166.54	162.53	164.87	155.28	160.84	140.67	158.83	1967.97
TOTAL NORTHWEST	344.71	337.26	357.14	303.49	320.16	333.8	327.95	259.44	190.50	198.28	179.33	197.74	3349.80
MATA-MAMON I AND II	151.22	110.63	175.35	203.95	197.80	180.03	168.60	164.30	143.34	167.33	145.15	120.16	1927.85
SABANA PERDIDA	181.71	167.82	171.17	162.32	177.31	185.96	187.19	181.96	138.81	131.63	170.83	169.55	2029.26
SECTORAL	340.18	290.05	338.57	308.33	501.07	518.27	499.09	481.26	429.22	484.28	412.38	532.50	5135.20
TOTAL NORTE	717.38	606.45	727.66	712.16	917.49	922.377	887.27	863.023	746.58	820.68	767.02	861.116	9549.21
LOS MAREÑOS	808.59	751.75	807.30	723.41	866.82	803.09	780.45	756.77	756.88	774.41	767.41	824.25	9421.13
EL NARANJO	192.13	152.41	156.78	166.57	192.67	166.89	182.15	147.98	137.08	151.43	145.88	176.09	1968.06
LA CATALINA	171.88	151.44	167.22	137.28	155.54	166.93	209.58	154.96	166.65	178.12	140.14	131.37	1931.11
LA JOYA	776.57	707.03	727.94	574.45	749.44	827.73	837.27	784.97	704.35	846.51	636.14	791.42	8763.82
LA CALETA	119.08	88.60	117.30	171.12	187.70	163.44	185.03	183.79	175.66	186.79	181.49	186.74	1946.71
BRUJUELA	600.19	542.82	594.76	569.15	597.36	570.86	586.55	562.47	504.44	505.70	480.63	512.69	6627.62
SECTORAL	16.88	13.60	15.59	13.74	12.42	19.59	17.50	16.13	18.74	15.20	19.64	19.12	198.15
TOTAL EAST	2685.32	2407.65	2586.89	2355.72	2762.95	2718.53	2798.53	2707.07	2463.80	2458.16	2371.33	2641.68	30856.63
TOTAL	3967.163	3537.392858	3845.292635	3530.51	4161.283	4113.547	4167.615	3905.983	3559.631	3645.654	3466.534	3881.397	45782.00219

Table 2. Santo Domingo Aqueduct and Sewerage Corporation (CAASD). Monthly production of well fields in millions of gallons per month, 2011 (Source: Santo Domingo Water and Sewerage Corporation. CAASD)

													2011
Systems/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
LECHERIA	98.060	76.950	90.480	80.610	83.220	107.280	116.900	113.460	108.310	122.630	121.400	109.800	1229.100
SECTORAL	33.768	28.289	28.314	12.873	15.244	14.880	10.084	13.319	18.896	27.108	26.046	29.896	260.717
TOTAL NORTHWEST	131.828	105.24	118.794	95.483	98.464	122.16	126.984	126.779	127.206	149.738	147.446	139.696	1489.817
CAFÉ WELL FIELD	131.828	105.24	118.794	95.483	98464	122.15	126.984	126.779	127.206	149.738	147.446	139.696	1489.817
LAS CAOBAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.000
SECTORAL SYSTEMS	182.140	165.290	184.260	166.790	174.210	176.430	175.053	163.780	139.980	181.800	172.874	161.197	2043.804
TOTAL SOUTHWEST	208.59	190.06	214.35	196.11	201.44	196.81	195.623	182.61	157	195.83	186.624	178.217	2303.263
MATA-MAMON I AND II	39.712	42.725	55.670	65.647	65.585	67.040	66.183	58.408	49.210	35.630	33.711	40.737	620.258
SABANA PERDIDA	173.929	159.965	182.252	167.156	146.635	143.132	133.524	133.138	125.093	147.088	148.672	152.127	1812.613
SABANA PERDIDA	64.578	60.876	68.223	59.843	34.104	38.664	32.290	30.690	29.111	35.395	34.770	38.798	527.342
SAN FELIPE	38.471	30.555	31.193	28.466	22.504	27.302	16.750	13.012	20.637	16.958	12.953	7.335	266.736
SECTORIALES	441.481	365.330	414.922	402.810	401.634	429.286	428.381	407.857	399.706	453.146	403.303	414.502	4962.358
TOTAL NORTE	717.38	606.45	727.66	712.16	917.49	922.377	887.27	863.023	746.58	820.68	767.02	861.116	7800.24
LOS MAREÑOS	485.230	482.420	571.300	619.050	508.180	476.070	494.680	476.460	458.360	219.910	285.100	281.090	5458.850
EL NARANJO	155.090	143.340	148.240	149.880	126.590	108.520	122.920	121.220	67.370	96.220	120.940	123.940	1484.170
LA CATALINA	134.990	135.460	161.480	164.480	153.300	172.300	212.780	146.590	138.820	174.620	166.540	179.680	1941.040
LA JOYA	541.370	581.640	710.880	598.590	525.750	567.420	499.300	450.560	564.860	512.900	420.230	351.470	6324.970
LA CALETA	151.160	170.750	183.880	169.930	169.650	135.690	158.040	98.160	85.510	172.740	173.150	176.140	1844.800
BRUJUELA	430.820	393.880	380.660	361.730	350.900	335.480	432.470	410.283	412.410	417.120	452.650	475.710	4853.413
SECTORAL	35.380	31.970	32.250	32.640	35.110	34.370	33.450	40.140	26.010	23.000	29.160	29.490	183.070
TOTAL EAST	2685.32	2407.65	2586.89	2355.72	2762.95	2718.53	2798.53	2707.07	2463.80	2458.16	2371.33	2641.68	22290.313
TOTAL	3967.163	3537.392858	3845.292635	3530.51	4161.283	4113.547	4167.615	3905.983	3559.631	3645.654	3466.534	3881.397	33946.97

Table 3. Santo Domingo Aqueduct and Sewerage Corporation (CAASD). Monthly production of well fields in millions of gallons per month, 2013 (Source: Santo Domingo Water and Sewerage Corporation. CAASD)

													2013
Systems/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
LECHERIA	105.410	98.60	123.810	112.019	108.800	108.160	108.800	104.010	95.270	70.510	88.870	130.030	1255.289
SECTORAL	26.480	28.340	30.856	17.156	29.880	20.270	15.372	17.352	23.642	20.848	26.560	21.004	277.529
TOTAL NORTHWEST	131.89	126.94	154.666	130.175	138.68	128.43	124.172	121.362	118.911	91.358	115.43	151.034	1533.048
CAFÉ WELL FIELD	35.630	31.910	35.000	31.680	35.160	34.890	35.440	34.150	30.660	29.730	20.020	35.130	398.400
LAS CAOBAS													
SECTORAL SYSTEMS	227.250	198.180	205.780	158.980	165.820	169.180	173.240	178.000	175.320	176.140	175.260	174.020	2176.170
TOTAL SOUTHWEST	262.88	230.09	240.78	190.66	200.98	203.07	280.68	212.25	205.98	205.87	204.28	209.15	2574.57
MATA-MAMON I	20.911	20.450	19.730	15.375	14.157	10.841	19.956	11.179	8.332	25.270	27.909	28.771	222.914
MATA-MAMON II	141.462	149.193	157.223	140.023	139.006	141.332	134.542	132.960	137.351	146.479	139.609	115.035	1674.215
SABANA PERDIDA	39.846	35.624	39.058	36.176	36.725	34.804	35.552	30.308	28.348	38.443	57.810	58.716	471.410
SAN FELIPE	26.774	24.019	26.077	22.675	25.868	23.702	21.940	25.114	16.735	22.435	19.003	20.407	274.779
SECTORAL	350.155	339.061	353.536	331.031	363.769	336.403	339.212	331.284	300.549	340.383	328.627	382.665	4096.675
TOTAL NORTH	644.925	596.88	624.451	548.862	592.1819	563.089	569.944	564.736	520.952	577.401	580.7	635.808	7019.0339
LOS MAREÑOS	532.410	395.410	532.480	440.330	427.420	313.280	378.380	377.110	398.920	427.950	319.420	254.920	4797.930
EL NARANJO	112.420	88.200	111.090	68.430	65.080	61.540	61.850	63.470	65.310	51.360	45.030	74.210	867.990
LA CATALINA	123.580	114.980	128.390	117.490	124.390	94.410	70.250	67.780	208.880	200.870	208.030	228.830	1687.880
LA JOYA	112.420	461.510	483.800	497.140	470.130	412.700	409.170	417.100	550.610	506.590	506.080	421.470	5604.480
LA CALETA	186.200	122.400	143.630	176.050	189.930	164.370	181.370	181.370	176.530	144.040	162.270	185.140	2013.300
BRUJUELA	364.690	331.780	332.090	325.460	294.930	248.140	267.120	268.340	313.050	295.040	260.500	318.430	3619.570
SECTORAL	31.950	31.250	34.650	31.310	32.910	30.940	30.171	30.140	33.910	32.280	31.860	33.935	385.306
TOTAL EAST	1819.4	1545.53	1766.13	1656.21	1604.79	1325.38	1398.311	1405.31	1747.14	1658.13	1533.19	1516.935	18076.456
TOTAL	2831.137	2489.787	27.584	2504.075	2501.7979	2197.981	2276.037	2281.006	2580.763	2558.15	2428.759	2441,798	29845.8749

Table 4. Amount of water flowing daily into the city of Santo Domingo

Water supply sources for the aqueduct in the city of Santo Domingo can be divided into three groups:
1. Surface sources Isa, Mana, Duey, Guananitos, Haina, Isabela, Barrera Salinidad: 142 million gallons/day= 35%.
2. CAASD Wells: 138 million gallons/day= 33%.
3. Valdesia Dam:130 million gallons/day= 32%.

Source: CAASD

The following tables show the flows produced by the well fields built on the Eastern Coastal Plain, which supply the city of Santo Domingo.

2.1 Impacts of Urbanization on the Quantity and Quality of Water in the Dominican Republic

Urban growth in the Dominican Republic has severely impacted the quantity and quality of water available in major urban centers, to the extent that since the 1970s it was necessary to begin an extensive program for constructing dams, which now total approximately 34 and store about 2,500 million cubic meters of water, often a long way from urban centers, where residential and industrial pollution is much lower than in urban areas. These dams supply water, since the direct intake from major urban areas near rivers was insufficient for the growing demand, especially during long periods of drought. This situation is exacerbated by the high levels of urban pollution due to the lack of sewerage, residential and industrial wastewater treatment plants, landfills to properly dispose of solid waste, and public policies to protect water sources, since although the waters are protected by environmental legislation 64-00, this protection is not enforced.

2.2 Main Sources of Water Pollution in Santo Domingo

Thousands of filter wells constructed illegally in the city of Santo Domingo to discharge the waste from residential toilets due to the lack of a proper sewerage system for the entire city; the thousands of poor people without basic services who live on the banks of the Ozama, Isabela and Haina rivers and the streams that are tributaries of these rivers; the thousands of industries that lack treatment plants for their effluents, and waste dumps on permeable materials are the main sources of pollution of surface and groundwater in Santo Domingo, which is not being effectively addressed by the authorities.

2.3 Overexploitation of Water in the Dominican Republic

The main case of over-exploitation of water in the Dominican Republic involves groundwater from the city of Santo Domingo, where 33% of the daily supply is obtained from groundwater sources; and the tourist resort of Boca Chica, where 100% of the water is groundwater, drawn mainly from the Brujuelas-Casuí well fields; and Punta Cana and Bávaro, the main tourist destination in the Caribbean region, where 100% of the water supplied to the hotel business is groundwater, due to the absence of surface water sources, a regional aqueduct or dams, all of which means that hotels have had to resort to the widespread use of coastal aquifers in recent coralline limestone, leading to an extraordinary overexploitation of the aquifer, which has already produced various processes of saline intrusion, which in Bávaro has advanced four kilometers inland, and 15 kilometers in Boca Chica, partially damaging this important porous coastal aquifer, despite which the authorities have yet to decide to build a regional aqueduct, supported by dams built on major rivers in the east area.

2.4 Water Sources and the Distribution of the Urban Population

Since the time of colonization, from 1492 onwards, the major urban population centers in the Dominican Republic have developed on the banks of major rivers or nearby, in an attempt to be near drinking water sources. As urban areas have grown and urban water networks have extended laterally, many urban sectors have moved further away from rivers. It is now no longer as necessary to live near rivers as it was in the past, especially since many people have become aware of the dangers and risks involved. Since this is a tropical country, during periods of intense rains, storms and hurricanes, rivers may overflow and produce social disasters such as those experienced during Hurricane David and Storm Frederick in September 1979, Hurricane Georges in September 1998, the Jimaní Storm in May 2004, Storm Noel in October 2007 and Subtropical Storm Olga, in December 2007.

Nowadays, the Dominican middle and upper classes no longer need to live near rivers and streams to obtain access to safe drinking water, because dams and aqueducts are responsible for capturing and transporting water from tens of kilometers away. However, in marginalized human settlements, lack of economic resources forces very poor people to settle on the banks of rivers and streams in order to be able to gain access to water, even though it is not potable, which constitutes a social problem that the state should help resolve by relocating these people to other areas where they can have better living conditions.

2.5 Water Pollution in Informal Periurban Settlements

The most severe problems of urban water pollution and the resulting waterborne diseases affect informal settlements, which for decades have developed on the banks of the Ozama river, the Guajimía, Bonavides and Diablo ravines, and nearly 80 other ravines, mostly concentrated in the north and west parts of the city of Santo Domingo, where diseases such as cholera, gastroenteritis, amoebiasis, and frequent diarrhea have affected dozens of residents living on the periphery.

This situation occurs throughout the country, where extremely poor people settle on the banks of rivers, streams, and ravines, without having the basic services required to ensure their health.

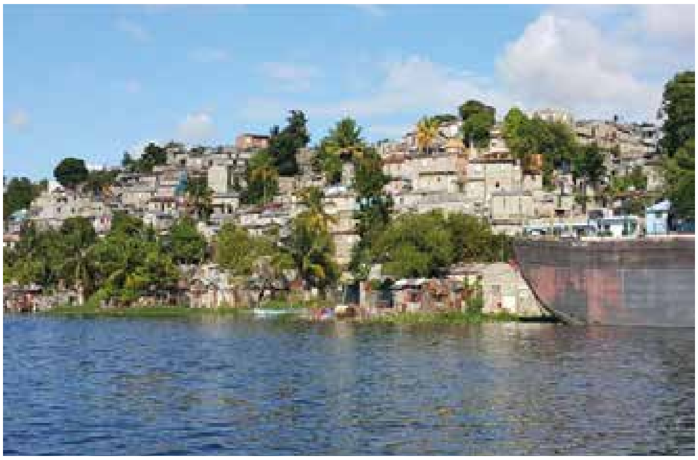
Photo 3. View of marginalized housing on the banks of the mighty river Ozama in Santo Domingo, which has become a permanent source of organic bacterial contamination and large amounts of refuse. Photo Osiris de León

3. Water Supply in the Urban Areas of the Dominican Republic

In the Dominican Republic, according to data published by the Demographic and Health Survey (DHS) and the United Nations Development Program (UNDP), 92% of the urban population have access to water indoors or very near their homes (improved water sources). However, according to the Ministry of Public Health of the Dominican Republic, the actual percentage is lower and stands at 87%.

However, the quality and potability of water entering homes through pipes means that it is not completely safe to drink, because while it is true that water treatment plants for human consumption are generally handled correctly, in actual fact, water is often contaminated in the distribution pipes, meaning that people trust bottled drinking water more than tap water, since nowadays very few people in the Dominican Republic drink water from the tap.

Photo 4. View of extraordinary spread of housing on the banks of the Ozama River in Santo Domingo. Photo Osiris de León



According to the Social Policy report (2010) prepared by the United Nations Development Programme (UNDP), by 2015, the total number of urban households with improved water services is expected to be 92%, although the Millennium

Development Goal (MDGs) for 2015 is for 98.5% of the urban population to have access to water indoors or very close to their homes, and fewer than 2% of the urban population to lack water services indoors or very close to their homes, a goal that apparently will not be achieved, as the population has grown more quickly than the potable water supply.

The Table 5 shows the percentages of Dominican households with access to piped water inside or outside their dwelling.

The Table 6 shows the percentages of Dominican households with access to piped water inside or outside their dwelling, the aim being to reduce the latter.

On the basis of the statistical data produced by ENDESA and ENHOGAR, over the past 20 years, the percentage of households consuming bottled water rose from a mere 8.8% in 1991 to 64.3% in 2011, mainly in urban zones. This is due to the fact that many people distrust the quality and potability of wastewater supplied through the pipes in urban aqueducts. Since these pipelines do not operate continuously 24 hours a day, they often receive external contamination through damaged joints, major breakages, faulty connections, or adjacent sewer pipes.

Fifty per cent of the Dominican urban population receive water through networks built

Table 5. Percentages of Dominican households with access to piped water inside or outside their dwelling

Zone	1996	2002	2007
Urban	97.0	90.7	91.9
Rural	56.0	63.8	73.3
Total	81.2	81.1	86.2

Sources: ENDESA surveys for 1996, 2002 and 2007 surveys, and UNDP 2010

Table 6. Percentages of Dominican households without access to piped water inside or outside their dwelling

Zone	Households without access in %					Growth effort	
	1996	2002	2007	2015			
				Expected by trend	Goal	By trend	Necessary
Urban	3	9.3	8.1	8.6	1.5	-0.72%	-19.00%
Rural	44	36.2	26.7	18.6	22	-4.40%	-2.40%
Total	18	18.9	13.8	11	9.4	-2.80%	-4.70%

Sources: ENDESA surveys for 1996, 2002 and 2007 surveys, and UNDP 2010

Table 7. Percentage distribution of drinking water sources in Dominican households

Source of supply	ENDESA 1991	ENDESA 1991	ENDESA 1991	ENHOGAR 2011
Indoor pipes	20.4	9.1	9.4	4.3
Outdoor pipes/in another dwelling or public tap	46.2	19.3	13.0	9.6
Well	3.6	2.5	2.0	1.5
Spring, river or stream	9.7	2.8	1.8	2.7
Rainwater	9.0	9.0	6.7	6.5
Tanker truck	1.1	2.0	0.6	1.7
Bottled water	8.8	55.0	55.7	64.3
Small truck	-	-	10.6	8.2
Other source	1.1	0.2	0.3	1.0
Doesn't know	-	0.1	-	0.0

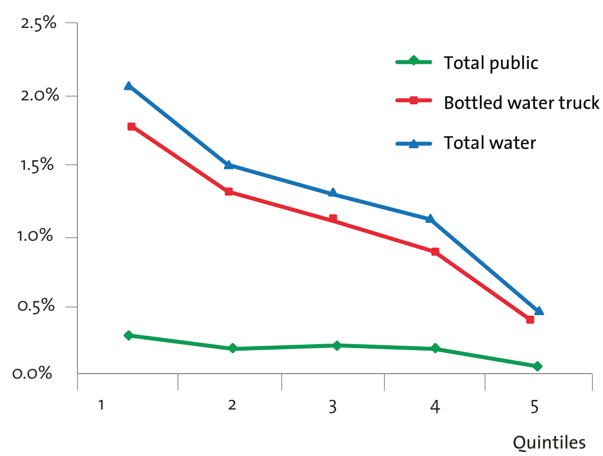
ENDESA Surveys 1996, 2002 and 2007, ENHOGAR Survey 2011 and UNDP 2010 by the National Institute of Water and Sewerage (INAP). This does not, however, include major cities such as Santo Domingo, a city that is home to 35% of the Dominican population, whose water services are provided by the Santo Domingo Aqueduct and Sewerage Corporation (CAASD), and includes Santiago, a city that comprises 8% of the Dominican population, whose water services are provided by the Santiago Aqueduct and Sewerage Corporation, while the remaining 7% is served by local water corporations.

This situation means that many middle-class households must assign between 2% and 3% of their income to purchasing bottled water, as the only means of drinking water, although bacteriological studies have often shown that many of the bottled waters sold in the Dominican Republic are contaminated with different types of bacteria, mostly fecal coliform bacteria due to the lack of permanent supervision of companies that sell bottled water.

3.1 The institutions that supply drinking water in the Dominican Republic

The National Institute of Drinking Water and Sewerage is the official institution responsible for supplying drinking water to most of the Dominican Republic (84.40%), followed by the Aqueduct and Sewerage Corporations that have local competences such as the Santo Domingo Aqueduct and Sewerage Corporation (CAASD), a public institution supplying drinking water to the 3.5 million inhabitants of the city of Santo Domingo, and the Santiago Aqueduct and Sewerage Corporation (CORAASAN), which provides the water

Figure 1. Monthly expenditure on water of Dominican households as a percentage of total income



Source: United Nations Development Program Office (UNDP 2010)

consumed by the nearly 700,000 inhabitants of the city of Santiago de los Caballeros, the second largest in the country, although in terms of geographic area, CORAASAN covers a larger area than CAASD albeit with a smaller population.

To meet the objectives of providing safe drinking water to the Dominicans, the National Institute of Drinking Water and Sewerage receives 74.08% of the budget assigned for the drinking water and sanitation sector, CAASD receives 21.07%, CORAASAN receives 3.88%, while the remaining local water and sanitation corporations receive less than 1% of that budget. These financial resources should be distributed more efficiently to match the actual scope of each institution.

Table 8. Percentage of Dominican territory covered by institutions that supply water and amount of aqueducts

Institution	Operational Jurisdiction Area		Number of Aqueducts
	Km2	%	
National Institute of Drinking Water and Sewerage (INAPA)	41,083.90	84.40%	448
Santo Domingo Aqueduct and Sewerage Corporation (CAASD)	1,400.80	2.90%	15
Santiago Water and Sewerage Corporation (CORAASAN)	2,836.50	5.80%	4
Moca Water and Sewerage Corporation (CORAAMOCA)	838.6	1.70%	6
Puerto Plata Water and Sewerage Corporation (CORAAPLATA)	1,856.90	3.80%	32
La Romana Water and Sewerage Corporation (CORAROM)	654	1.30%	8
Total	**48,670.60**	**100%**	**513**

Source: United Nations Development Programme Human Development Office (UNDP 2010) based on data supplied by the National Institute of Hydraulic Resources (INDRHI).

Table 9. Percentage of the Dominican population covered by institutions that supply water

Firm	Urban Area		Rural Zone		Totales		
	Male	Female	Male	Female	Male	Female	Total
CAASO	93%	94%	72%	73%	89%	89%	89%
CORAAMOCA	90%	92%	66%	67%	75%	77%	76%
CORAPP	91%	92%	62%	64%	76%	78%	77%
COAAROM	83%	83%	76%	75%	82%	83%	82%
CORAASAN	97%	97%	0%	0%	97%	97%	97%
INAPA	82%	83%	58%	60%	70%	72%	71%
Total	**88%**	**89%**	**61%**	**63%**	**78%**	**80%**	**79%**

Source: United Nations Development Programme Office (UNDP 2010)

3.2 Water Availability in the Dominican Republic

Although in general terms, except during the years of long droughts, Dominicans have sufficient volumes of water, the water supply map drawn up by the National Institute of Water Resources (INDRHI), although valid, fails to reflect the reality of water availability in the country, since the map was drawn on the basis of water availability per capita, and the areas of greatest total water availability, such as the city of Santo Domingo and the Cibao Valley, where the Ozama-Nizao, Yuna and Yaque irrigation zones are located, are the most heavily populated, while the areas with the lowest water availability, such as the Yaque del Sur irrigation zone, are the least populated.

The population is obviously more heavily concentrated in regions where there is greater water availability to meet their needs, including both urban and rural communities, since cities in central and east Cibao Valley, where there is greater water availability, have grown much more than cities in the West Cibao Valley cities and Neiba Valley, where water is scarce.

Given the challenges of climate change, it is essential for the Dominican Republic to continue constructing dams for water storage during periods of intense rainfall due to heavy rains, storms and hurricanes, which are typical of the Caribbean tropical summer, and for all that water to be available in times of drought, since in recent years, very few public funds have been invested in the construction of dams for water storage, while virtually nothing has been invested in the maintenance of the watersheds feeding the dams or dredging to remove the sediment accumulated in the dam reservoirs. The demand for drinking and irrigation water is growing rapidly and these challenges must be addressed through appropriate public policies defined by experts in the field, leaving nothing to improvisation or chance.

3.3 The Enormous Wastage of Water in the Dominican Republic

For decades it has been pointed out that in the Dominican Republic, about 60% of the water in primary networks is lost due to the obsolescence of the distribution system, malfunctions and the

INAPA: 60% of water lost through faults and citizens' misuse
El Día. July 31, 2014

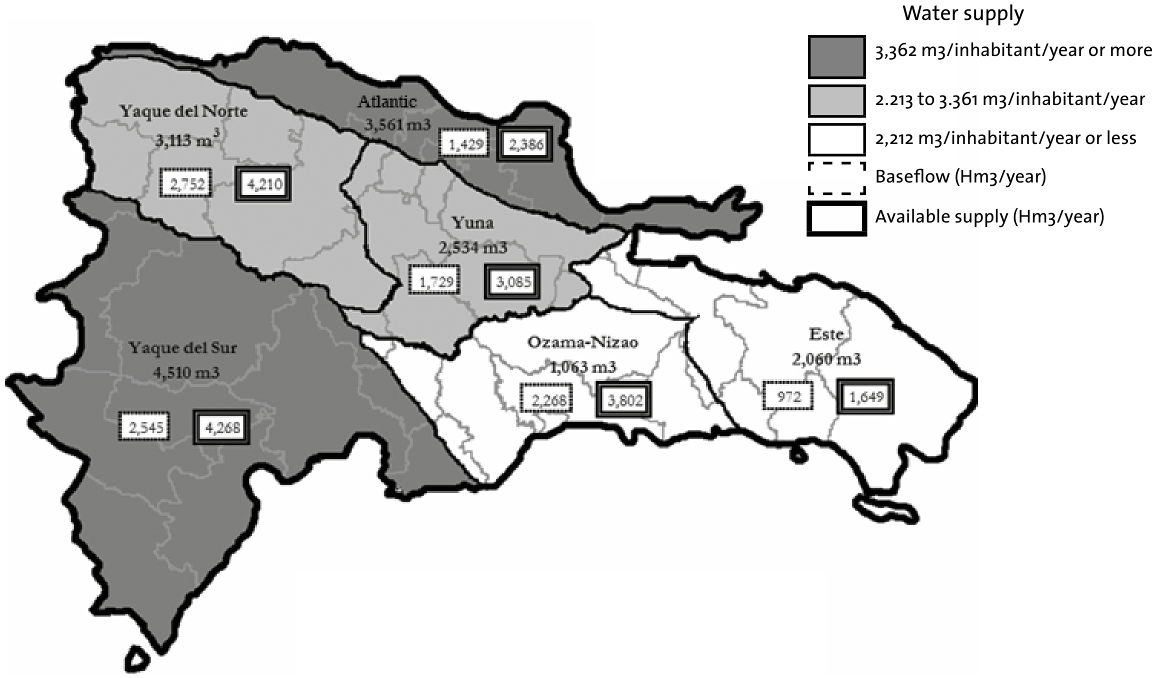
Throughout the country, it is estimated that nearly 60% of the water produced is lost due to faults and citizens' misuse, according to the National Drinking Water and Sewerage Institute (INAP).

Director of the institution Alberto Holguín said that of the 56 treatment plants existing in the country, 14 are in operation, while approximately 20 are under repair.

"We currently have an investment of $150 million USD, with a program in which the government has already provided an advance payment of six billion pesos for sewerage in San Fernando, Villa Vásquez de Montecristi, San Cristobal, Azua and Neiba," he said.

He declared that 45% of the institution's investments are currently assigned for sewerage, whereas in 2012 only five percent were invested and in his view, attention should be paid to this aspect, while political and social leaders should be asked to allocate more resources to this issue.

Figure 1. Water supply in the Dominican Republic, according to the six different regions defined by the National Institute of Water Resources INDRHI



Source: PNUD, 2010.

inhabitants wasteful use of water in their homes, because since water costs very little, just $ 0.14/cubic meter, and many do not pay, people waste it and place very little value on it. It is therefore necessary to launch a mass media education program for the population on proper water use, but also to establish a sliding scale of rates, whereby high consumption above the norm (250 liters per person per day) is penalized through extremely high rates.

3.4 Drought, Waste and Current Water Crisis in Santo Domingo

Not since the mid-90s had the cities of Santo Domingo and Santiago suffered a crisis as severe as the one in 2014, the result of a long drought that reduced water reserves in the Valdesia and Tavera Dams.

As a result of the severe drought in 2014, Director of the Santo Domingo Aqueduct and Sewerage Corporation (CAASD) Alejandro Montas said that the capital city was receiving 100 million gallons of water less than the normal rate of approximately 408 million gallons of water per day to supply about 3.5 million inhabitants of the capital. This shows that greater Santo Domingo was receiving 25% less water, in addition to the 60% of water wasted due to the obsolete networks and damaged pipelines. Meanwhile, the population in the Capital continues to expand and demand more water, and given that the public is given insufficient education and guidance about the correct use of water, frequent crises in the water supply of large urban centers can be expected.

The severe drought of 2014 forced the government institutions administering the waters for human consumption and irrigation to change the administration of the water stored in the Valdesia Dam, from which six cubic meters per second must flow into the Santo Domingo Aqueduct and 12 cubic meters per second into the Marcos A. Cabral Aqueduct. Since the Valdesia Dam is now about 23 feet below its crown, the authorities have had to ration water for the Marcos A. Cabral canal and prioritize water for human consumption in the Santo Domingo aqueduct.

A similar situation occurred in the city of Santiago de los Caballeros, where the water supply was reduced by 30%, since for much of 2014, the level of the two reservoirs in the Tavera and Bao dams, linked by a canal, was 18 meters below its crown, and eight meters below its critical level, significantly affecting everyday life in the country's second largest city.

Drought-driven Water Crisis Affects approximately 100 Inapa Aqueducts
Hoy. July 3, 2014

Approximately 100 (28%) of the 315 water drinking water systems administered by the National Institute of Water and Sewers (Inapa) in 29 of 32 provinces have been affected by the severe drought prevailing in the country in recent months.

A general report on the situation, provided by Inapa Director of Operations Nicolás Garrido Almonte says that there are aqueducts that are only serving 50% of the water delivered under normal circumstances.

Meanwhile, the National Water Observatory, which leads the National Institute of Water Resources (Indrhi) admits that farmers in the southern region have been affected by the rationalization of the water supply to this area three days after the drought affecting the Valdesia and Jigüey dams.

Critical Levels in Reservoirs Feeding the Gran Santo Domingo
Diario Libre. July 24, 2014

With the Jigüey Dam and the Valdesia Dam system, the two systems that contribute most to the Gran Santo Domingo water supply, with just 3% and 11% of their useful water supply capacity respectively, Director of the National Institute of Water Resources (Indrhi) Olgo Fernández, commended himself to God and the predicted rain for the weekend, hoping that the water crisis affecting the country would improve over the next few days.

"All we can do is ask God for rain," said Fernández, who explained that in the rest of the country, reservoir levels are at 34.84%. However, he emphasized the status of the systems serving Santo Domingo , San Cristóbal and Baní.

The national situation is "manageable" and irrigation and power generation activities can continue, together with human consumption, said Fernández, although concern over the intakes previously mentioned persists.

Director of the Santo Domingo Water and Sewerage Corporation of (CAASD), Alejandro Montas described current levels as "critical" and announced that if the crisis worsens, a strict water distribution plan has been prepared.

This worrying situation requires urgent government strategies to capture every drop of rain that falls on the country; together with the proper administration of all available flows in dams, irrigation canals and aqueducts networks; the reduction and subsequent elimination of all sources of contamination of surface and groundwater, the optimization and proper use of urban water, the elimination of water leaks in networks and households, and payment of fair prices for water services for aqueducts and irrigation channels, because here we all believe that water should be free forever, despite the fact that it is the most important natural resource for life, and since water is free, no-one values it, since users do not value what is free.

INDRHI reports that, "all the country's Reservoirs are in a critical condition"
Diario Libre. July 31, 2014

All the country's reservoir systems are in critical condition," warned the National Institute of Water Resources (INDRHI), an organization that leads the Water Observatory, which evaluates the disposal of the country's liquid on a weekly basis, together with the short- and medium-term perspectives.

Olgo Fernández, the director of the institution, said that although the reservoirs that feed the provinces of Peravia, San Cristobal, Santo Domingo and the National District are in the most critical condition, "The country's other basins are also in a critical condition. They are at the red stage."

Fernández noted that, "When a basin is at the red stage, it is because it is below its normal level. Once this happens, it must be observed and operated on a schedule, as is done in the observatory." He said the Taveras reservoirs and Lower Angostura, "Must have their operating levels rescheduled, because they have fallen. Sabana Yegua's has too. And so has Sabaneta's, proving that the country is still affected by the stationary drought that hit us in recent months."

He explained that this problem will not be solved, "Until it rains heavily, and the basins are filled with water and the soils are saturated, so that the rain can drain the dams. That is what we are hoping will happen in the next few days."

3.5 Rationing and the Higher Cost of Scarce Water

Society must understand that water is a vital natural resource, but a finite one, which is valued in an inverse proportion to its abundance, since those with very little water value it highly and waste very little, while those with plenty of water undervalue it and waste a great deal.

It should also be made quite clear that a major challenge of today's society is to address the imbalance between geometric population growth and the linear reduction of river flows. This imbalance is exacerbated when population growth does not go hand in hand with sanitation, and instead of building proper sewage systems, what we do is discharge our domestic and industrial wastewater into urban ravines, streams and rivers wastewater, polluting the already diminished flow of our streams and making people sick.

People drink a great deal of water, but most people do not know where water comes from, let alone how much it costs to capture, purify and bring it to homes. They are not interested in knowing, because for many people these data are not important. This ignorance explains why people place very little value on the water in their homes, and simply say that the government is required to supply drinking water through networks that reach our homes, and that if the government fails to do so, then we will organize strikes, call the press, and exert pressure until we are provided with water, which will solve the problem.

Governments should consider the possibility of providing the first 150 liters of water free for every citizen, approximately 750 liters for the average household, after which any additional volume of water consumed should be charged at very high rates, as a means of forcing water use to be rationed and of reducing losses due to careless use. Sooner or later, this measure will be compulsory.

To give one example of curbing excess water use and wastage, the Municipal Water Department in Santa Cruz, California, decided that as of May 2014, water supplies should be rationed, giving each household a ceiling of 28,317 cubic meters of water per month, equivalent to 943 liters of water a day. Those who exceed this level must pay up to four times the monthly bill of about $40 for permitted consumption levels.

3.6 Conflicts Over the Use of Scarce Water

In the Dominican Republic, there is an increasing gap between water demand and availability, and although it is true that since 1995 the Dominican Republic had not suffered such a severe drought as the one it experienced from December 2013 until winter 2014, it is also true that the sedimentation of most of the dams has reduced their water storage capacity, which, added to the lack of investment in the construction of new dams, and the large leaks in the aqueduct networks and the wastage in homes and irrigation canals, led the country to suffer one of the worst droughts in all history, which found almost all the population ill-prepared for dealing with the situation, severely affecting major sectors of producers of food for local consumption and export. This affected the country's economy and the quality of life of many people, and today certain communities, including the province of Peravia, take to the streets demanding better water management, so as not to be affected again, which has turned into a conflict over water use.

Another example of conflicts over water used occurred in the community of Sabana Iglesia, adjacent to the Bao Dam, where a crowd of 300 people seized the operating station of the water supply system linking the Tavera and Bao dams to the Santiago and Moca aqueducts. Under normal conditions, this system provides approximately 125 million gallons per day to Santiago and about 25 million gallons per day to Moca, but nothing to Sabana Iglesia or Baitoa, the communities closest to both dams.

The crowd gathered there shut off the water flow to Santiago and Moca, claiming that if they, who are owners of those two dams, have no water, then Santiago and Moca cannot have water either, which is a serious sign of conflicts over water, which are likely to increase unless water management improves.

The newspaper clipping taken from the *El Caribe* newspaper, dated July 30, 2014, clearly shows one example of conflicts over water use in the Dominican Republic.

Crowd turns off valve, leaving Moca and Santiago without Water
El Caribe. July 30, 2014

A crowd demanding drinking water service for the town of Sabana Iglesia turned off the valve on the intake at the Tavera dam, depriving the Moca and Santiago communities of water.

Approximately 300 residents from Sabana Iglesia went to the intake, tied up the operator, and shut off the valve controlling the water supply to Santiago and Moca.

The Moca Aqueduct and Sewerage Corporation (Coramoca) reported that the city only receives 100 liters of water per second.

The water crisis in communities that receive very little water and on an intermittent basis was exacerbated, since most of them did not have time to stock up.

They suggest that the water supply should be administered by the Santiago Aqueduct and Sewerage Corporation (Coraasan) rather than Inapa, which is currently responsible.

3.7 Basic Sanitation and Urban Water Pollution in Santo Domingo

Santo Domingo, the capital, with a population of nearly 3.5 million people, concentrated in about 300 square kilometers, has grown rapidly as a result of migration from the countryside to the city. This growth has not been accompanied by the provision of basic sewerage, since the city is built on a terrace system of highly porous coralline limestone, which are the main aquifer in the country. They receive an annual net recharge of approximately 1,100 million cubic meters of rainwater, but in the absence of adequate sewerage, all new buildings, apartment blocks, industries, schools and hospitals, dispose of their sewage through vertical filter wells that discharge directly into the same groundwater we later extract through adjacent wells to supplement the precarious and intermittent water service. Our tanks therefore combine the drinking water supplied through pipes with the water we extract from the contaminated subsoil, and despite knowing that this groundwater is full of fecal coliform, we are forced to brush our teeth and bathe in the same water we previously discharged through our toilets, which would be unacceptable in an organized society, committed to health and basic sanitation.

Just 5% of the population in the Dominican capital have proper sewerage. There is an urgent need for the Dominican government to make the necessary investment in modern sewerage for buildings that have already been constructed, which may involve an investment of approximately two billion USD. It also requires the establishment and implementation of strict legislation obliging the developers of new housing projects to provide their own sewerage and wastewater treatment plants, all of which must be strictly controlled by the Ministry of the Environment and the Ministry of Public Health as a means of solving the problem within a period of not more than 12 years, equivalent to three periods of government.

The newspaper clipping taken from the *La Información* newspaper, dated December 4, 2012, shows that the highest authority of the Santo Domingo Aqueduct and Sewerage Corporation (CAASD) admits that over 3 million people in Santo Domingo have a dysfunctional sewage service, and that only 5% of that population have sewerage.

CAASD presents Master Sewage Plan for Santo Domingo and its Province
La Información. December 4, 2012

Over three million inhabitants of Greater Santo Domingo have wastewater treatment service that does not function properly, according to a study presented by the Santo Domingo Aqueduct and Sewerage Corporation (CAASD).

During his presentation of the "Master Sewerage Plan for Santo Domingo and its Province" research project, Alejandro Montás reported that only five percent of that population has sewerage system coverage.

The CAASD director said that the study was conducted by the consulting firm Hazen and Sawyer, with funding from the Inter-American Development Bank (IDB).

The results showed that 95 percent of the population discharges its waste into the subsoil through filter wells, and through ravines and rivers that reach the Caribbean.

Montás stressed the importance of the study, adding that it is the first step that will allow the government to have a tool with viable solutions to facilitate decision-making to build a new sewerage and storm drain system.

He said that the Master Plan will allow Greater Santo Domingo to be cleaned up and help decontaminate the Ozama, Isabela and Haina rivers and the south shore on the Caribbean Sea.

4. Improved Sanitation Coverage and Millennium Development Goals

Improved sanitation, meaning the availability of a private toilet or latrine adjacent to the household, has grown significantly in the Dominican Republic from 69.8% urban coverage in 1996, to 84.5% urban coverage in 2007. By 2015, 91.5% of the urban population is expected to have improved sanitation.

The Tables 10 and 11 show that in 1996, 64.2% of the total Dominican population had improved sanitation coverage, which had risen to 80.3% by 2007.

These favorable results indicate that significant progress has been made in improved basic sanitation, since almost all people with some schooling realize the importance of having a suitable place to properly dispose of personal and household organic waste.

4.1 Although the Problem is global, Each Country Must Find its Own Solutions

The World Health Organization (WHO), through its Department of Public Health and Environment, presented its latest global statistics on progress in access to drinking water and basic sanitation, stating that nearly 2.5 billion people worldwide lack access to basic sanitation facilities, indicating that a third of the world population has serious problems with the final disposal of its contaminating excreta, the main cause of surface and groundwater pollution worldwide.

The total lack of basic sanitation services is directly related to the spread of diseases such as cholera, diarrhea, dysentery, hepatitis A and typhoid, whose treatment costs and indirect costs due to absenteeism far outweigh the cost of installing sewerage, which is why each of the countries affected by this problem must make the necessary investment to ensure that the entire population is gradually provided with basic sanitation services.

In this order of ideas, the WHO admits that Ecuador, Honduras and Paraguay have made significant investments to improve public access to sanitation facilities, whereby they have achieved 25% more coverage since the early 1990s. However, Bolivia and Haiti are still the countries in Latin America and the Caribbean with the lowest rates of access to health care systems, meaning that international organizations must prioritize investments and loans to expand sanitation coverage, and that national and local governments must do the same, to eliminate the bad practice of defecation in the open air. In the book of Deuteronomy 23:13, the fifth book of the Old Testament, written some 3,500 years ago, it clearly states that , "You shall have a stick with your weapons and when you sit down outside, you shall dig a hole with it, and turn back and cover up your excrement," indicating that for more than three millennia, people have known that excreta left outdoors pollute the environment.

The WHO states that Latin America and the Caribbean have the highest rate of potable water in developing regions, achieving 94% coverage of water services. Nevertheless, there are a total of 748 million people worldwide without access to safe water, in other words, 10% of the world population lack water services, and it should be a priority for rich countries to help poor countries to concentrate investments in projects that increase potable water services.

In terms of access to basic sanitation and drinking water for human consumption, the WHO states that the most notable progress in Latin American since 1990 corresponds to Paraguay with 33% and 35% respectively; Honduras with 30% and 26%; Guatemala with 28% and 29%; Mexico with 21% and 19%; Colombia with 18% and 16%; Chile with 18%

Table 10. Percentage of Dominican households with access to improved sanitation inside or outside the dwelling

Zone	1996	2002	2007
Urban	69.8	78.2	84.5
Rural	53.3	68.9	70.8
Total	**64.2**	**74.9**	**80.3**

According to the ENDESA 1996, 2002 and 2007 surveys and UNDP 2010

Table 11. Millennium Development Goals for 2015 in terms of improved sanitation, and expected results as a percentage of the population without access to improved sanitation

Zone	Households without access in %					Growth effort	
	1996	2002	2007	2015			
				Expected by trend	Goal	By trend	Necessary
Urban	30.2	21.8	15.51	9.5	15.1	-5.88%	-0.33%
Rural	44.7	31.1	29.2	21.4	22.3	-3.80%	-31.10%
Total	35.8	25.1	19.7	12.7	17.9	5.29%	-1.19%

Sources: ENDESA Surveys 1996, 2002 and 2007 and UNDP 2010.

and 15% respectively, while the Dominican Republic improved by just 17% and 9%, respectively, making it the country that achieved the least in this group.

The WHO report shows that over the past 22 years, a third of the world population (2.3 billion people) gained access to clean water suitable for human consumption, while two billion people achieved basic sanitation, reflecting substantial progress, which although insufficient, demonstrates a commitment to finding solutions to these two major social problems.

In terms of drinking water, in the early 1990s, 95% of urban residents had access to the supply of this basic service, whereas only 62% of rural residents had water service. However, 22 years later, these percentages had risen to 96% in urban areas and 82% in rural areas, showing that rural areas have achieved greater progress than urban areas, although urban areas still have more net coverage.

5. Climate Change and its Potential Effects on the Dominican Republic

Since the Dominican Republic is a tropical island territory, it usually benefits from the meteorological phenomena that occur in the period between May and December of each year, mainly heavy rains, tropical waves, tropical depressions, tropical storms and hurricanes, which contribute heavy rains that increase the flow of rivers and streams that supply dams, irrigation canals and aqueducts. However, the obvious effects of climate change, which have significantly reduced the amount of water vapor in the Atlantic Ocean, have reduced the meteorological phenomena that pass very close to the Dominican Republic in an east-west direction, which has dramatically reduced rainfall, causing severe droughts that affect dams, aqueducts, irrigation canals, agriculture, livestock and the Dominican economy in general.

In 2014, very few meteorological phenomena occurred in the Atlantic Ocean, and the few that did had very little hydrological importance for the Dominican Republic, making 2014 one of the driest years the country has seen in recent decades.

In order to mitigate these potential impacts on the Dominican economy, it is necessary to adopt public policies aimed at increasing investment in research and the construction of new dams for multiple uses. A policy for reforesting watersheds and a permanent cleanup plan for removing the sediment from all the reservoirs across the country are also required.

6. Greater State Investment in Drinking Water and Basic Sanitation

The Dominican Republic urgently requires greater state investment to provide drinking water and basic sanitation for the growing population, since the population of just over 10 million is growing in a swift, disorderly fashion. This problem is compounded by the growing Haitian migration, pressured by international organizations which understand that the Dominican Republic offers better living conditions for some of the neighboring Haitian population, which increases the pressure on drinking water and the need for more basic sanitation.

Given that the state admits that it lacks the financial resources to address the problem of sanitation, we have prepared a preliminary draft law to enable the Dominican government and the private sector to partner to build sectoral sewerage and the respective wastewater treatment plants.

Contributors

Alejandro Montás, Director of the Santo Domingo Aqueduct and Sewerage Corporation, CAASD. Ing. Luis Salcedo, Assistant Director of Operations of the Santo Domingo Aqueduct and Sewerage Corporation, CAASD.

7. Conclusions

1. Santo Domingo, the Dominican capital, which usually receives about 400 million gallons of water daily, has seen a 25% reduction of these volumes as a result of the long drought that lasted from November 2013 to July 2014, creating an acute drinking water shortage for the city's 3.5 million inhabitants.
2. The severity of the drinking water crisis in the city of Santo Domingo has required a reduction of the supply of irrigation water in the Marcos A. Cabral canal, where irrigation has been reduced from seven to just one day a week. Although this is an appropriate measure since the first use of water should be for human consumption, it is equally true that it affects food production for the population, and worsens the living conditions of many of those whose livelihood is agriculture.
3. The drinking water crisis has caused worrying inter-municipal conflicts, since people living in the vicinity of the Tavera and Bao dams, understand, quite rightly, that they should be taken into account in the distribution of these waters, which have always belonged to them. However, due to the water shortage, these waters are now being prioritized for important, distant urban centers, while those in the immediate vicinity are dying of thirst.
4. The flow of urban waters in Santo Domingo, Santiago and other cities in the country, is becoming increasingly reduced and contaminated by direct discharges from inhabitants who lack basic sanitation, and untreated discharges from industries near rivers and streams, which paints a worrying picture for the present and future of urban water in Santo Domingo.
5. The growth of the Dominican population, coupled with the increasing migration of Haitians seeking better living conditions, puts pressure on the already precarious drinking water and basic sanitation services, compounding the problem.
6. According to the World Health Organization, as regards access to basic sanitation and drinking water services, over the past 22 years the Dominican Republic has only achieved an improvement of 17% and 9% respectively, well below countries such as Paraguay, Honduras and Guatemala.
7. Whereas in major cities in the Dominican Republic, particularly Santo Domingo and Santiago, water is scarce, due to a lengthy drought, communities around Lake Enriquillo have been inundated by extraordinary floods for seven consecutive years, while the state has failed to devise a solution to take advantage of these waters.

8. Recommendations

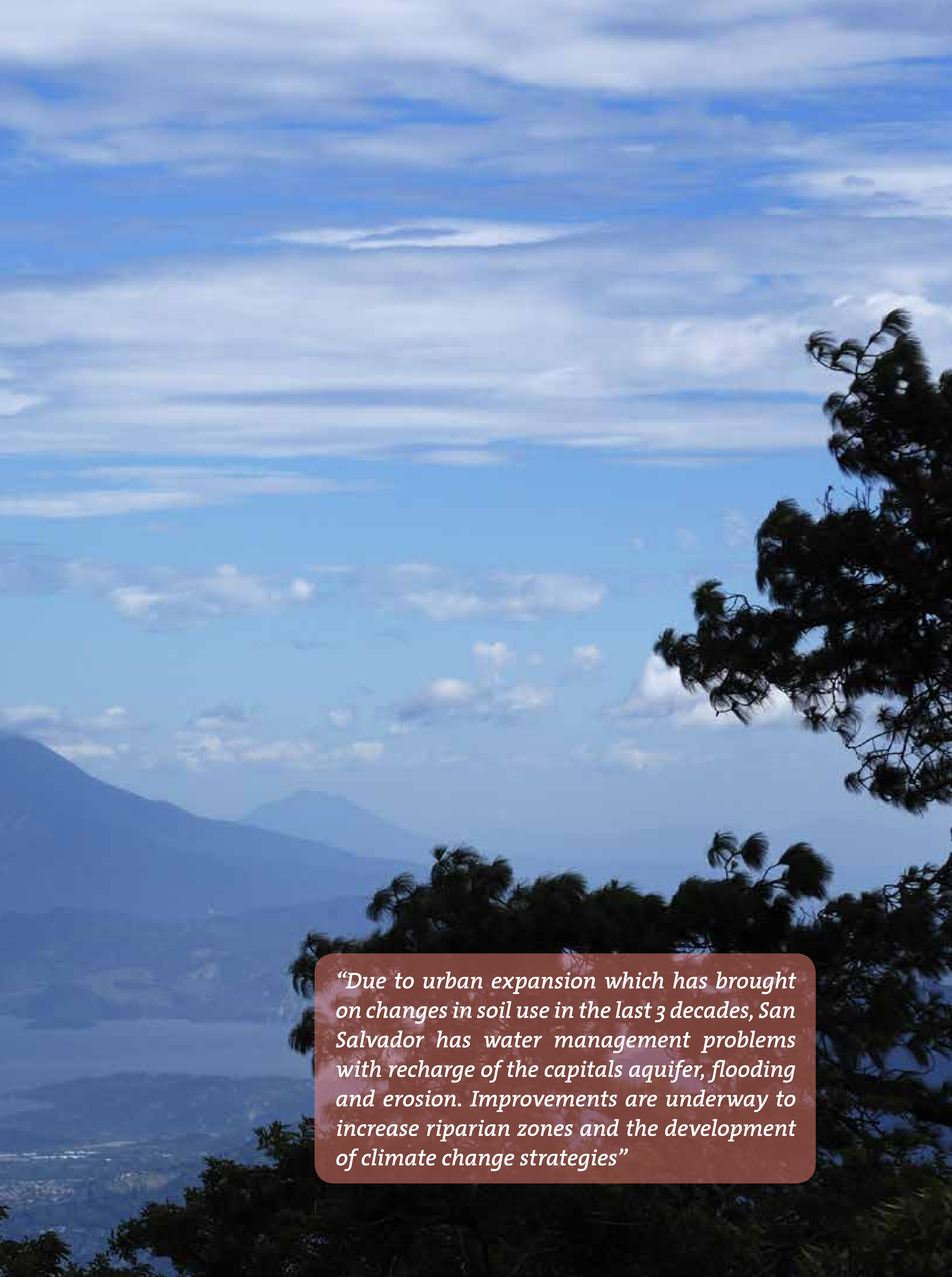
The Dominican government must urgently make major economic investments to ensure full drinking water and basic sanitation services. The international community and the Dominican business sector must make financial contributions to help solve this serious problem, which is becoming increasingly complex.

The city of Santo Domingo, which has grown without proper sewerage, requires a two-billion-dollar investment for the construction of a modern sewerage system, which should be begun as soon as possible and completed in no more than 12 years.

It is necessary to enact a law requiring the next three governments, lasting four years each, to prioritize investment in drinking water and basic sanitation, with particular emphasis on investments guaranteeing that the entire capital city is provided with the necessary sewerage.

El Salvador

Distant view of Volcano San Vicente and Lake Ilopango near the city of San Salvador.
Photo credit: ©iStock.com/GomezDavid.



"Due to urban expansion which has brought on changes in soil use in the last 3 decades, San Salvador has water management problems with recharge of the capitals aquifer, flooding and erosion. Improvements are underway to increase riparian zones and the development of climate change strategies"

The Perspective of Urban Waters in El Salvador*

Julio César Quiñonez Basagoitia

Summary

In this chapter on *Urban Waters in El Salvador*, we discuss San Salvador's Metropolitan Area (SSMA) as the primary region for analysis. San Salvador's Metropolitan Area is divided into fourteen municipalities and includes the nation's capital of the same name. One of the first considerations to note is the gradual variation in land use occurring over the last three decades. This variation is primarily the result of urban sprawl into wide areas of forest lands –lands which are essential for the hydrologic recharging of the capital's aquifers. These forested areas also act as buffers and inhibit surface runoff during extreme environmental events. On many occasions, these extreme events have resulted in loss of life; high-risk zones have emerged, principally in low areas of the capital. Extensive investments have been made in riparian zones to regulate water flow, widen and confine drainage canals, avoid erosion and reduce the likelihood of flooding.

Another noteworthy consideration is the current status of aquifers and surface water, as well as their strategic importance for supplying water to the population. A multitude of factors must be taken into account in this regard, such as the current extent of potable water delivery, problems related to water production and level of investment during the last few years. Losses throughout the delivery system, primarily due to leaks, in addition to fraudulent connections, could be contributing to artificial recharging of San Salvador's aquifers.

One aspect of great importance within the *Urban Waters* dynamic covered in this chapter is sanitation and concomitant issues such as human waste disposal; water quality; recycled water; extent of wastewater treatment services for the population; and the regulatory and legal framework in relation to international parameters. The topic of sanitation is vitally important due to its close relationship

*A Chapter developed thanks to the support of the Global Water Partnership GWP

to population concerns such as contamination and health problems. This chapter covers current levels and statistics for principal illnesses related to water and sanitary conditions reported by the Ministry of Health (MINSAL). We also cover current issues and problems, efforts being carried out through the national public health care system and budgetary aspects. Budgetary aspects include, to a large extent, state spending on health problems resulting from the vulnerable socio-environmental situation of a large sector of the population.

We conclude the chapter with the impacts of climate change on water resources; on subterranean and surface water; on water availability; and projections for the future based on various studies which have been carried out. We also report on national climate change strategy measures and the adaptation plan currently in place.

1. Introduction

The perspective of *Urban Waters in El Salvador* has gained greater importance and priority in dealing with a variety of related dynamics, challenges, risks and problems, primarily during the last two decades, with special emphasis around the time of the 1992 peace accords. Following the end of armed conflict, El Salvador entered a new stage - one of stability leading to an economic boom, primarily among the financial, real estate, commercial, importation and logistics sectors. This boom was expressed to a large degree in greater economic development and modernization in urban processes, i.e., those processes operating within the metropolitan arena. The productive agricultural and economic processes of the 1970s and earlier, taking place primarily in rural areas, with an agriculture-based economy which played an important role in determining the country's social and cultural dynamics in terms of livelihoods for broad sectors of the rural populations, did not share in the post-conflict economic boom to the same degree.

The socio-political crisis in the 1970s, prior to the period of armed conflict (1980-1992), and the turnaround in the socio-productive model within a relatively short period of time (the decade of the 1990s), generated a profound level of migration from the countryside to the city. San Salvador Metropolitan Area (SSMA) became the urban zone with the highest population growth in the country. According to the National Center for Statistics and Census Data (DIGESTYC), the department of San Salvador where the SSMA is located grew from 733,455 inhabitants in 1971 to 1,512,125 inhabitants in 1992, i.e., a population increase of more than 100%. According to a study carried out by Lotti & Associates in 2001, unplanned urban expansion in the metropolitan area grew by 21% between 1994 and 2002.

At the same time, seismic events in 1965, 1986 and 2001 resulted not only in loss of life but in significant damage and extensive destruction to social infrastructure in areas with scant economic resources. This situation contributed in later years to a gradual increase in urban and peri-urban squatters' settlements, many of them illegal and without land titles. These settlements occupied riparian and buffer zones in close proximity to gullies, rivers and natural drainage systems which gave rise to situations of vulnerability during storms and extraordinary meteorological events.

In addition, urban sprawl has extended into the higher and mid-level slopes of the Metropolitan Area basins, primarily during the past fifteen years and in the southwestern sector of the capital in particular. This sprawl has combined with frequently occurring flooding to create a new pattern of runoff which has resulted in considerable damage and loss of life in the lower elevations. In this regard, it is fitting to mention the memorable event of July 3, 2008 which produced colossal flooding in one of San Salvador's lower elevation sectors (*La Málaga* neighborhood); the river overflowed its banks and swept away a bus carrying passengers, resulting in tragic loss of life.

According to an analysis based on hydrologic modeling of changes in land use in SSMA (Erazo, A. MARN-2009), the flow rates occurring at the site of the tragedy were 22% higher than the flow rates generated by the same meteorological conditions in 1992. What's more, forest cover is currently 12.7% less than forest cover in 1992, and the peak flow rate during the 2008 flood occurred 25 minutes before the peak flow rates would have occurred in 1992. In other words, between 1992 and 2009, the watershed basin has lost its lamination capacity or ability to reduce or restrict high flow rates due to an increase in the magnitude and rapidity of the flows. Since this tragic event, there have been other instances of waterways overflowing their banks in different sites within the capital due to low pressure meteorological events associated with Hurricane Ida (11/7/2009), Tropical Storm Agatha (29-30/05/2010 and Tropical Depression 12E (10-20/10/2011). All three events resulted in loss of life and significant material damage.

On the basis of the aforementioned damage and loss, substantial investments in protection and mitigation have been made over the last few years including rehabilitation of some sections of the rivers along with the formulation of a watershed management plan; construction of peripheral walls and drainage canal confinement; and storm drain rehabilitation and enlargement.

These efforts have contributed significantly to reducing critical flood points, high-risk zones and riverbank overflows in various sectors of the capital.

There are a number of other issues of concern in addition to the previously mentioned problems. The challenges presented by the sanitation process, sources of water and water distribution are important in the analysis of *Urban Waters*. So are water quality monitoring and water contamination, and their impact on public health. The SSMA currently represents 43% of the country's urban population. It is also the geographical area subject to the greatest study, discussions, analyses and actions related to Salvadoran *Urban Waters* dynamics.

2. Urban Zone Water Sources and Impacts Caused by Urbanization

2.1 Changes in Land Use in the San Salvador Metropolitan Area (SSMA)

El Salvador has a total area of 21,040.80 km² divided into fourteen departments. The largest department is San Salvador in which the SSMA is located. The SSMA, in turn, is home to the nation's capital, San Salvador, and thirteen neighboring municipalities.

In 2011, the nation's total population was 6,213,730 inhabitants (Multi-Purpose and Household Survey 2011 – EHPM-2011). The EHPM reports that 62.5% of the population (3,871,332 inhabitants) lives

Figure 1. Map of El Salvador's local and regional governmental divisions

in the urban area, while 37.7% (2,342,398) lives in rural areas. San Salvador currently has 1,683,726 inhabitants. El Salvador is located on the Pacific coast of Central America, bordering Guatemala to the west, Honduras to the east and Nicaragua to the southeast. The Gulf of Fonseca separates El Salvador from Honduras and El Salvador. Figure 1 reflects the country's local and regional governmental divisions; the continuous red line corresponding to the SSMA.

The Metropolitan Area lies within the central western zone of the volcanic chain that crosses El Salvador from east to west, bordering the San Salvador volcano, extending out broadly from the foothills to the east, northeast and southwest. The city occupies a great portion of the volcano's slopes – 15% to 18%, which possess great capacity for generating rapid water flows, principally in zones with scarce vegetation and greater impermeability. These slopes descend until they reach zones with inclines measuring less than 3% which are considered to be the low zones with the greatest susceptibility for accumulating flows and experiencing flooding.

The geological formations surrounding the SSMA, along the interface between the city and the peri-urban region, are volcanic in nature, consisting of pyroclastic rock, Quaternary lava with lava produced during recent volcanic activity (less than ten thousand years) and volcanic fragments or rubble. These materials allow for a high degree of permeability.

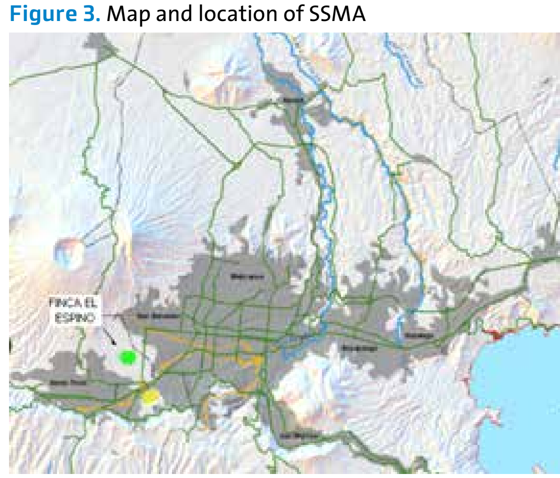
The predominant soil in the SSMA comes from volcanic ash known as Andisol (40-50 cm depth) which possesses a loamy (loamy-sandy) texture and a granular structure. These soils have a high degree of water retention and very good water infiltration, principally in areas where the slopes are moderate or low (<8%), with ample forest cover. These factors help restrict surface runoff and prolong humidity retention which benefits water infiltration and subterranean percolation toward the capital's aquifer. The aquifers exploited by San Salvador are located in the city's mid and low altitude zones.

There has been a slow process of degradation in these essential water recharge and natural surface runoff restriction zones during the last few decades. The extreme manner in which this is evidenced can be seen in the intervention and progressive destruction of the *Finca El Espino* as a consequence of urban sprawl. The *Finca El Espino* is the most

Figure 2. Panoramic view of San Salvador's southwest zone

Source: http://ht-i2012-773-sansalvador-sanmiguel.blogspot.mx/2012/05

Figure 3. Map and location of SSMA



important hydrographic area for recharging the waters of San Salvador's aquifer, as well as the urban area's rain water buffer zone, which contributes significantly to reducing the risk of flooding downstream. This hydrographic area is located to the southwest of the capital as shown in the map of SSMA in Figure 3.

As shown in the Dada Architects Report -2010, the Finca El Espino had a total area of 798.1 ha at the end of the 1970s. During the conflict years in the 1980s, 31.1 ha became the property of a military academy. During the 1990s, a 12.45 ha portion became the site of university campuses and private educational institutions. Later, between 2002 and 2005, another 27.7 ha were turned into commercial centers and parking, which were accompanied by the construction of preferential axis roads and highways consisting of an estimated 33.2 ha. Finally, in addition to completing the road building projects planned since the 1990's, the most important alteration to the *Finca El Espino* took place between 2010 and 2013. This consisted in the gradual formulation and implementation of luxury residential and housing projects which now occupy 110.8 ha in one of the most important hydrological areas of the country, not only because of the type of soil found there but because of the native vegetation and modest slope.

It is noteworthy that the *Finca El Espino* possesses not only the most favorable soil types and geological characteristics mentioned previously but as a completely forested plain with broad vegetative cover and modest slopes, it is an area of high laminate runoff retention and presents one of the highest levels of water recharge on the national level, determined to be between 450 mm and 500 mm (Balance Hídrico, SNET-2005, and Junker. M. Método RAS-2005). This level of recharge is equivalent to sub-surface and subterranean water storage greater than 3.6 million m annually.

At the same time, due to its vegetative cover including original forests, coffee plantations and secondary forests, this territory plays an essential role in the preservation of biodiversity close to the capital; in oxygen generation, in carbon fixing, as a regulator of atmospheric contaminants; and as a landscape filled with natural beauty within the city's borders.

Economic interests have played an important role in contributing to worsening problems associated with changes in land use and the impacts of urbanization in the SSMA. During the 1990s a legislative decree approved urbanization in these essential zones while evading or ignoring guidelines established in the 80s and 90s, and even prior, regarding the characterization of the territory and environmental management.

The METROPLAN-80 initiative, formulated in 1969, held that urban planning for the coming decades was to have focused on reaching social and economic goals, requiring strengthening in the areas of institutionalism, and the legal framework for sustainable administration, within the spatial and environmental policies for urban territory. In line with this approach, the Forestry Law was approved in 1973 which contained the first declarations on Protection Zones for the San Salvador volcano. In the 1980s, the PLAMDARH-1982 established the importance of wide sectors of the San Salvador volcano foothills. The foothills in Hydrographic Region A, Sub-region San Salvador fulfilled strategic functions in terms of recharging the San Salvador aquifer. The hydrogeological characteristics of this region included high water infiltration (within the C=0.4 – 0.6 range), and high percolation towards deep strata, characterized by the study as "zones of maximum potential for infiltration and minimal runoff". As a result, the report established their protection as a priority; even more so when the same study found that the aquifer was already over-exploited by that time, with an annual decrease of 1.0 m.

The report findings were based on observations of fluctuating levels in nine wells between 1967 and 1971 within the framework of a project by ANDA – PNUD (National Association of Aqueducts and Sewers, and the United Nations Development Program). Later, through the PLAMDARH study, a digital model of the San Salvador aquifer was prepared, which determined a reduction in the phreatic surface level of 0.6 m/year.

Taking this history and experiences into account, a Urban Development Master Plan was created in the 1990s (PLAMADUR-1996) which defined land use categories which established protection and development zones from an environmental planning perspective. In a way, this planning effort protected and categorized the *Finca El Espino* as a "maximum protection zone", that is, not for urbanization, along with other zones essential to the southwestern sector of the SSMA.

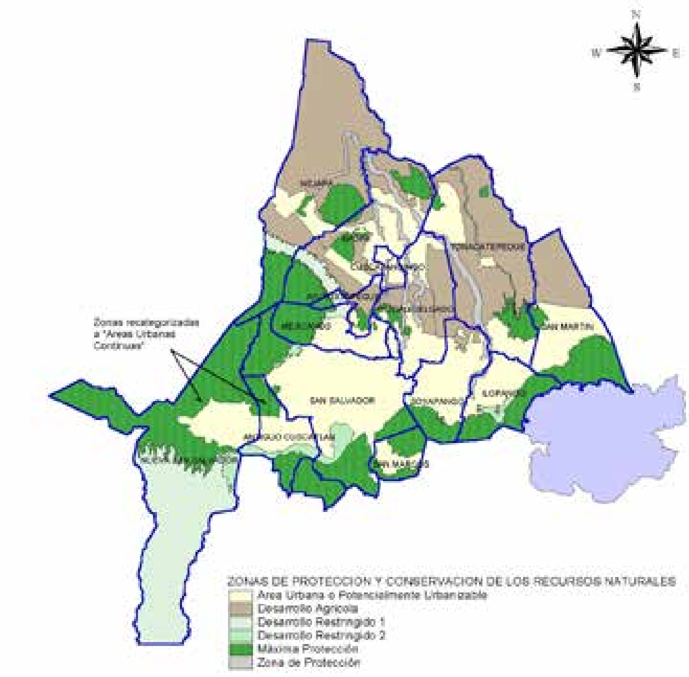
Nevertheless, given that PLAMADUR came about under the protection of the SSMA Development and Territorial Administration Law, approved in 1993, it was open to modifications and amendments according to municipal plans or those coming from private or legal entities and individuals that might consider that "their special plan could provide greater benefits or make better use of the site in question", or that the site of interest and its "initial use guidelines had been overturned due to the evolution of territorial development". Under this reasoning, all previous hydro-geological, socio-environmental, downstream risk reduction and water resources preservation guidelines became relative and could be easily over-ruled.

In the mid 1990's, Inspector Mario Lungo, Director of the SSMA Planning Office (OPAMSS) considered that the market for urban land in San Salvador (PRISMA-1996) was primarily in the southwestern sector of the capital. This land market came about with newly established land values and gradually included the old coffee farms which belonged to a reduced number of owners, who, although reduced in number, still had the capacity to drive the urban development dynamic outside the realm of a true socio-environmental planning scheme created by the State, and, more importantly, outside of a regulatory framework promoting equity and the preservation of resources. In Inspector Lungo's view of the perspective of the urban land market, not only is the vision of sustainable development lost due to accelerated environmental degradation, but social and spatial segregation and exclusion in the cities are intensified as well. The great majority of the population with low income is without access to that new urban elite sector into which, paradoxically, the State must invest great quantities of resources to facilitate and provide transportation infrastructure, lighting, services, security, etc.

In recent years, a significant reformulation in terms of the re-categorization of land use is presented in various municipal reports and guidelines for Environmental Zoning and Land Use, established by the Ministry of the Environment and Natural Resources (MARN-2013). These same reports and guidelines referring to the southwestern zone of the capital present significant sections of land, previously considered in the PLAMADUR-96 to be under "maximum protection", today are presented in a reformulated manner as "continuous urban area" zones, which demonstrates the adaptation and adjustment of the current environmental administration plans to follow the logic of urbanization. In Figure 4 we show the zoning proposed by PLAMADUR-96 in which the color green signifies maximum protection zone.

Currently, more than 110.8 ha have been re-categorized in the zones indicated as "continuous urban zone" and "rehabilitation areas".

Figure 4. PLAMADUR - 96



From this perspective the recurrent and progressive changes in land use aggravate two fundamental problems in the analysis of the *Urban Waters* dynamic. The first problem entails the continuous reduction of forest cover in the San Salvador aquifer's water recharge zone and the impacts this has on the aquifer. The second entails the increase in surface runoff and peak water flows, intensifying risk zones in the capital's low elevation zones.

2.2 Reduction of Forest Cover

Reduction of forest cover in the water recharge zone and impacts on the dynamics of the San Salvador aquifer, taking into account recharge activity stemming from water leaks.

The reduction in water recharge and fluctuations in static water levels in the San Salvador aquifer is a topic which has been undergoing analysis since the 1970s. As was mentioned previously, the PNUD-ANDA studies in 1972 and the PLAMDARH in 1982 established a reduction in static water levels of 1.0 m and 0.60 m respectively. In recent times, new studies

Figure 5. Location of the Acelhuate River urban basin

Source: Barrera, M. "Caracterización Hidrogeoquimica...", Sept. 2010.

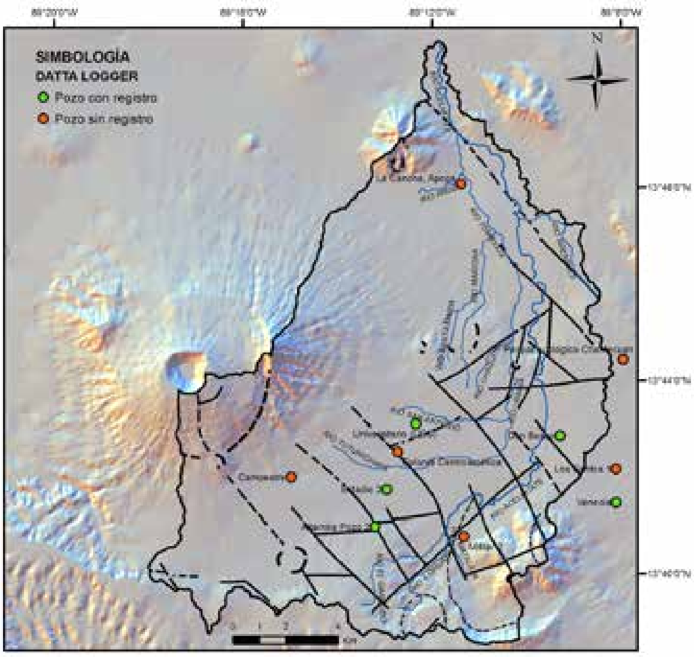
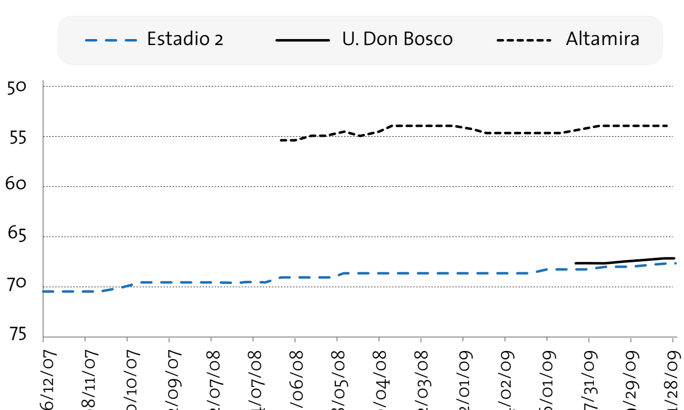


Figure 6. Temporal variation in well water levels

Source: Barrera, M. "Caracterización Hidrogeoquímica...", 2010



and analyses have been carried out which reflect the same tendency, determined principally from phreatic levels in wells situated in low elevation zones.

Two important university studies are cited and reproduced within the framework of hydro-geochemical characterization studies of the San Salvador aquifer (Barrera, M., 2010), which highlight the decrease in the phreatic water level by approximately 1 m per year (Coto, UCA-1994), discovered in analyses carried out in 1994, as well as through more recent analyses in 2005, which estimated decreases of 2.47 m per year for San Salvador and 1.47 m per year for Soyapango (Arévalo y Vásquez, UCA-2005).

The analysis of fluctuations in the static water levels of wells and of the possible recharging of the aquifer as a result of water leaks from San Salvador's potable water and sewage systems, is the central objective of research carried out by Marcia Barrera in 2010 using hydro-geochemical characterization of the waters that recharge the aquifer.

At that time, the report states, monitoring was carried out on the level of five wells using a data logger device, with records covering the period of 2007-2009. Two wells are located in the water basins high elevation zone and three are in the intermediate zone. Figure 5 presents the placement of these wells in green, immersed in the hydrographic basin of the *Acelhuate* River which is where San Salvador's aquifer is located.

One of the wells in the basin's intermediate zone had an increase in water level on the order of 0.60 m (*Don Bosco* well), yet there is only one record of five months during the 2009 rainy season. A second well in the same zone did not present any variations within the short period recorded, however, there was a decrease of 4.79 m in relation to the initial 2007 record.

One of the wells monitored in the higher altitude zone (*Altamira* well) generally maintained a fluctuation corresponding to the annual rain cycle, in other words, from May to October, considered to be the rainy season, and from November to April, considered to be the dry season, presenting a reduction in a certain period and then an increase in another period of the year, with a relative increase of 0.16 m.

Nevertheless, one of the particular aspects of this well is that it is located precisely within the corridor of geological faults coming from the high zones of water recharge, one of which extends in the direction of the San Salvador volcanic crater, contributing significantly to its maintenance as it is within the preferential flows circulation zone and would not be very representative of other sectors of the aquifer.

The other well situated in the high zone (*Estadio* well) lacks this cyclical-seasonal fluctuation; its behavior reflects a continual tendency toward increase regardless of the annual periods of recharge and discharge.

This condition could lead to the assumption of an "artificial recharge", stemming precisely from leaks in the potable water, rain drainage and sewage systems, as well as a reduction in water exploitation in the zone from disuse of some of the wells, and also of the well under analysis as the latter was not functioning during the period being recorded. Figure 6 reflects the behavior described in the wells analyzed between 2007 and 2009. The left hand column reflects the depth of the wells' phreatic levels in meters.

One of the aspects of the research which stands out is the decrease in the potentiometric lines, or lines that establish the water levels in the aquifer, principally in the intermediate low elevation of the water basin. This is reflected in low productivity or disuse of some important wells situated in popular sectors in the Soyapango and San Marcos municipalities.

Given the configuration of the geological structure, the wells situated on or near fault lines heading towards the recharge zones, which are primarily located in the intermediate and higher elevation levels of the water basin, conserve their yearly recharge pattern, and some of them experience a certain increase in their phreatic levels. However, those wells found in the lower zones, formed hydro-geologically by a porous and sedimentary aquifer formation of greater consolidation and intermediate permeability, experience a gradual decline and even disuse due to low productivity and the high costs of keeping them functioning.

Although the amount of water for consumption is not quantified in the hydro-geochemical characterization study - water that could be recharging the aquifer in the form of water leaks – the study does establish qualitatively the significant contribution that this volume of water can be providing to the San Salvador aquifer.

To do so, taking into account the analysis of some physical-chemical parameters (pH, temperature, electric conductivity), a concentrations analysis (mg/l) was performed on the ions of some hydro-geochemical elements of San Salvador's water sources and supplied water, principally calcium (Ca), Sodium (Na2) and Magnesium (Mg2), which were comparatively correlated with samples obtained from SSMA wells. The results obtained presented a correlation between the characteristics and concentrations found in some sectors of the aquifer and those coming from the two principle external sources of water supply that feed the capital's water distribution system. In this regard it is important to note that SSMA water is supplied through the use of three systems, their corresponding contributions for 2013 being: 1. *Las Pavas* (38.5%); 2. *Zona Norte* (north zone) (20.9%); and 3. *Systema Traditional* (traditional system) (40.6%). The first two are external systems of water supply for SSMA while the third is a system of internal wells that extract water from the San Salvador aquifer.

Through an analysis of the environmental isotopes Oxygen 18 and Deuterio, which are related to altitude and inversely related to temperature, it was determined that subterranean recharge from rain occurs primarily in the intermediate and high elevation zones of the water basins and in the corridors of the structural geology of fault lines located in these zones, which are characterized by lesser urban population density. At the same time, the subterranean water sample which was analyzed from within the water basin presented isotopic compositions similar to the two systems of water supply coming from the basins outside of the capital, those being "Las Pavas" and "Zona Norte".

Finally, the analysis revealed that a significant contribution comes from the city's human waste sewage system, due to the presence of high concentrations of nutrients and other reference elements such as nitrate ions (NO3), chlorides (Cl) and sodium (Na) which are present to a greater degree in the central and intermediate zones of the basin where sectors with fragile and outdated sewage pipes (over fifty years) are located.

According to the ANDA-2013 annual report, water production for SSMA totaled 183.3 million m^3, representing 518% of water produced on a national level by the institution, the national total being just under 3.354 million m^3. Other operators produced 9.1 million m^3 nationally.

Total water consumption (billed for) in SSMA was 113.8 million m^3, while 69.5 million m^3 constitute losses due to leaks in the networks from outdated pipes and unbilled water consumption. Unbilled water consumption consists of water extracted from hydrants and from illegal water connections, as well as the existence of a small group of users who have not yet had a water meter installed, the percentage of the latter group according to ANDA being 9.8%, and another group of users with non-functioning meters (3.5%). The bill for these two last groups is fixed and estimated.

According to ANDA, loss due to illegal connections and permanent theft of water has been reduced considerably during the last few years. This has been made possible thanks to a series of administrative and technical measures, including:

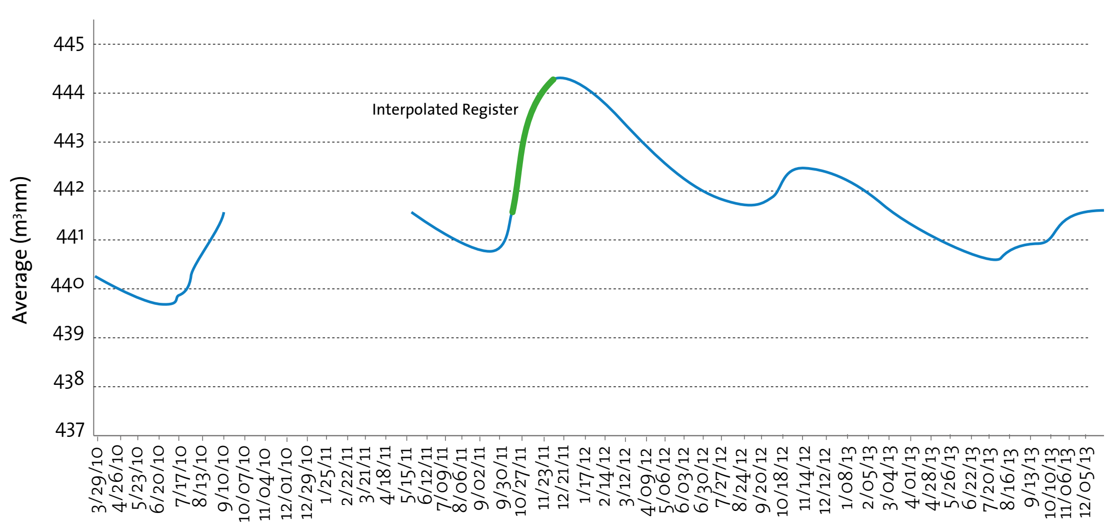
- Systematic monitoring and inspections of distribution networks and water connection points, having legalized a significant quantity of illegal connections.
- Modernization of the customer enquiry, service and participation through implementing 24 hour communications centers for reporting fraud, water leaks, problems with service and billing problems, etc.
- Implementation of hand held or portable mini-computer devices to read meters, control the amount of water supplied, photography for the control and verification of water connection points, problem reporting, historical record of water usage, etc.
- Installation of meters in the pumping stations with devices for controlling flow in order to be able to establish a balance between water produced in the circuits and networks, distribution and billing. This improvement provided the ability to localize, trace and identify problems of fraudulent connections, among other things.
- Modernization of land registry and computerized maps of users which contributes to better control of grey water.
- Opening of kiosks and branches for better client attention.

With the above in mind, losses from illegal water consumption have been significantly controlled and thus their contribution to non-billed water consumption is low. If we consider that they still represent 10% of current losses, the losses for unbilled consumption represent 23.3%, making the losses from water leaks responsible for 53.3 million m^3 of water, a large portion of which will directly recharge the aquifer and a lesser portion could be contributing to sub-surface baseflows of some of the springs in the intermediate and low zones of the city.

To this artificial recharging of water must be added the recharging resulting from leaks in pipes and black water tanks which can be assumed to provide considerable quantitative contributions to

Figure 7. Record of phreatic levels Nejapa Well No. 6

Source: Subterranean Water Monitoring Network records, Environmental Hydrology Observatory Administration-MARN 2013



the aquifer yet which has substantial detrimental repercussions on the quality of the water later extracted, as was discovered in the study previous mentioned.

It is important to point out that the International Water Association (IWA) considers losses within the potable water system to be on an intermediate level when the percentage of losses oscillates between 8% and 15% (Gerlingen, D., 2001, cited by Barrera, M., Characterization Hydro-geochemical…2010).

In general, although the San Salvador aquifer maintains its dynamic equilibrium in the intermediate-high zones of the basin, according to the analysis of the records of the five wells, this situation is not reproduced in the low zones where the wells reflect a reduction, as was reported in the study on hydro-geochemical characterization.

However, this equilibrium in the intermediate-high zones does not correspond to natural recharge but to an acute problem of leaks which signifies high operational costs for ANDA, not only due to economic losses which can reach several million dollars in surplus production to satisfy the demand for water supply, but also for the growing need for purification of the extracted waters.

From this perspective, the water recharge zones possess not only an essential function in the conservation of the aquifers, but also in contributing to the dilution capacity and the preservation of subterranean water quality.

Interrelated to the San Salvador aquifer, the Nejapa population aquifer is located within the SSMA, but formed by its own hydrographic region –the San Antonio River basin, which in turn forms part of the second most important external source of water supplied to the capital, known as *Proyecto Zona Norte*, the North Zone Project.

The Nejapa aquifer, although much smaller than that of San Salvador, acquires strategic importance due to its close proximity to the capital, and provides good quality water which requires much less treatment, and thus investment, than water coming from other sectors. This is due to its water recharge zone being well preserved with ample forest cover and free from sources of direct urban contamination. As a result, and due to its low level of urbanization, the Nejapa aquifer is not influenced by artificial recharging but instead depends primarily on the yearly rain cycle.

Nevertheless, during that last few years, given the problems which have affected the San Salvador aquifer such as environmental deterioration, increasing contamination of subterranean waters and a reduction in phreatic levels in the low altitude zones, all of which results in the need to increase production costs for well water, diverse industries including water and beverage bottlers have transferred or expanded their operations in the Nejapa aquifer.

This displacement phenomenon in various industries and economic projects has generated a condition of greater pressure upon the aquifer which has already experienced a reduction in phreatic levels, revealed in different studies analyzing hydro-geological balances and monitoring of one of its representative wells (ANDA Well No. 6).

Figure 7 presents the monitoring of Nejapa Well No. 6 during the period from March 29, 2010 to December 5, 2013, revealing that during the period of continuous recording, maximum recharging of the aquifer occurred between December 2011 and December 2013, reaching elevations of 444.25 meters and 441.5 meters above sea level respectively, which means a decrease of 2.75 meters in two years.

From the perspective of surface water, changes in land use and urban sprawl generate a second problem in the cities –an increase in surface runoff and peak water flows during extreme meteorological events and an increase in risk zones, principally in the low altitude zones.

2.3 Increase in surface runoff and generation of peak water flows during extreme meteorological events in San Salvador's low altitude zones

The effect of an increase in peak water flows related to changes in land use which began in the high recharge zones began to be studied following extreme hydro-meteorological events in recent years (208-2011) which lamentably resulted in loss of life and material damage. One of the most memorable and tragic events occurred in the neighborhood of *La Málaga* on July 3, 2008, as was mentioned earlier. Following that dramatic event, new flooding occurred in the same neighborhood and in other sectors of the city as a result of low pressure associated with Hurricane Ida (November 7, 2009), Agatha (May of 2010), Tropical Depression 12E

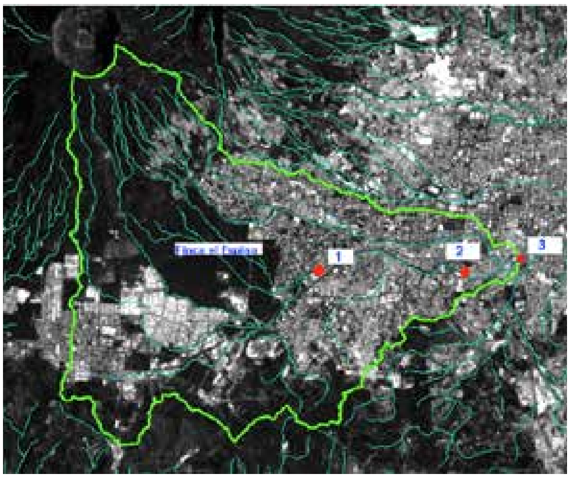


Figure 8. *Arenal Montserrat* micro-basin analysis

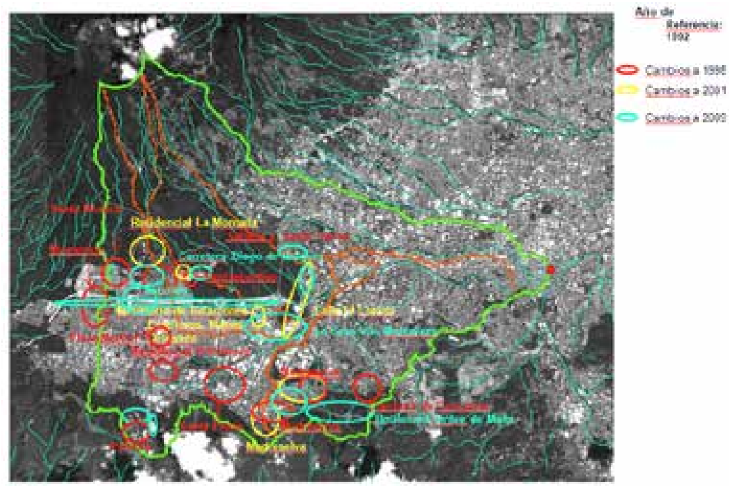


Figure 9. Changes in land use in the Arenal Montserrat micro-basin

(October of 2011). Of these three events, the one with the greatest magnitude and consequences occurred in 2009 which again caused flooding and volumes of water greater than the event of 2008.

In 2010, the National Territorial Studies Service (SNET), now known as the MARN Environmental Observatory, carried out an analysis using hydrological analysis on the maximum flood levels registered in the 2008 and 2009 events, using the *Avenida Revolución* (Avenue of the Revolution) (1), *La Málaga* neighborhood (2) and *Puente Belloso* (Belloso Bridge) (3) as control points as shown in Figure 8. Also shown is the micro-basin of SSMA, known as *Arenal Montserrat*, whose high zones are located in the San Salvador volcano while its low zones are in the central sector of the capital, where the *La Málaga* neighborhood is located. The study consisted of comparing hydrograms of water flows generated by these events with water flows generated through hydrological modeling for the same meteorological conditions, with based on 1992 land use data.

Figure 9 reflects the gradual changes in land use which came about beginning in 1992 and continuing until 2009, with zones modified in 1998 circled in red, zones modified in 2001 circled in yellow and zones modified in 2009 circled in blue. Overall, between 1998 and 2009 a total of 5.53 square kilometers of permanent forest cover were urbanized.

Figures 10, 11 and 12 present the results obtained from the three control points. The figures reflect the times at which peak flow rates occur and a notable increase in these rates under current conditions of reduced vegetative cover.

Figure 10 reflects the calculated flow rate with current land use as 14.8 m^3 per second vs. the simulated flow rate considering 1992 land use patterns, of 10.78 m^3 per second.

This control point has experienced the urbanization of 13.68% (3.73 km^2) of this point's basin area (27.3 km^2) and an increase of 4.1 m^3 per second, equivalent to 38% of the peak water flow rate.

Figure 11 shows the flow rates calculated for the point at which the 2008 tragedy occurred. At that point, the basin area for this point is 40.95 km^2, 5.20 km^2 (12.70%) of which were urbanized. Flow rates increased by 10.5 m^3 per second, representing an increase of 74% in the peak flow rate, with a 30 % reduction in time.

Lastly, Figure 12 presents the flow rates calculated for the *Puente Belloso* station. The basin area for this control point covers 53.47 km^2, with 5.52 km^2 (10.33%) of urbanization. Flow rates increased by 16 m^3 per second (98% of the peak flow rate) and a 40% reduction in arrival time.

2.4 Evaluation, location and use in urban zones of the principal surface and subterranean water sources on the national level

Water is supplied to urban zones or greater population density sectors through the capture of surface water in rivers and springs, and through extraction from wells situated in the country's principal aquifer zones. Figure 13 represents the updated MARN-SNET 2002 hydro-geological map of the country, although this map was original based on PNUD-ANDA 1972 and PLANDARH 1982 studies. The interior aquifers in the area of the central volcanic chain are represented in blue. These aquifers were formed by pyroclastic materials and are of moderate to high productivity. Aquifers shown in violet are formed by alluvial deposits located along the coastal strip and in riverine areas, reservoirs and wetlands. Water recharge zones are shown in orange, located especially in the volcanic foothills.

Aquifers in the area of the volcanic chain have a strategic function because of their close proximity to the country's principal cities (SSMA, Santa Ana and San Miguel). Nevertheless, their vulnerability has increased during the last few decades due to greater pressure on water resources and the effects of contamination from urban areas. Aquifers situated along the coastal plain have been better exploited historically for supplying urban zones, although they also play an important role in supplying water to the local rural population and cultivation zones using irrigation methods. However, one problem affecting these aquifers is the presence of trace contaminants originating from the intensive use of agro-chemicals, principally in the large agricultural plantations of cotton and sugar cane beginning in the 1950s. At the same time, focal points of marine water intrusion have appeared which results in less water availability in terms of quality. One of the most strategically important aquifers in the coastal zone is "*El Jocotal*" and "*Olomega*", located in the extreme southeastern portion of the country. This zone, unlike the other coastal areas, is confined in the south by the "*Jucuarán-Intipucá-Conchagua*" cordillera or mountain range, which isolates it from interaction with marine dynamics, and facilitates its conservation as completely fresh water. It has not been very exposed to direct contamination by pesticides and agro-chemicals in the past, being located as it is in a protected nature zone, Ramsar sites and species conservation zones, formed by the *Olomega* and *Jocotal* lakes. However, it is still vulnerable to contaminated effluent from the *Rio Grande de San Miguel* River, which interacts directly with that aquifer zone.

Table 1 presents the country's aquifers and their location is shown on the map in Figure 14. The Santa *Ana-Chalcuapa* and *San Miguel* aquifers

Figure 10

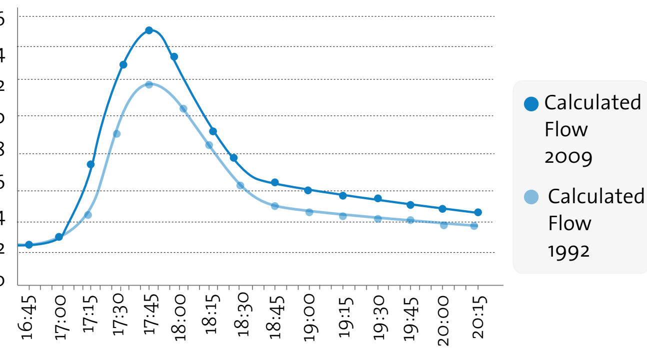


Figure 11

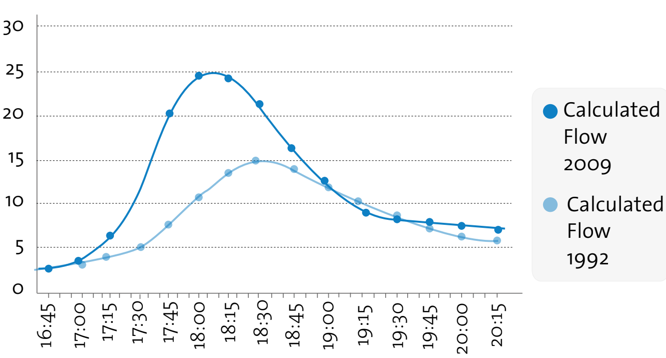
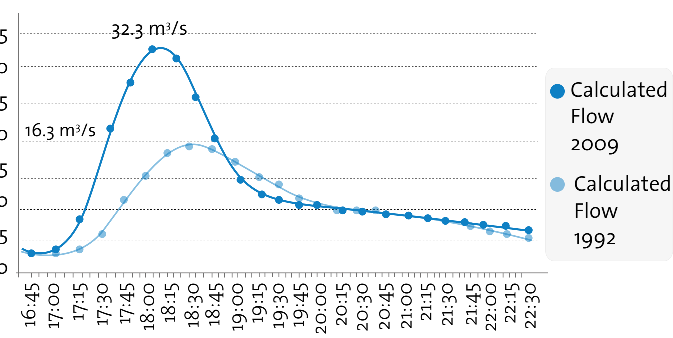


Figure 12



supply the majority of water (80%) to *Santa Ana* (560 thousand inhabitants) and *San Miguel* (470 thousand inhabitants), these being the second and third most important cities and departments in the country, after San Salvador and SSMA.

The San Salvador aquifer is the primary supplier of the country's urban waters. It supplies 33% of the capital's water supply. The *Quetzaltepeque-Nejapa*

Figure 13. Hydro-geological map of El Salvador

aquifer supplies another estimated 21% of the capital's water supply.

Surface waters constitute another strategic source of water supply to different cities and lower density populations in the country. The principal source of surface water is the catchment and purification station in the Lempa River known as "*Las Pavas*". This station captures and estimated flow of 2 m^3 per second which it supplies to SSMA and represents approximately 38% of the capital's water supply. Another watershed of importance as a water supply is the *Tamulasco* River located in the department of *Chalatenango*. The National Aqueduct and Sewage Administration (ANDA) has a capture and purification station installed in this river to supply water to the department capital, providing water service to more than 50 thousand inhabitants.

Figure 14. Location of aquifer formations across the country with names corresponding to those indicated in Table 1.

One of the problems presented by making use of surface water has been its availability in terms of quantity and quality. Regarding quantity, the nation's surface waters are undergoing outright decline over the last few decades due to the gradual reduction in the base flow rate, principally during the dry season. This situation was studied in detail by the National Territorial Studies Service (SNET-MARN) in 2005. These studies revealed that a great portion of the country's principal rivers were experiencing a reduction in their baseflow rate primarily during the dry season such that many

Table 1. Characterization of aquifer formations in El Salvador (PNUD-ANDA 1972)

Cod	Name of aquifer	Hydrogeological characterization	Extension Km^2	Thick Ness m	Annual recharge m^3 /year x 10^6
A-1	Singüil	Redeposit of Quaternary pyroclasts	24	30	7,00
A-2	Texistepeque	Redeposit of Quaternary pyroclasts	40	40	10,00
A-3	Santa Ana-Chalchuapa	Quaternary lava and pyroclasts	200	80	90,00
A-4	Aguilares	Redeposit of Quaternary pyroclasts	60	60	30,00
A-5	Coatepeque	Quaternary pyroclasts	45	60	23,00
A-6	San Salvador	Quaternary lava and pyroclasts	160	100	42,00
A-7	Zapotitán	Pyroclastic Deposits and lake sediments	200	100	200,00
A-8	Quezaltepeque-Nejapa	Quaternary lava and pyroclasts	130	60	100,00
A-9	San Vicente	Quaternary lava and pyroclasts	100	100	55,00
B-1	Chalchuapa-Ahuachapán	Quaternary lava and pyroclasts	250	80	114,00
B-2	Omoa	Quaternary pyroclasts and interleaved lava	100	60	9,00
C-1	Paz-Acajutla	Deposits of alluvial sediments	185	60	81,00
D-1	Izalco	Quaternary lava and pyroclasts	160	40	55,00
D-2	Sonsonate	Quaternary lava and pyroclasts	300	40	143,00
D-3	San Julián	Quaternary lava and pyroclasts	20	20	41,00
E-1	Libertad-Comalapa	Deposits of alluvial sediments	85	40	30,00
F-1	Comalapa-Lempa	Deposits of alluvial sediments and Quaternary pyroclasts	400	60	418,00
F-2	Ilopango	Quaternary pyroclasts	40	100	20,00
G-1	Lempa-Usulutan	Coastal sediments and Quaternary lava and pyroclasts	450	100	298,00
H-1	Usulután	Quaternary pyroclasts	150	100	200,00
H-2	El Jocotal	Lava and alluvial sediment deposits	130	60	100,00
H-3	San Miguel	Quartenary Lava and pyroclasts	150	100	57,00
H-4	Olomega	Alluvial Deposits	100	60	30
H-5	Quelepa	Quaternary lava and pyroclasts	150	60	30

of them could be transformed in the intermediate future into mere natural drains during the rainy season. This problem was attributed principally to a lack of protection, soil conservation and forest cover in various hydrographic basins in the country, as well as to hydro-meteorological variations yielding a gradual loss in infiltration capacity and regulation of sub-surface flow which is what maintains the springs and water sources such as river tributaries. The study carried out a process of classification based on "anomaly levels), establishing the *Tamulasco* River as presenting one of the most critical situations with an anomaly level considered to be "very high", as the river is losing its flow at an accelerated rate during the dry season such that urgent actions must be taken within the framework of integrated water resource management in its high elevation basin, as an important population center depends on this river for their water supply.

Table 2 presents the comparative capacity information obtained by ANDA in some of the principal springs, rivers and capture points which make use of surface water, both above and below the water collection points on the same day. The levels of extraction in many cases extend beyond 50% of availability, and even up to above 80% of water availability, such as in the case of the *Tamulasco* River during the dry months of the year (February and March), which significantly reduces the base water flow rates or environmental flow rates required for maintaining the ecological equilibrium of fluvial systems.

This same situation is repeated in water extractions during some months of the year at various capture points (*Suchitoto, Nueva Concepción, Aguilares y Ahuachapán*).

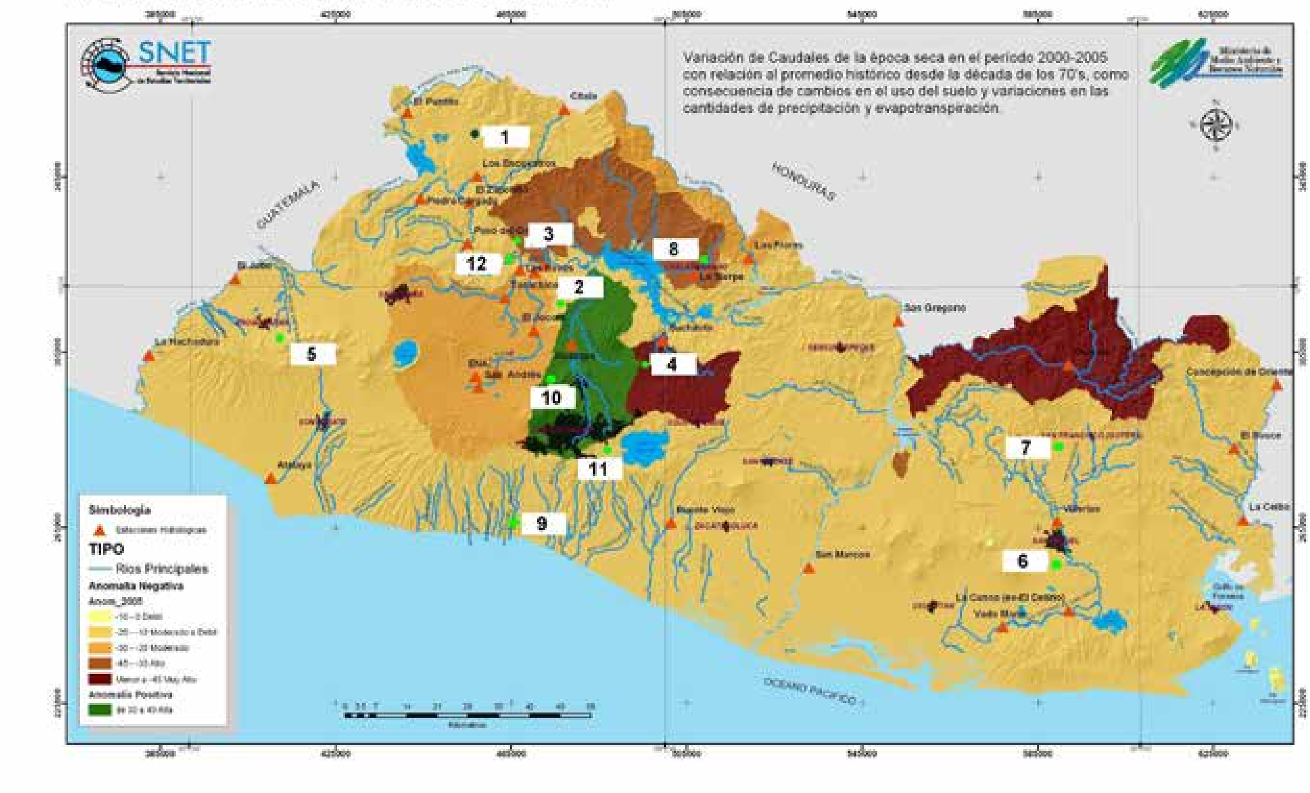
The map in Figure 15 presents the location of some of the most important springs or surface water sources on the national level. This map also illustrates the zones of moderate and greater anomaly levels (light brown and dark brown areas) in terms of the reduction in flow rate during the dry season. An increase in the flow rate (in green) is due to the *Acelhuate* River basin being an urban basin which drains residual water and treated water from SSMA in increasing amounts during the last two decades.

Table 2. Sources of superficial water and capacity provided by ANDA study (2009-2013)

No	Surface water source	Name	Municipality or Population	Date	Department	Flow Rate (l/s)
1	River	El Rosario	Metapán	Feb. 2012	Santa Ana	12.23
	River (Upstream from water intake)	El Rosario	Metapán	15 Jan. 2013	Santa Ana	147.97
	Río (Downstream from water intake)	El Rosario	Metapán	15 Jan. 2013	Santa Ana	64.08
2	Spring (upstream)	Caballeros	Aguilares	08/March 2012	San Salvador	10.34
	Spring (outflow)	Caballeros	Aguilares	08/March 2012	San Salvador	5.45
	Spring (upstream)	Caballeros	Aguilares	07/Dec. 2012	San Salvador	11.17
	Spring (outflow)	Caballeros	Aguilares	07/Dec. 2012	San Salvador	1.74
3	Spring	El Chaguitón I (Total Flow)	Nueva Concepción	27/March 2012	Chalatenango	31.64
	Spring	El Chaguitón I (Outflow)	Nueva Concepción	27/March 2012	Chalatenango	16.39
	Spring	El Chaguitón I (Total Flow)	Nueva Concepción	7/Jun. 2013	Chalatenango	22.73
	Spring	El Chaguitón I (Total Flow)	Nueva Concepción	7/Jun. 2013	Chalatenango	3.88
4	Spring	El Molino	Suchitoto	11/April 2012	Cuscatlán	29.70
	Spring (outflow)	El Molino	Suchitoto	11/April 2012	Cuscatlán	3.87
5	Spring	El Cashal I y II	Ahuachapán	June 2009	Ahuachapán	10
	Spring	El Cashal I y II	Ahuachapán	June 2009	Ahuachapán	1.73
	Spring	El Cashal I y II	Ahuachapán	May. 2012	Ahuachapán	12.11
	Spring (total flow)	Apunián	Ahuachapán	22 Feb. 2013	Ahuachapán	787.41
	Spring (outflow)	Apunián	Ahuachapán	22 Feb. 2013	Ahuachapán	638.88
6	River	El Jute	San Miguel	24/May 2012	San Miguel	192.89
	River	El Jute downstream from ANDA plant	San Miguel	24/May 2012	San Miguel	178.32
7	Spring	El Borbollón	San Francisco Gotera	16/May 2012	Morazán	21.51
8	River(upstream from water intake)	Tamulasco	Chalatenango	January 2009	Chalatenango	126.4
	River(downstream from water intake)	Tamulasco	Chalatenango	January 2009	Chalatenango	49.1
	River(upstream from water intake)	Tamulasco	Chalatenango	March 2009	Chalatenango	74.8
	River(downstream from water intake)	Tamulasco	Chalatenango	March 2009	Chalatenango	0.81
	River(upstream from water intake)	Tamulasco	Chalatenango	16 April 2013	Chalatenango	37.44
	River(downstream from water intake)	Tamulasco	Chalatenango	16 April 2013	Chalatenango	7.62
9	River(upstream from water intake)	Chilama	La Libertad	January 2009	La Libertad	217.3
	River(downstream from water intake)	Chilama	La Libertad	January 2009	La Libertad	130.5
	River(upstream from water intake	Chilama	La Libertad	March 2009	La Libertad	134.3
	River(downstream from water intake)	Chilama	La Libertad	March 2009	La Libertad	62
10	River	San Antonio (before the origin of inflow Tres Piedras)	Nejapa	March 2009	San Salvador	60.8
	River	San Antonio (after the origin. Tres piedras)	Nejapa	March 2009	San Salvador	208.7
	Spring	Tres piedras (inflow of Río San Antonio)	Nejapa	13 March 2014	San Salvador	56.96
11	River	Cuaya (water intake)	Ilopango	January 2009	San Salvador	130
	River	Cuaya (water intake)	Ilopango	Feb. 2009	San Salvador	77.3
12	River	Lempa (Las Pavas)	San Pablo Tacachico	Feb. 2009	La Libertad	815

Source: Author, based on the capacity program carried out by ANDA (2009-2013)

Figure 15. Map of flow rate variation and location of surface water capture sites (numeration corresponding to that used in Table 2)



From the perspective of water quality, the country has a monitoring program (Water Quality 2011) which has been in operation since 2005 through the Environmental Observatory of the Ministry of the Environment and Natural Resources (MARN). Monitoring takes place at 123 sampling sites in 55 of the country's rivers, which are of great importance due to their different environmental uses consisting of water for human consumption, irrigation, recreation, maintenance of aquatic life, etc. The Water Quality Index (ICA) is used for evaluation purposes, consisting of a points scale from 0 to 100 awarded based on national norms for water quality and WHO guidelines. According to results obtained in 2011, 88% of rivers have a level of environmental quality somewhere between regular and bad, as presented in the historical records for river water quality shown in Table 3. According to the report, the principal cause of contamination in the majority of rivers is due to untreated domestic wastewater and a lack of basic sanitation measures, evidenced by the presence of high concentrations of fecal coliforms whose maximum values reach 3.5 million bacteria per 100 ml and BOD (2) up to 122 mg/L, with the consequential reduction of dissolved oxygen.

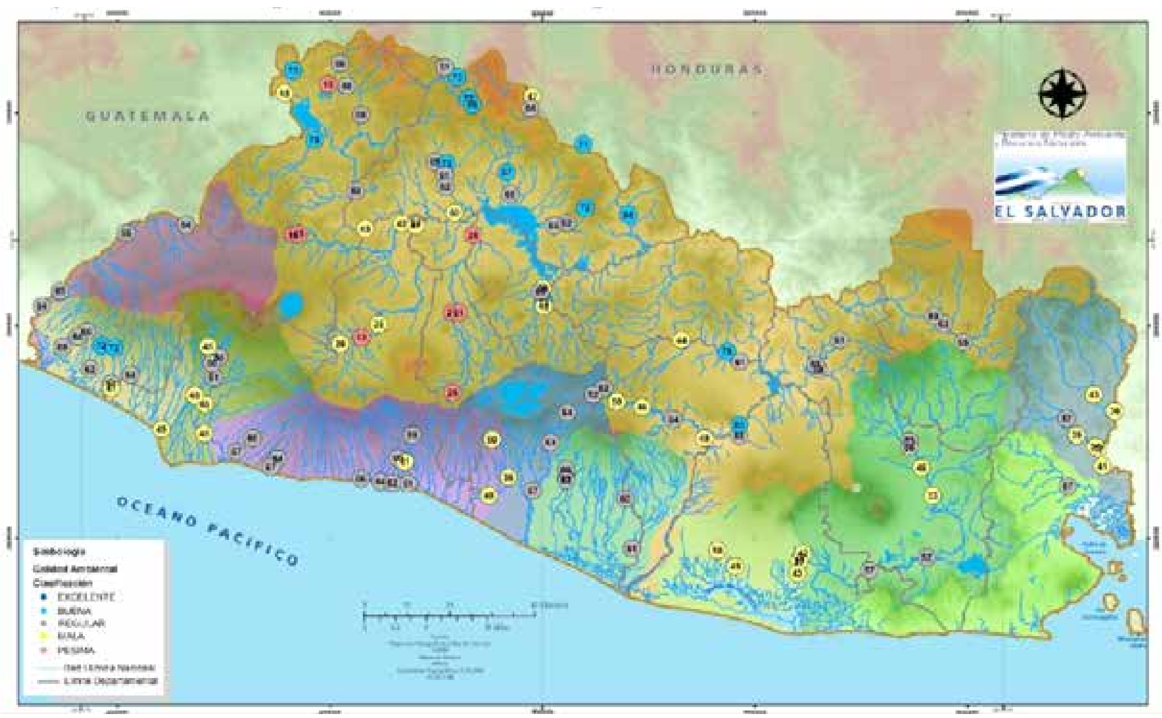
With regard to the feasibility of applications for purification by conventional methods, the monitoring program reported that barely 23 of the 123 sites evaluation, corresponding to 17% of the total, comply with the requirements of Decree 51 norms, "Regulation on water quality, waste control and protection zones" for purification using conventional methods.

Table 3. Water quality in El Salvador's principal rivers

Environmental Quality	Percentage of Sites				
	2006	2007	2009	2010	2011
Excellent	0	0	0	0	0
Good	17	3	0	2	12
Regular	50	45	60	65	50
Bad	20	46	31	27	31
Very bad	13	6	9	6	7

Source: MARN Water Quality Report 2011

Figure 16. National water quality and monitoring network map



The map shown in Figure 16 presents the location of sampling sites and the level of water quality found. Sites with good quality water are shown in blue while sites with regular, poor or bad quality are shown in grey, yellow and red, respectively.

It is important to note that the water quality in sections of the *Lempa* River before the "*Las Pavas*" capture and purification station present water quality levels between regular and bad, which translate into higher purification costs for ANDA in the strategic production of the water supply system for SSMA.

3. Potable Water Service in Urban Zones

Potable water service is provided throughout the country to El Salvador's populace by the National Aqueduct and Sewage Administration (ANDA), which is an autonomous public entity created by legal decree in 1961 to provide and guarantee potable water service to the population as well as removal and disposal of wastewater. This entity is in charge of carrying out projects and programs aimed at the construction and amplification of infrastructure for aqueducts, sewers and wastewater treatment as well as the administration of financial mechanisms for carrying out the objectives of the institution. ANDA is in charge of creating and putting into practice technical norms for the design and construction of hydraulic projects, emitting "non-encumbrance permits", carrying out hydro-geological studies for exploring subterranean water sources, water purification and quality control at extraction points, water capture and distribution network, and implementation of water consumption tariffs.

3.1 Characteristics of the decentralization process, current situation and production of water and consumption on the national level

Between 2001 and 2004, a decentralization process (SACDEL-2005) was discussed by ANDA's "Decentralization Unit". This process was later implemented by conferring the administration of a small part of services to diverse municipalities or local entities through the legal entity known as Municipal Associations, or to micro-regions or mixed enterprises (municipal-private-community), principally in rural areas. This process was formed without interfering with ANDA's legal obligations, as ANDA continued holding the title and ownership of assets, while transferring the local administration of water resources to these new operators, with an agreement for technical accompaniment, advice, personnel training and shared financial administration for the develop and maintenance of infrastructure to carry out the sustainable operation of the new administrative model.

In this way, ANDA could untangle itself from direct administration in rural zones which required great investment in administrative, technical and logistical resources, and could otherwise continue receiving income under agreement with the new operators through local billing for water supply and sewer services.

In 2009 (*Boletín Estadístico* – Statistical Report, ANDA 2009), ANDA supplied potable water to 122 of the nation's 262 municipalities (representing 46.6% of municipalities). Forty-five municipalities (17.2% of the total) were supplied by decentralized operators and 95 municipalities (36.2% of the total) were supplied by other operators. In general, this spatial distribution throughout the territory does not correspond to distribution in terms of population density and especially in terms of water production, as decentralized operators and other supply operators historically produce all together an average of between 5% and 6% of water production on the national level.

According to generalized data, within an average national production of 366 million m^3 of water annually, the decentralized operators contribute 20 million m^3 as will be shown later. Nevertheless, they play a primary role in providing water services to many rural municipalities categorized with a moderate to high level of poverty and the tariffs are adjusted to meet the economic possibilities of the population on the order of US$ 0.20 to US$ 0.70 per m^3, contributing greatly to combating price speculation and abuse on the part of intermediate sellers using transportation vehicles such as cistern trucks, while having previously sold water by the barrel with a price equivalent to US$ 10.00 per m^3.

Beginning in 2012, the process of decentralization began to be reversed when ANDA began to consider management by decentralized operators as lacking efficiency and technical-administrative capacity which led to increased costs and reduced income for the institution. This dismantling of local institutionalism has resulted in serious conflicts and a rejection of these methods because it implies not only a reversal of administrative management but also a direct impact on the formation of community and municipal organization which was building empowerment of local social actors in local development throughout the last decade.

One of the aspects that prevailed in the political discussion in the years preceding its implementation was the importance and value of the measure in terms of strengthening and developing citizen, municipal and community participation in the rural area, principally in decision-making and in building responsibility for the management of water resources and organized labor efforts around a service essential to the population.

In an initial evaluation of the decentralization process in 2005, carried out by RTI International (Moncada, L., RTI-2005), and cited in the analysis made by SACDEL, the most important achievements in the process carried out by ANDA were seen as "the development of local human resources, respect for users' rights and greater awareness of the need to protect water resources".

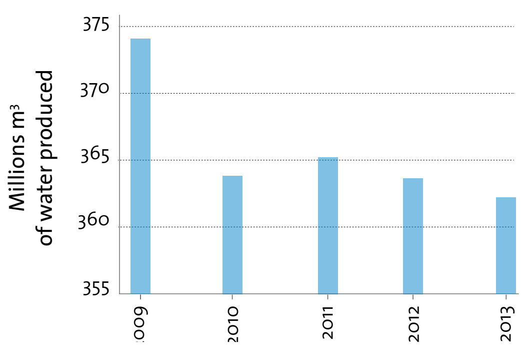
In 2012, the contribution of decentralized units was 16.4 million m^3, while in 2013 the contribution was 9.4 million, representing 2.4% of water produced on the national level. According to the annual account report ANDA 2009-2014, six of the most important decentralized units have been incorporated once more by the institution since 2012, generating in that year an increase in their management costs of US$ 85,100.00. Although it is still too soon to evaluate expected increases from this new centralization process, in terms of efficiency and returns for service on the part of the institution, Table 4 shows that for 2012 and 2013 the national production and consumption levels have remained practically the same, or have experienced a decline compared to previous years as illustrated in Figure 17. However, losses from leaks or illegal connections show a gradual increase between 2008 and 2011.

Table 4. Comparison between water production and consumption on the national level (millions of m³)

Year	Production of ANDA	Production other decentralized systems	Total of Water produced on national level	Consumption from System of ANDA on National level	Consumption of decentralized operators and self-supply on a national level	Total of consumption	Loss due to leaks and illegal connections	% of loss
2008	351.1	20.8	371.9	206.2	35.6	241.8	144.9	41.3
2009	353.4	20.3	373.7	202.4	36.9	239.3	151	42.7
2010	341.4	23.3	364.7	187.5	39.1	226.6	153.9	45.1
2011	345.7	20.4	366.1	179.8	39.7	219.5	165.9	48.0
2012	348.3	16.4	364.7	nd	nd	nd	nd	nd
2013	353.6	9.4	363	186.5	35.9	222.4	167.1	47.3

Source: Author, based on ANDA 2008-2011 statistical reports and ANDA 2013 annual report and ANDA-2009-2014 accounting reports. nd= no information available

Figure 17. National water production levels



3.2 Financial capacity of ANDA in relation to water production and loss due to leaks or illegal connections on the national level

One of the strengths of the institution has been, unlike other state entities or ministries, the fact that the great majority of income and allocated budget is derived from direct billing for services provided such that it is not dependent upon a budgetary line item from national coffers for operation expenses, although it does receive national funding yearly as part of its budgetary support; according to the tariff schedule, water service is provided in a subsidized manner according to the level of consumption. The allocated budget is also comprised of investment loans, non-reimbursable amounts, international cooperation financing, etc.

Thus, the total allocated budget determines the yearly objectives in terms of water and sanitation, improved services, maintenance and rehabilitation, increased coverage, etc.

Table 5 shows that between 2008 and 2013, income from billing for services has seen a notable increase which is attributed to a series of actions related to the modernization of the billing system, opening of branch offices and "express service" centers for easy payment and access for customers, improved customer service, updating and new informatics through implementation of new and improved software packages for managing the database, introduction of portable hand-held computers for meter-reading and better control of wastewater, leaks and illegal connections; better management in recovery of arrears, increased efficiency in operational tasks and logistics of maintenance and repairs of conduction lines and domestic hookup points, and extending services to new users, etc.

At the same time, in some years the allocated budget was strengthened with support from the national budget and through loan financing, and investments by international cooperation, principally during years in which extreme meteorological events have generated damages or disasters in the water conduction/distribution and sewage system. One year that stands out in this regard is 2011, in which Tropical Storm Ida impacted extensive areas of El Salvador. In general, the total executed budget has tended to increase between 2009 and 2011.

One aspect worth mentioning is that in spite of all the significant efforts and increases in yearly budgetary execution, water production nationwide has remained practically unchanged, or has experienced a decline as shown in Table 5, reaching

Table 5. Water production and executed budget amounts

Year	Invoicing and other commercial income (millions of US$)	budgetary reinforcement of the general fund of the Nation, loans and international cooperation (millions of US$)	Total executed budget (millions of US$)	Water produced on a national level (millions of cubic meters)	Index of relation of budget to produced water (US$/m³)
2008	81.1	52.3	133.4	371.9	0.36
2009	80.1	13	93.1	373.7	0.25
2010	102.8	14.6	117.4	364.7	0.32
2011	102.8	64.5	167.3	366.1	0.46
2012	nd	nd	nd	364.7	nd
2013	110.1	25.7	135.8	363	0.37

Source: Author, based on ANDA-2008-2011 statistical reports, ANDA-2013 annual report and ANDA-2009-2014 accounting report. nd= information not available

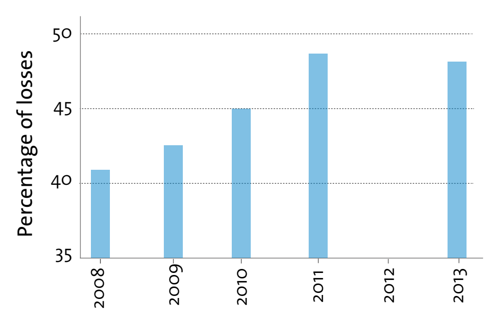
its peak of greatest efficiency in 2009 and its lowest output within dates on record in 2011 (data for 2012 is currently unavailable).

From information provided in institutional reports and taking into account funding destined for emergencies caused by hydro-meteorological events, some of the aspects attributable to the high costs of operation are the high price of energy and the need to increase the energy efficiency of the pumping system, the purification plants and the water supply system, as these costs have risen significantly in recent years. In this regard, inter-institutional agreements have been launched with the national hydro-electric generation entity known as "*Lempa* River Hydro-electric Executive Commission" or CEL, to come to agreement on the energy distributor's prices and not those of large consumers. Another aspect has been the outlay of funding destined for investing in new wells (26) and the rehabilitation of old wells (45) which had been in disuse for many years. In addition, the modernization of the billing system, control of leaks, use of portable instruments for meter-reading, installing software with greater capacity for administrative management and investment in human resources have been other factors which have resulted in increased budget investment in the last few years. Finally, a significant increase in funds destined for disinfection of crude water extracted from deep wells and surface sources must be included. According to institutional records, in 2009, 1.5 million pounds of chlorine (chloride gas and calcium hypochlorite) were used at a cost of US$ 1.02 million; however in 2011 some 14.8 million pounds of chemicals were used, at a cost of US$ 3.24 million, which reflects an increase of 300% in necessary purification costs for the same, and even for a lesser amount of water.

This fact is of great concern because it is an indication of the gradual contamination of water resources or the low quality of crude water that the institution must purify, as was indicated previously with respect to the results obtained from water quality monitoring in sections of the Lempa River prior to the "*Las Pavas*" station.

Leaks in the water distribution system, considered to be between moderate and high, have historically represented a significant problem for the institution, with an estimated value in 2013 of 47.3% nationwide, as presented in Table 4. In Figure 18 one can see that this value has gradually increased although it has decreased slightly this past year, which is associated with ANDA's efforts and improvements within the framework of diverse preventative maintenance and corrective programs for the aqueduct and sewage system on the national

Figure 18



level. This programs have allowed the institution to correct faults brought about principally by the outdated pipes and tubes. On the national level it is reported that during 2013, some 51,257 repairs were made, of which 46,794 (91.72%) were made in the networks and connection points of the aqueduct, and 4,463 (87%) were made in sanitation sewer networks.

3.3 Sources of water supply for the Metropolitan Area, volumes of production and consumption, and situations of water loss due to leaks and illegal connections

Regarding the SSMA, ANDA possesses four systems or primary sources of water production: 1. *Las Pavas,* which consists of a surface water source whose capture point is in the country's principal river, the *Lempa*, which has a current operational capacity of 2.2 m³ per second. This system constitutes the principal source of surface water in the country human consumption and is located 44 km from the SSMA. It provides approximately 38% of the capitals current water supply. 2. *Sistema Tradicional* consists of water production through deep well extraction, supplying 33% of the city's water supply. 3. *Zona Norte System*, consists of a water production system using deep well extraction and is located in the low foothills north of the San Salvador volcano (¨*Nejapa-Quetzaltepeque-Opico*¨) aquifer, providing 21% of the city's water supply. It is located an average of 18 km from the SSMA, and has strategic importance due to its low level of contamination and good conservation of the water recharge zones, a system which has been maintained for many years due to its restricted development category and limited urbanization efforts in the 1980s and 1990s. However, this system is currently under pressure from a new scenario of urban residential and industrial development and the previously restricted recharge zones' loss of protection, with the opening up of primary highways in the previous decade and the re-categorization of land use, and where it is now common to observe, along the new highways, logistics plants, factories, bottlers, great expanses of impermeable roofs and parking lots, signs indicating land for sale with industrial use permits and ultimately, the initial stage of construction of an extensive high density residential complex, totally incompatible with the strategic hydro-environmental function of this region. 4. *Guluchapa* System, which is a combined system capturing both surface and subterranean

Table 6. Water production system for SSMA water supply administers, by ANDA and other systems (millions of m³)

Year	Las Pavas	Traditional System	System Northern Zone	Guluchapa	Other Systems	Total
2008	75.7	64	40.4	11.1	0.6	191.8
2009	78	62.3	41.5	10.6	0.51	192.9
2010	75.6	63.7	37.9	10	0.44	187.6
2011	75	65.1	35.7	10.7	0.5	187.0
2012	70.5	*73.5	35.4	---	0.5	179.9
2013	70.5	60.6	38.3	13.9	0.51	183.8

Source: Author, based on ANDA -2008-2011 statistical reports, ANDA-2013 annual reports and ANDA-2009-2014 accounting reports. nd= information not available *Includes Sistema Tradicional and Guluchapa

Table 7. Summary of water consumption by category in the Metropolitan Region in the system administered by ANDA, private exploitation and decentralized operators (2004-2011) (in millions of m³ per year)

User	2004	2005	2006	2007	2008	2009	2010	2011
Residential	120.7	117.4	121	120.1	102.8	100	93.7	88.9
Industrial	1.9	1.7	1.4	1.3	3	2.6	2.2	2.4
Commercial	14.5	15.2	15.9	14.9	20.5	19	18.6	18
Public Sector	8.3	8.5	8.7	8.5	8.8	9.3	8.3	8.2
Total	145.4	142.8	147	144.8	135.1	130.9	122.8	117.5

Source: ANDA statistical reports

Table 8. Comparison between water production and consumption in the SSMA (in millions of m^3)

Year	Produced by ANDA	Production of other decentralized systems	Total Produced	Total consumed	Loss by leaks and illegal connections	% of loss
2008	191.2	0.6	191.8	135.1	56.1	29.3
2009	192.4	0.51	192.9	131	61.4	31.9
2010	187.2	0.44	187.6	122.8	64.4	34.4
2011	186.5	0.5	187.0	117.5	69	37.0
2012	179.4	0.5	179.9	nd	nd	nd
2013	183.3	0.51	183.8	nd	nd	nd

Source: Author, based on ANDA 2008-2011 statistical reports, ANDA-2013 annual reports and ANDA-2009-2014 statistical reports. nd= no information available

Table 9. National status of water supplied for human consumption in the year 2011

Description	Rural		Urban		Country	
	Families	Percentage	Families	Percentage	Families	Percentage
Water Services						
Piped water	348565	63.05%	940137	90.42%	1288702	80.9%
Storage of water in pottery jugs	29073	5.26%	39037	3.75%	68110	4.3%
Excavated well	96440	17.44%	45420	4.37%	141860	8.9%
Spring	70083	12.68%	7047	0.68%	77130	4.8%
Rain Water	6391	1.16%	6252	0.60%	12643	0.8%
Others	2324	0.42%	1864	0.18%	4188	0.3%
Total	**552876**	**100.00%**	**1039757**	**100.00%**	**1592633**	**100.0%**
Bath Services						
Shower	199008	36.0%	843272	65.4%	1042280	65.4%
River or Ravine	57544	10.4%	6728	4.0%	64272	4.0%
Barrel or Open Air Sink	295506	53.4%	189674	30.5%	485180	30.5%
Others	818	0.1%	83	0.1%	901	0.1%
Total	**552876**	**100.0%**	**1039757**	**100.0%**	**1592633**	**100.0%**

Source: Author, based on EHPM-2011

water in the southeastern zone of the capital in the hydrographic region known as *Guluchapa*, whose basin extends from *San Jacinto Cerro* to *Ilopango* Lake. This system provides 8% of the city's water together with a minority contribution from the only decentralized operator contributing to the SSMA water supply. This system is often taken into account together with contributions from the *Sistema Tradicional*, making their joint supply total 41% of the city's water. Table 6 presents water production in millions of m^3 from each of SSMA's systems throughout the past six years. Once again, production has tended to decrease during the period analyzed.

Table 7 shows the distribution by category of water use from 2004 to 2011 in the San Salvador Metropolitan Region, which verifies a gradual decrease in total consumption through the period analyzed. Within the residential sector in 2011, water consumption was established as 88.9 million m^3. According to the categorization established by ANDA, during that year, the lower economic classes consumed 38.32% of the city's demand for water, with an average of 11 m^3 per month; the middle classes consumed 41.2% with an average of 30 m^3 per month; and the upper classes consumed 20.6% with an average of 87 m^3 per month.

Table 8 shows that the percentage of loss due to leaks in the SSMA is repeated in a similar fashion on the national level, as these percentages have tended to increase, as opposed to consumption which has tended to decrease between 2008 and 2011, while data for 2012 and 2013 is not known.

3.4 National water services coverage in urban and rural zones

The analysis of piped potable water supply coverage, along with a 2011 domestic and multi-purpose survey, reveals that 90.42% of the urban area is covered by this service while only 63.05% of the rural area is covered. Table 9 shows the different kinds of water services supplying the urban and rural populations with water.

3.5 Quality control of water supplied by ANDA

The quality of supplied water is another topic of great importance for potable water consumption on the national level and from the perspective of urban waters, especially in SSMA. ANDA has a recognized Water Quality Control Laboratory which is accredited by the Salvadoran Accreditation Office (OSA) and by the international standard ISO/IEC 17025:2005, making it the national referral center for wastewater analysis for the US/EPA. Some of the characteristics regarding the laboratory's compliance with Obligatory Salvadoran Norms (NSO) are the following (Water Quality Laboratory, ANDA-2014):

- Complies 100% on the national level with respect to minimum, normal and complete samples required by the NSO for evaluating water quality; as well as monitoring according to frequency, number of samples and parameters which are the sanitary requirements established by the NSO for potable water.
- Regarding the number of parameters per type of analysis, the laboratory complies with 100% of the parameters that establish minimum samples. However, only 65% of the parameters that stipulate normal samples are currently met (15 of the 23 parameters required by the NSO). The laboratory's short-term goal is to obtain 100% compliance.
- Regarding the parameters which stipulate complete samples, only 66% of them are met (23 of the 35 parameters required by the NSO). The laboratory's short-term goal is to obtain 100% compliance.
- The gamut of parameters not currently carried out by the laboratory correspond principally to the category of heavy metals (Barium Ba, Cadmium Cd, Chrome Cr, Mercury Hg, Antimony Sb, Selenium Se, Boron B and Nitrites NO2) which have great importance in terms of health, according to NSO criteria. However, efforts are currently underway for the acquisition of an ICP/MS and for updating the informatics software for the chromatography equipment and mass spectrometer for analyzing pesticides. At the same time the laboratory intends to increase its scope in analytical determination of organochlorine, organophosphate and heavy metal pesticides.

According to institutional reports, the establishment of the institutions own laboratory has allowed it better control and monitoring of the quality of the water consumed by the public, with an investment of between US$ 360 thousand and US$ 400 thousand per year, compared to subcontracting a private laboratory which would mean an outlay of funds on the order of US$ 1.6 million.

4. Urban Water Treatment

4.1 Sanitation and wastewater treatment coverage in cities and on the national level

Sanitation services in the country have been characterized as presenting a marked difference between rural and urban coverage, as the urban coverage for black water disposal via a system of sewers reaches 59%; while rural coverage is barely 0.64%; the principal method for disposing of and treating human waste in rural areas being septic tanks (13.1%) and latrines (76.9%), as shown in Table 10.

Although the cities enjoy greater coverage of waste disposal through the sewage system, a sizeable portion of the population disposes of and treats human waste through toilets and septic tanks (13%) and latrines (27%), principally in the peri-urban areas with limited economic resources.

According to the evaluation and analysis of experiences in marginal and peripheral zones, such as those reported in the Home and Multi-Purpose Survey (EHPM-2010), scarcely 24% of the one-family systems for disposing of grey water function adequately with the help of absorption pits, as the great majority have no pits, and in many cases,

Table 10. Sanitation conditions on the national level

Description	Rural		Urban		Country	
	Families	Percentage	Families	Percentage	Families	Percentage
Water Services						
Toilet connected to sewage system	3255	0.6%	610983	59.0%	614238	38.6%
Toilet connected to septic tank	72268	13.1%	137810	13.0%	210078	13.2%
Latrine	425188	76.9%	284553	27.0%	709741	44.6%
None	52165	9.4%	6411	1.0%	58576	3.7%
Total	552876	100.0%	1039757	100.0%	1592633	100.0%
Others	2324	0.42%	1864	0.18%	4188	0.3%
Total	**552876**	**100.00%**	**1039757**	**100.00%**	**1592633**	**100.0%**

Source: Author, based on EHPM-2011

Table 11. Sanitation coverage through a system of wastewater treatment plants with a sewer system. Public and private-municipal administration

Description	Public administration (ANDA) (with sewage system)	Municipal administration private (with sewage system)	Total
Number of treatment plants	20	69	89
Served population with treatment of waste waters (inhabitants)	124,481	349,551	474,032
Percentage of Served population (%)	26%	74%	100%
Anual production of waste waters in sewage system (millions of m^3/year)	111.12	73.82	184.94
Flow rate of waste waters treated in sewage system (millions of m^3/year)	9.46	16.40	25.86
Waste waters with treatment in sewage system (%)	8.52%	22.23%	13.98%

Source: FOCARD-APS 2013

crude wastewater is thrown into the streets without any form of treatment; the system in its entirety functions in a deficient manner such that it doesn't comply with required standards for the removal of the components of wastewater, contributing greatly to the contamination of subterranean and surface waters, soils and foods, principally through the generation of pathogenic microorganisms and the consequential effects on public health.

Within the SSMA, there is no integrated system for the city's wastewater treatment. Instead, treatment is carried out by some treatment plants in residential complexes and other similar private systems, which are not capable of properly treating all of the city's wastewater, as many of them function with a low degree of efficiency. According to the study carried out by the Center for Consumer Defense (Quiñonez, J. CDC-2014), the evaluation done by international organizations such as the World Bank, for 2007, assigned the country a low level of wastewater treatment, on the order of 3%. The study sustains that in regard to investments in this sector, there is currently no clearly established allocation of funding for this purpose, as it is funded in a general manner, directed toward the potable water and sanitation sector. According to the FOCARD-APS 2013 report, cited in the study, combined investment for 2011 between ANDA and FISDL was US$ 56.3 million, with 30% of this amount destined for sanitation. In the same vein, the FOCARD report assets: "This situation is the result of abandonment of this sector for at least the last 25 years in terms of planning and development, delay in tending to reforms in the sector's norms and institutions and the absence of political will to face the administrative challenges. In this sense, the country currently lacks adequate institutionalism to face the challenges inherent in the integrated management of water resources".

Table 12. Sanitation coverage through a system of septic tanks and tanks without a sewer system. Community-Municipal Administration

Description	Comunity-Municipal Administration		Total
	Urban	Rural	
Population (Inhabitants)	3,871,332	2,342,398	6,213,730
Disposal and some degree of treatment with Septic Tank (inhabitants)	124,481	349,551	474,032
Percentage (%)	13	13	
Disposal and some degree of treatment with latrines(inhabitants)	1,045,260	1,801,304	2,846,564
Percentage (%)	27	77	
Total	1,548,533	2,108,158	3,656,691
Percentage	40	90	59

Source: FOCARD-APS 2013

According to FOCARD-2013, there are currently 89 treatment plants in the entire country, 20 of which are administered by ANDA and 69 are administered by municipal and private operators. According to the study and information supplied by ANDA, the volume of wastewater produced in the sewage system is 111.1 million m^3 per year, equivalent to a flow rate of 3.52 m^3 per second, 9.46 million m^3 of which receive treatment each year, equivalent to 0.30 m^3 per second. This means that only 8.52% of wastewater in the sewer system receives some form of treatment prior to being discharged into disposal sites.

According to calculations made by FOCARD-APS 2013, the wastewater systems administrated by municipalities and some residential complexes produce an estimated volume of 73.82 million m^3 per year of which 16.4 million m^3 (22.23%) per year receive treatment prior to being deposited into a receptive body of water. Nevertheless, there is no systematic follow-up by a competent entity of the system's functioning and efficiency, therefore it is unknown if the treated waste falls within established norms and ranges. Table 11 presents the data on sanitation coverage with sewer systems on the national level.

Table 12 presents sanitation coverage through the use of septic tanks and latrines on the national level.

4.2 Evaluation of the institutional approach and the legal framework for disposing of wastewater in the country

The country currently lacks a general law regarding water through which a leading authority could be established to regulate and control the situation of wastewater, and to create an overall plan for purification, and promote a sustainable development approach in line with the framework for adequate protection of resources and hydrographic basins. The draft bill is currently in discussion in the Legislative Assembly.

Historically, various State entities have intervened in this area according to their particular and sectoral competencies, in diverse fields of action regarding control of wastewater, water quality, and sanitation, agro-production and environmental approaches. For ANDA, the primary focus is the protection and control of water quality of waters obtained from surface and subterranean sources, as well as the water present in the transportation, distribution and consumption lines. For the Ministry of Health, importance lies in control and surveillance from a health perspective, in the eradication of vectors, water borne diseases and promoting adequate sanitary practices, principally in rural areas through single family supply systems. For MARN, the emphasis is on regulation and monitoring of wastewater, control of contamination and the environmental protection of disposal sites receiving the waste. Finally, for the Ministry of Agriculture (MAG), their work emphasis is on verifying water quality for agricultural irrigation.

In light of the above, in many instances the State entities have not worked in an inter-institutional format, jointly coordinated and united, but rather in a disperse manner without taking on the responsibility of the problem of contamination and water quality with a comprehensive approach.

It has been only been within the last few years that efforts have been made to develop a coordinated approach and inter-institutional actions that are more systematic and integrated; agreements have been reached through which information is shared, methodology mechanisms have been established jointly and the water problem is seen in all its entirety as something that affects diverse sectors of national life.

However, in spite of all this effort, the existing legal framework for the control and disposal of wastewater presents serious deficiencies in terms of facilitating real protection and integrated management of water resources from a health, ecosystem and sustainable development perspective as in many instances the regulated parameters present permissible ranges, differing greatly from international standards and references.

One example of this is the significant modification that was made in establishing the ANDA-2005 Technical Norm for permissible values discharged into the public sewer system compared to Decree No. 50 of October 1987, which established permissible ranges far lower for this same purpose, i.e., the ANDA-2005 Technical Norm substantially raised the permissible limits of contaminant concentrations which could be introduced into city sewer systems.

This situation must have had a significant impact the treatment system capacity since they were designed for certain flow rates and certain concentrations; and the new ANDA-2005 Technical Norm permitted a substantial increase in these without ordering at the same time, through one of its articles, the rehabilitation or transformation of the treatment systems to the new conditions of non-ordinary effluents.

Table 13 presents a comparison between the modified ranges of the ANDA-2005 norm and the ranges established in Decree No. 50, art. 81, 1987.

At the same time, a similar situation is present in the values defined in the Salvadoran Obligatory Standards (NSO), which establishes permissible intervals for dumping wastewater into the disposal sites, from different industrial sectors, and the guideline values established by the EPA. Table 14 presents some of the comparative parameters.

The Salvadoran Obligatory Standards (NSO) on "Wastewater discharged into a receiving body" NSO 13.49.01.09 was adopted based on executive agreement in March 2009 between the Economic Ministry, business entities and academics. These standards established the value limits of wastewater from industrial use introduced into disposal sites (ravines and rivers), which supersede considerably the permissible values for domestic black water (60 mg/L). In addition, the limits established for one parameter were different depending on the industrial sector from which it came. For example, limits for DBO6 varied between 200 mg/L and 3,000 mg/L; for diary product factories (600 mg/L, distillation of alcoholic beverages (3,000 mg/L), soap manufacturing (300 mg/L) or the textile industry (200 mg/L).

The Salvadoran standards, far from regulating the control and reduction of sources of contamination and promoting the preservation of the wastewater disposal sites and ecosystems, have the opposite effect by officially and legally permitting the dumping of high concentrations of contaminants from industrial use, far removed from the objectives of sanitation and international requirements, guidelines and norms. These contaminants cannot be self-purified by natural currents and by the disposal sites themselves.

It is important to remember that the guidelines promoted by the World Bank for the disposal of industrial waste into surface water and natural drainage systems establish as a fundamental guideline the preservation of the environmental quality of water in the disposal site and establish a legal framework with parameter limits based on Environmental Protection Agency (EPA) and World Health Organization (WHO) guidelines.

According to the CDC study mentioned earlier, "The criteria for preserving good environmental water quality is clearly defined in the water quality recommendations established by the EPA, 'US-EPA National Recommended Water Quality Criteria.' Based on these recommendations, the multi-lateral agency World Bank (WB) created a document on guidelines directed at industry to emphasize preservation of health, the environment and safety, 'Industry Sector Environmental Health and Safety Guidelines (EHS)', in which it is established that all industrial processes must prioritize the incorporation and implementation of internal and *a priori* processes to avoid, minimize and control

Table 13. Maximum permissible values for the disposal of wastewater in the public sewer system

Parameter	Units	Máximum permitted value, norm of anda (2005)	Decrete no. 50 (1987)
Oil and Fats	mg/l	150	20
Aluminum (Al)	mg/l	10	
Arsenic (As)	mg/l	1.0	0.05
Boron (B)	mg/l	3	
Cadmium (Cd)	mg/l	1	
Total Cyanide	mg/l	1	0.10
Zinc (Zn)	mg/l	5	5
Cobalt (Co)	mg/l	0.5	
Copper (Cu)	mg/l	3	0.20
Color	mg/l	Not different to domestic discharge	
Phenolic compounds	mg/l	5	0.005
Hexavalent Chrome (Cr+6)	mg/l	0.5	0.05
Total Chrome (Cr)	mg/l	3	
Biological Oxygen Demand 5	mg/l	400	
Detergents (SAAM)	mg/l	35	
Chemical Oxygen Demand	mg/l	1000	
Fluor (F)	mg/l	6	3
Total Phosphorus Total (P)	mg/l	45	
Total Herbicides	mg/l	0.1	
Hydrocarbons	mg/l	20	
Total Iron (Fe)	mg/l	20	
Total Manganese	mg/l	4	
Floating Materials	mg/l	absent	
Mercury (Hg)	mg/l	0.02	
Molybdenum (Mo)	mg/l	4	
Nickel (Ni)	mg/l	4	0.80
Total Nitrogen (N)	mg/l	100	
Organic Chloride Pesticides	mg/l	0.05	
Organophosphorus Pesticides and Carbamates	mg/l	0.25	
pH	unid	5.5-9.0	5.5 - 9.0
Silver	mg/l	3	
Lead (Pb)	mg/l	1.0	
Selenium (Se)	mg/l	0.15	
Sedimentable Solids	mg/l	20	
Total Suspended Solids	mg/l	450	
Sulfates (SO4)2	mg/l	2000	
Radioactive Substances	-	absent	
Temperature (°C)	°C	20-35	T°< 35
Vanadium (V)	mg/l	5	

Source: CDC Study, Calculations based on technical standards

Table 14. Comparison of permissible value limits for components of wastewater disposed into disposal sites, between the Salvadoran standards (NSO) and the guideline values indicated by the EPA

Contaminants	Unit	Limit of Concentration Norm of El Salvador NSO.13.49.01:09	Limit of Concentration Guide BM-EHS/EPA from industrial use
Biological Oxygen Demand	mg/l	200 – 3000	30
Chemical Oxygen Demand	mg/l	400 – 3500	125
Total Suspended Solids (TSS)	mg/l	150 – 1000	45
Total Nitrogen	mg/l	50	10
Total Phosphorus	mg/l	15	2
Fats	mg/l	30 - 200	10
pH	Uni.	5.5 – 9.0	6 – 9
Total of Coliform Bacteria	NMP/100 ml	10,000	400
°T	°C		37
Color			Not acceptable a distinct color on visual observation
Mercury (Hg)	mg/l	0.01	0.01 – 0.015
Cadmium (Cd)	mg/l	0.1	0.01 – 0.015
Lead (Pb)	mg/l	0.4	0.1 – 0.15
Arsenic (As)	mg/l	0.1	0.010 - 0.015
Cyanides (Cd)	mg/l	0.5	0.20 - 0.30
Copper (Cu)	mg/l	1	0.25 - 0.375
Nickel (Ni)	mg/l	0.2	0.20 - 0.30
Chromium (Cr)	mg/l	1	0.10 - 0.15
Zinc (Zn)	mg/l	5	1.0 - 1.5
Antimony (Sb)		---	Not required for most resources
Cobalt (Co)		0.05	0.03 (Not required for most resources)

Source: CDC Study, Calculations based on Salvadoran standards NSO 13490109 and Guideline Values from "Industry Sector Environmental Health and Safety Guidelines (EHS)" promoted by the World Bank based on "US-EPA National Recommended Water Quality Criteria".

adverse impacts on public health, the environment and the comprehensive security of the population."

A fundamental aspect within the guidelines which stands out is the importance of having knowledge of and a characterization of the waste disposal site in terms of its ability to assimilate the waste and to self-purify, taking into account the seasons of the year, given that the dilution capacity is much greater during the rainy season than in the dry season, and therefore a "seasonal baseline" must be established. Having established the baseline, it is possible to determine and construct a matrix of users and the feasibility of establishing maximum concentrations; volumes to be discharged; frequencies; and the proper moment and locations at which to discharge.

As the CDC document states, "One of the weaknesses of El Salvador's regulatory standards and guidelines is precisely this point. Within the country, a pattern of permissible ranges and limits for wastewater disposal have been established without deep hydrologic knowledge of the discharge site and of the quantitative and qualitative characteristics associated with the rainy and dry seasons and of its true capacities for self-purification. Thus a practice of discharging "treated waste" is exercised with authorization but without truly contributing to the sanitation objective, environmental hydrologic preservation of the disposal site and of it natural surroundings.

From this perspective, a national strategic initiative is still pending; one that will begin to reverse the current degradation process and incorporate sanitation and decontamination of the discharge sites as a fundamental action that must be adopted inter-institutionally and in frank dialogue with the country's social, economic and political actors. This requires effort on the part of institutions, aimed at developing investigative, technological and administrative capacities, as well as financial administration, to allow for not only the realization of important programs and focused actions but to develop and implement in stages a national sanitation system, framed within an appropriate administrative model and in the planning and creation of public policies.

4.3. Evaluation of recycled waters

Recently, efforts were made in the direction of recycled waters through the Social Investment and Local Development Fund (FISDL) in coordination with the Spanish organization *Alianza por el Agua* (Alliance for Water – AxA), which is cooperating in strengthening cooperative links and relationships between the institution and CENTA of Spain. This effort has led to training courses for local technicians and improving manuals and instructions for promoting a new sanitation agenda principally in peri-urban and rural zones. The focus is primarily on launching extensive treatment systems which will provide the opportunity to apply appropriate and low-cost technologies through combined preliminary treatment systems, separation of solids, filtration, horizontal and vertical bio-filters, and treatment ponds. These methods will allow the treated fluids to be re-used on crops and areas planted in forests and fruit trees, as well as in garden maintenance and other landscape environments. Among the requirements for the application of these recycled waters are the preference for a convenient geography that would permit the use of gravity-fed systems to avoid pumping costs; enough space; and appropriate zones for receiving the treated water.

4.4 Per capita spending on the treatment systems within the national sanitation strategy

The investments required for implementing the national sanitation strategy have already been estimated within the FOCARD-APS 2013 framework, which established the total amounts and the costs per capita for the type of treatment system to be implemented, as shown in Table 15.

5. Urban Water and Health

Public health status is directly linked to the availability and quality of water in both rural and urban areas. In general, during the rainy season the country reports an increase in dengue fever, hemorrhagic dengue fever and other illnesses including gastrointestinal, associated with undisturbed, standing water, puddles which facilitate the growth of mosquito larvae (Aedes aegypti), and contamination of water supply, which has a direct effect on food safety. However, according to Ministry of Health (MINSAL) data, this problem exists even during the dry season. Although the coverage of potable water in urban areas via household plumbing is high, only 66.5%

Table 15. Necessary investment in sanitation according to the target population and type of system to be implemented

Description	Population (Inhabitants)	Amount per capita (US$/inhabitant)	Total Amount (Million US$)
Urban Population without sewage system	27,050	325.00	8.79
Rural Population without improved sanitation	243,295	150.00	36.49
Urban Population without treatment of waste waters	2,378,735	275.00	654.15
Improved individual systems	3,090,702	30.00	92.72
Total Amount			**792.16**

Source: FOCARD-APS 2013

of those with plumbing enjoy a continuous supply of water (a condition that is defined as having domestic water supplied for seven days per week for at least four hours daily), while only 34.6% of homes in rural areas have continuous water coverage. This situation forces households to store water in recipients and in laundry sinks, resulting in health risks as evidenced by MINSAL records which reveal that 83% of water stored in recipients inside homes during the dry season test positive for the dengue mosquito vector.

The absence of enhanced black water services, the existence of wastewater without prior treatment and the less than adequate treatment of black water prior to final disposal into natural drainage systems or through infiltration mechanisms are other variables that directly impact public health. Although improved service coverage is high in urban areas, families lacking these services are the most affected and vulnerable, and also those who repeatedly present with infectious illnesses associated with oral-fecal disease transmission such as diarrhea, including intestinal parasites, typhoid fever, paratyphoid fever and salmonellosis, with 303,393 cases reported and attended within the hospital system in 2012. Through sampling and laboratory analysis, these infections can be determined to be in large part due to risk factors related to contaminated water in artisanal wells and sources of surface water which are reported to contain coliform bacteria including fecal coliforms, parasites, virus, E. coli and others. Among them, 615 cases of rotavirus, which affects primarily children under four years of age, were reported in that same year.

In Table 16, the top ten most frequently attended illnesses during ambulatory consultations within the MINSAL health services network are shown. “Other Causes” refers to external injuries (accidents, falls, injuries), neonatal, child and maternal care, and other illnesses. Diarrheal illnesses, although appearing as a low percentage of the total ambulatory consultations, require other related consultations for laboratory and other exam services, which increase health care services for infectious illnesses related to water and health. In terms of hospital services, MINSAL has established that in regard to these top ten causes, 44.3% of the hospital care and expenses are due to infectious-contagious illnesses, among them diarrheal and gastrointestinal illnesses as well as urinary infections and pneumonia. Another 13.8% consist of chronic-degenerative diseases, principally chronic renal insufficiency.

It is important to note that water contamination, both surface and subterranean, stemming from industrial and agricultural practices, has acquired great relevance in recent years and is material for discussion and attention by health and environmental authorities, due to the notorious increase in some areas of the country of chronic renal disease (CRD), associated with the use of pesticides and water contaminated by chemicals and metals, which have as their principal causes the intensive

Table 16. Most frequent causes of ambulatory consultations in MINSAL health services network

Nr in order	Diagnosis	Total
1	Other acute infections in upper respiratory tract	1,525,620
2	Hypertension (Primary)	710,779
3	Acute Pharyngitis and acute Tonsillitis	699,125
4	Other diseases in urinary tract	530,477
5	Persons in contact with health attention services for research and examination	481,498
6	Diabetes mellitus	360,785
7	Diarrhea of probable infectious origin	302,393
8	Other symptoms, signs and findings of abnormal clinic and laboratory, not classified	293,704
9	Other injuries of specific regions, in nonspecific regions, and in multiple areas of the body	287,378
10	Other diseases of the skin and subcutaneous tissues	282,221
	Other causes	5,288,705
	Total	**10,762,685**

Source: MINSAL 2013 annual report

fumigations of the old cotton haciendas and to some degree in the current cane sugar plantations, as the phreatic levels of local aquifers have very low depth, oscillating between 4 m and 12 m, which makes them very susceptible to contamination.

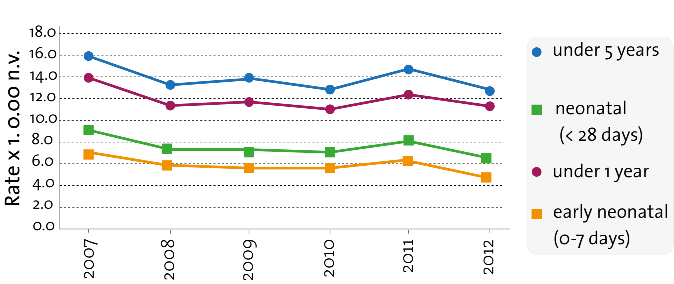
In 2007, health consultations for CRD totaled 16,464, with 505 deaths reported, while consultations and deaths have gradually increased in recent years, reaching 32,366 in 2012 with 809 deaths. Within the departments most affected, the mortality rate for this illness per 100,000 inhabitants is 28.8 and 25.6

Although many of the outbreaks with numbers that have soared have not occurred specifically in urban areas, they are still an important factor for the urban area as the high levels of contamination of surface water produced in the SSMA generates direct impacts all along wastewater's journey to the sea; all along the trajectory there are diverse uses associated with risk such as fishing, recreational use, retention in hydroelectric dams, among others, until the waters finally reach the lower Rio Lempa delta area on the coastal plain, whose wide expanses are repeatedly flooded, affecting artisanal wells, community gardens, domestic animals on family farms, local aquifers and other agricultural uses.

Deaths from all causes reported in 2012 in MINSAL's hospital network totaled 10,024, a reduction of 116 from the previous year. The overall mortality rate for 2012 was 160.4 per 100 thousand inhabitants.

Although MINSAL does not explicitly report investments and spending in regard to the principal causes of ambulatory and hospital care, it is clear that according to the data previously presented, the costs to the country of medical care for illnesses

Figure 19. Fluctuations in Child mortality rate



Source: MINSAL 2013 annual report

related to water and sanitation are quite significant and could be estimated at 10% - 15% of the total annual budget of US$ 625 million, considering the high percentage of infectious-contagious, urinary and gastrointestinal illnesses, along with chronic renal disease and those requiring the necessary additional exams and laboratory analyses.

The central government's annual budget and financing from diverse MINSAL sources is presented in Table 17. A tendency toward increase in the annual budget can be seen; the annual budget in 2008 was 1.9% of GDP while in 2012 it 2.4% of GDP.

The mortality rate for children under five years and newborns has decreased markedly in the last few years. In 2007, the mortality rate for children under five years was 15.8 per 1,000 live births. In 2012, the rate was 12.5, as shown in Figure 19.

This important decrease in the mortality rate of newborns, infants and children under five years, registered within the last few years, is due in large part to the implementation of a health model that prioritizes Integral Health Primary Care (APSI), which offers extended prenatal sign-up programs to improve maternal-child care, controls and education, which have greatly benefitted and contributed to a reduction in the principal causes of infant death, including perinatal asphyxia, neonatal sepsis and premature birth.

These programs have contributed significantly to reducing maternal death, with 64 cases of death reported in 2011 and 53 cases reported in 2012. MINSAL reports that they have reached the Millennium Development Goal 5 for 2015 which consists of reducing maternal death by two-thirds, equivalent to a rate of 52.8 per 100 thousand live births (LB), in relation to the 1990 rate of 211 per 100 thousand LB. The rate for 2012 was reported as 42 per 100 thousand LB.

From this perspective, it is important to note that the country's principal challenges, including not only: efforts to increase health services in terms of ambulatory and hospital care; increase professional human resources and infrastructure, treatments and medications based on State budgetary allocations; but also generating conditions for promoting a social and economic development model, with equality and hydro-environmental sustainability facilitating conditions for elevating and improving the living conditions of the population in terms of decent housing with basic services, protection of ecosystems and population livelihoods; environmental decontamination; integral administration of hydrographic basins for the maintenance of water quantity and quality; promotion of healthy life habits and cultural guidelines that promote less consumer dominated social practices, among others, are all intimately linked to the top ten causes for requiring health services such that an economic-social turnaround in this direction can contribute to regulating and greatly reducing the social burden placed year after year upon the health system, and offering more efficient services with the possibility of strengthening other strategic areas in the development of preventative health services, diagnostics, treatments and cures.

6. Variability and Climate Change - Their Impact on Urban Water Resources

Climate variability and change, and associated impacts on the urban water dynamic have been felt with greater intensity during the last few decades, evidenced by an increase in the frequency of extreme hydro-meteorological events, an increase in the intensity of the rains (mm/min) and their periods of return, a decrease in average precipitation and an increase in temperature in some sectors of the country, an increase in consecutive days without rain during the wet season and a reduction in consecutive days with rain, principally. All these aspects have been studied in previous years from the perspective of climate variability by the National Territorial Studies Service (SNET), known today as the MARN Environmental Observatory, and from the perspective of climate change by different studies carried out collaboratively between national and international entities, through climate projections of temperature and rain variability under different scenarios of emissions and through downscale modeling using results obtained from global circulation models.

Based on interdecadal analysis, the National Hydrological Service of SNET analyzed rain and temperature activity in 2005 in a series of meteorological sub-stations nationwide. Temperature results from ten stations with data spanning more than forty years indicated a generalized tendency for increasing temperatures beginning in the mid 1970s with intervals that varied between 0.4°C a 2.2 °C. Figures 20 and 21 show the tendency toward increasing temperatures in two meteorological stations located in different altitudes in the west of the country in the department of Santa Ana as well as a record of more than forty years.

Table 17. Variation in the annual budget in recent years and sources of funding

Total Budget per Financial Source	2007	2008	2009	2010	2011	2012	2013p
In Millions $US							
Government of El Salvador	307.1	329.4	328.4	384.4	488.3	483.8	555.4
External loans	41.4	40.2	105.1	76.2	38.5	45.3	42.3
Donations	6.7	13.2	8.2	12.8	13.3	15.1	12.6
Own resources	14.8	14.8	15.5	11.3	11.5	14.6	12.6
FAE	1.4	1.7	1.7	1.7	2.3	2.3	2.6
Total Budget	371.4	399.3	458.9	486.4	553.9	561.1	625.5
Rate of Annual Growth	**0.8%**	**7.5%**	**14.9%**	**6.0%**	**13.9%**	**1.3%**	**11.5%**
In Percentage							
Government of El Salvador	83%	82%	72%	79%	88%	86%	89%
External loans	11%	10%	23%	16%	7%	8%	7%
Donations	2%	3%	2%	3%	2%	3%	2%
Own resources	4%	4%	3%	2%	2%	3%	2%
FAE	0%	0%	0%	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: MINSAL 2013 annual report

Figure 20. Santana El Palma A-2, 725 msnm

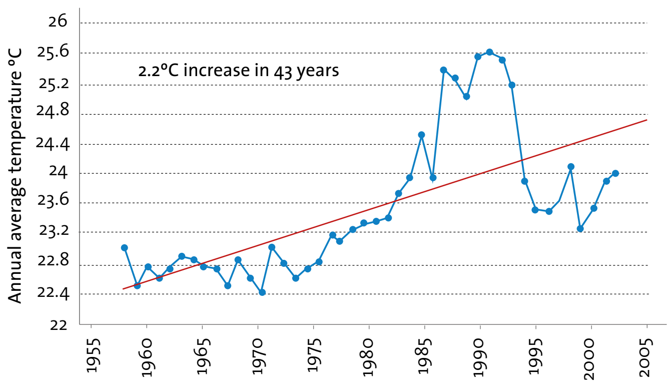


Figure 21. Estación Guija A-15. 485 msnm

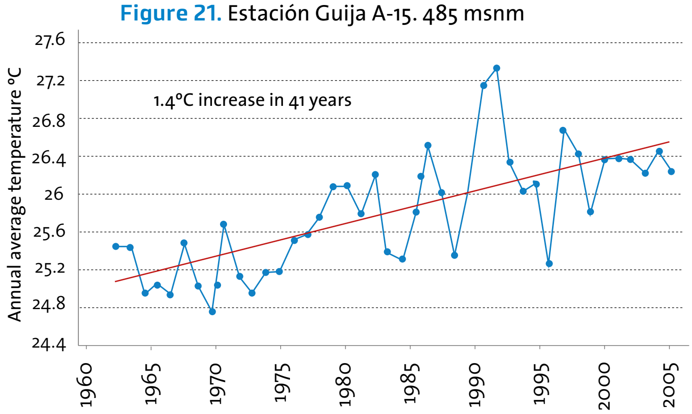
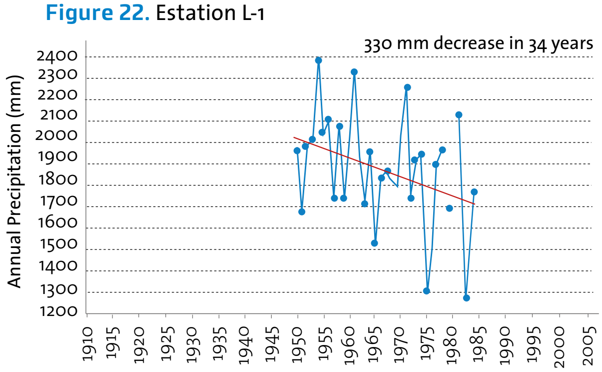


Figure 22. Estation L-1



In terms of rain, an analysis of seventeen stations nationwide was carried out for the period between the decade of the 1950s and the year 2005, in which a considerable reduction in rain was established, principally in some stations in the east of the country, a zone which is being affected yearly by droughts and an increase in consecutive days without rain during the wet season. The analysis determined that approximately 70% of stations analyzed experienced a decrease in rain and 30% experienced an increase in rain. The station reporting the severest reduction was in the department of *La Unión*, with a reduction of 800 mm in 78 years of recorded data, dropping from 2100 mm to 1300 mm on average.

This profound reduction in the amount of rain has caused great concern and occasioned greater attention, with continued analysis and validation of the data, principally of records from the first half of the last century. Figures 22 and 23 present the behavioral tendencies previously mentioned, reflected in the records of two stations.

From the perspective of climate change, one of the first studies of great importance for the country was carried out in 1998 by Abel Centella, an investigator with the Cuban National Climate Center, with support from the University of El Salvador and the Ministry of Agriculture and Livestock (MAG). The study consisted of elaborating climate scenarios (Centella, 1998) constructed from global circulation models outputs (GCM) and through the application of the MAGICC model which is the climatic model that reproduces concentrations of greenhouse gases, temperature and sea level between 1990 and 2100, and the SCENGEN model which contains a database and results of 14 GCM for temperature and sea level and produces scenarios for climate change on the regional level using different suppositions or scenarios for greenhouse gases and their future projections (2020, 2050 and 2100) for warming, combining and reproducing the results of GCM and MAGICC.

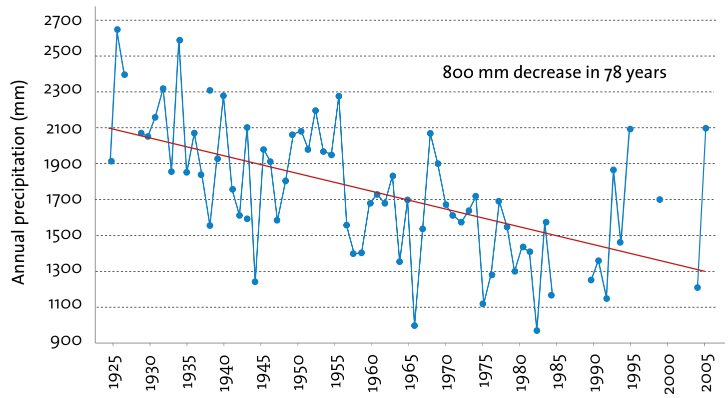
The results of the study, taking into consideration a climatic referential baseline of thirty years (between 1961 and 1990), indicate an increase in temperature between 0.8° C y 1.1 °C for the year 2020, and up to between 2.5°C a 3.7°C for the year 2100. Regarding precipitation, the results indicate intervals of reduced rain from -11.3% to increases of 3.5% in 2020 and reduction from -36.6% to increases of 11.1% in 2100.

Later, in 2006, a new study was carried out on the Central American region coordinated by the "University of Costa Rica (2006)", in which the same techniques and analytical models of the 1998 El Salvador study were utilized, with the difference being an updated application of parameters and algorithms. According to the analysis of regional climatology, the Central American isthmus is divided into a northern zone and a southern zone, each divided by the 10N parallel. In the case of the northern zone, where El Salvador is located on the Pacific slope, the study determined once again an increase in temperature and a decrease in precipitation, which will be intensified during some months of the year due to the El Niño phenomenon and a greater intensity of water use. The results obtained for the emissions scenario, one under B1 and another medium-high A2, indicate an increase in temperature from between 0.8°C - 0.9°C for 2030 and between 2.7°- 3.3°C for 2100. In terms of rain, the results established a decrease from between -2.8% and -4.9% for 2030 and between -11.5% and -20.1% for 2100, principally in the months of May and September, this last month being characterized as the month with the highest annual rain amounts; this study didn't report possibly projections of an increase in precipitation as was indicated in the results of the 1998 study.

In 2008, a new study was carried about by the University of Santa Clara in California (E.P.Maurer 2008) for the purpose of analyzing the impacts of climate change on hydro-electric energy generation capacity by the country's principal dam, the result from this study going in the same direction as results from the previous studies. Establishing the same baseline as a climatic reference point (1961-1990) for the hydrographic basin of the *Río Lempa*, and for the two emissions scenarios (B1 and A2), the results indicated increases in temperature from between 1.9 °C to 3.4 °C for the second half of the 21st century, as well as a decrease in average precipitation on the order of from 5% to 10.4% for the two emissions scenarios and for the same projected period. In addition, results show a reduction in the water flow rates into dams and reservoirs principally during the rainy months of June through September on the order of from 13% to 24% and a decrease in water accumulation capacity in hydro-electric dams on the order of from 33% to 53%, as a result of an increase in the frequency of years with reduced flows and increased evapotranspiration.

In 2010, CEPAL published a study called "*The Economy of Climate Change in Central America*" that ratified the same tendency shown in the previous studies in terms of a reduction in rain amounts and an increase in temperature in El Salvador, expressing as well a greater tendency toward more intense water use by 12.01% in relation to other countries in the Central American isthmus. According to the

Figure 23. Cutucu station N-2, 5 msnm



A2 higher emissions scenario, we might expect an increase of between 0.77°C y 2.03°C for the first half of this century and between 2.9°C y 4.73°C for the second half. In terms of precipitation, we might expect a decrease of between -2.67% a -15.23% for the first half of this century and a reduction of between -15.73% and -31.67% for the second half. The same CEPAL study results show a reduction in net water availability nationwide (precipitation minus losses from evaporotranspiration) of -44% for 2050 and of -82% for 2100, as well as a reduction for that same year of 93% of water availability per capita (estimated on the order of 3,200 m^3 per inhabitant per year, according to MARN calculations) which represents the lowest level in Central America.

In addition to the analysis of impacts generated by an increase in temperature and a decrease in average rainfall, the projections of the different studies of impacts from climate change reflect a notable increase in rain intensity (mm/min) and an increase in their recurrence, as well as the presence of tropical storms or meteorological events that bring great quantities of rain in short periods of time, as demonstrated in the events of the last few years indicated in this chapter's introduction. The models and analyses project a greater probability of events bringing various consecutive dry days and a lesser duration of periods with various consecutive days with rain greater than 10 mm.

Taking into consideration this situation of high susceptibility to impacts from climate change, in April of 2013 the MARN launched the National Climate Change Strategy (ENCC) which is oriented toward the implementation of priorities of adaptation that converge with key sectoral plans and initiatives of other State economic and social portfolios, such as agriculture and water basin management, transportation infrastructure, hydro-electric energy generation and energy efficiency, land administration, sanitation focused on the control and management of domestic and industrial waste, as well as the promotion of public health, investments in the coastal zone and the restoration of ecosystems and rural landscapes, which are directly interrelated with agro-forestry programs and hydrographic basin management, with the implementation of REDD+ mechanisms for forestry amplification and management as a component of mitigation procedures.

From this perspective, some of the prioritized actions intended as adaptation measures on the national level are oriented, in the agricultural sector, toward the development of diversified family agricultural programs through the implementation of household vegetable gardens, water reservoirs for local irrigation, efficient irrigation systems and soil conservation works, among others. This program has been promoted by MAG for several years with an emphasis on promoting food security and benefiting broad sectors of families with limited resources in rural zones; a short and medium term evaluation and monitoring of results in relation to the reference baseline is pending, for analysis within the focus of climate change adaptation.

In the area of transportation infrastructure, the Ministry of Public Works (MOP) plans to intensify works designed for protection in zones at risk for flooding and overflowing of currents, erosion and the formation of gullies, principally in urban zones, as well as large-scale works destined to improve roadway interconnectivity, primarily in the capital (development of the SSMA Integrated Transportation System, SITRAMSS), as a means of generating greater efficiency in mass transit and thus, contribute to a reduction in greenhouse gas emissions in the country, conceived as a means of making a greater contribution to mitigation rather than adaptation. It is estimated that El Salvador produces 0.04% of global emissions.

In terms of low-carbon urban planning and development, adaptation and mitigation guidelines are directed at promoting land planning based on architectural styles that integrate components of ecological value, promoting the construction of tall buildings and promoting the updating of design and construction codes based on this new perspective of climate change adaptation, as well as placing more emphasis on research and the application of compatible and appropriate technologies, the introduction of ecological guidelines and adaptation to climate change into the education programs of different professions, awareness building for the protection of eco-systems and forest areas in the mid elevation zones of aquifer recharging in the hydrographic basins, controlling levels of impermeability, etc.

Another initiative incorporated into the ENCC is the promotion of energy diversification and efficiency, with priorities already included in the work plans of the National Energy Commission, an agency attached to the Ministry of Economics. One of the initiatives that stands out is the introduction of energy saving lighting, low-consumption wood burning turbo stoves and the redesign of great hydro-electric dams such as "*El Cimarrón*" and "*El Chaparral*", which have been given serious attention in the past because of their high impact on zones of great importance for the conservation of water resources and ecosystems. In the case of "*El Cimarrón*", the attention received stems fundamentally from its location in the principal stretch of the *Río Lempa*, which possesses the best quality surface water in the country, as well as being essential for dilution, for maintenance of hydrodynamics and fluvial geomorphology, and principally for a potable water supply for the SSMA, as ANDA's principal water connection is located downstream, mentioned previously and known as "*Las Pavas*". One of the most important technical and administrative variables is that the hydrographic basin, at the location of the dam, is a trans-border basin with approximately 80% of its extension belonging to neighboring countries, with which there are no international agreements regarding guaranteeing quantity and quality of design flows required for hydro-electric power generation, even more so when sizeable reductions in water flow and water availability have been foreseen for the coming decades, as a result of the impacts of climate change established in different studies.

With the launching of the ENCC, work is currently being carried out on the National

Climate Change Plan (PNCC) and the National Adaptation Plan (PAN), both of which will integrate the central predominating issues and priorities, legal framework, institutionalism, work and administrative agenda for financing; being viewed as essential instruments within the framework of the Third National Communication on climate change, to be held this year.

It is important to point out that the challenge as a country is to have plans based upon and corresponding to the information, analysis and results obtained from studies on climate change so that the projected critical situation regarding availability of water resources, the increase in frequency of extreme events (which are capable of generating losses due to floods and drought), impacts on agricultural cycles from greater evapotranspiration and reduction in periods of soil humidity, as well as loss of ecosystems, are aspects which must be tightly linked to strategic adaptation measures so that application mechanisms, actions and measures that contribute collaterally or marginally to adaptation and respond more to economic and sectoral interests are not incorporated, in consideration of the fact that their implementation can be contradictory and questionable in terms of adverse impacts, and a detriment to the same adaptation objectives that they pursue.

Such is the case with the construction of the great hydro-electric dams conceived in an environment of hydro-climatic crisis, along with transportation infrastructure companies that open preferential throughways which favor urban sprawl precisely in zones that must be conserved, as is the case in the forested zone and hydro-retention zone located in the foothills of the *Bálsamo* mountain range, *Santa Tecla* and the southwestern sector of the capital, as indicated in section 2 of "sources of water in urban zones and impacts caused by urbanization", and which are essential for recharging the San Salvador aquifer, and for the natural restriction of the high level runoff during flooding.

It is important to highlight, from the perspective of *Urban Waters* management, the current development of designs being carried out by the Ministry of Public Works of a system of lamination ponds, many of which make use of the topography of natural drainage channels; or hydraulic regulation projects to be implemented in different sectors of SSMA as part of structural solutions for reducing urban risk and vulnerability to impacts of climate change in terms of the occurrence of extreme events of intense rains and of long duration. These hydraulic regulation projects are designed to restrict and regulate water flow and to avoid possible overflows downstream, hence their placement in mid-elevations of the capital. One of the issues that has been raised in terms of their design and placement is that they should be implemented with a eye toward environmental compatibility and integration in the interior of the city to avoid collateral effects that are counterproductive to the ecological services they provide for the principal drainage basins and ravines situated in the intermediate and high elevation zones. These natural drainage channels, historically maintained in their original condition, are characterized by their abundant forest cover which must be preserved as it provides the only biological corridors for the oxygenation of broad urban areas, habitats of different bird species, thermal regulation resulting from the shade, restriction of solar radiation and carbon capture. In general, as mentioned earlier, the best mitigation effort is the protection of the existing forest cover in broad areas in the intermediate and high altitude zones of the capital and the emphasis on non-structural measures from the perspective of sustainable development.

In regard to recycled water, among ANDA priorities there is currently an intensification of measures concerning sanitation, among them the promotion of recycling treated water aimed especially at business and industry. Recycled waters are governed by the legal framework of the special regulations for wastewater, Decree No. 39, 2000, and defined for different uses (urban, agricultural irrigation, recreation, landscaping, and construction sector), before or in substitution of final disposal. The parameters of the quality of recycled waters are established in part by Decree No. 50, 1987, concerning water quality and control of wastewater.

In addition, efforts have been launched between FISDL, MINSAL and Alliance for Water (AxA) to promote more intensely the use of recycled water in peri-urban, community and rural zones, as was indicated in section 4 concerning urban water treatment.

7. Conclusions

The integral management of Urban Waters is a topic which must continually acquire more importance and a central place in the nation's agenda and in public policy; as a result of it prioritization, key aspects will be discovered and focused upon for a coordinated and inter-institutional effort, with interaction with other social and economic sectors, to approach the fundamental problems related to water availability and supply, sanitation, hydro-environmental land planning and preservation, public health promotion and a strategy for authentic adaptation to climate change.

Through an inter-disciplinary and participative analysis and perspective, the strategic guidelines can be conceived and defined for urban planning and the promotion of a new model for hydro-sustainable development, that regulates, controls and orchestrates the logic of the foundationless progress of the preservation of natural assets, as well as the investments and urban and economic projects, with knowledge and understanding of the current conditions caused by the grave hydro-environmental crisis in which the country finds itself, in order to contribute jointly to generating a process that reverses or neutralizes them in the short and medium term.

In that regard, a fundamental aspect in the legislative agenda is the approval of the General Water Law, the draft for which is currently under discussion and analysis in the Legislative Assembly since March of 2012. The General Water Law will offer the country a legal framework to move toward a strategy of hydro-environmental planning, carrying out the actions required within a national policy and under the public-State governing authority.

In parallel with this effort, it is important to promote the National Water Plan (PNH) and the National Climate Change Adaptation Plan (PAN), which must be based on the studies, analyses and results of the diagnostics and studies of the current critical hydro-environmental situation, previous hydro-environmental behavior over the last decades and projections for the future, and in conjunction with those basic aspects, allow the prioritization of hydrographic areas and actions and measures within the legal, political, economic, social, communications, and financial realms, so as to focus efforts on key topics within the administration of water with an eye on the future, with equality, solidarity and participation, covering with determination the Urban Waters dynamic in all its variables, challenges and dimensions, as has been laid out in this chapter on El Salvador.

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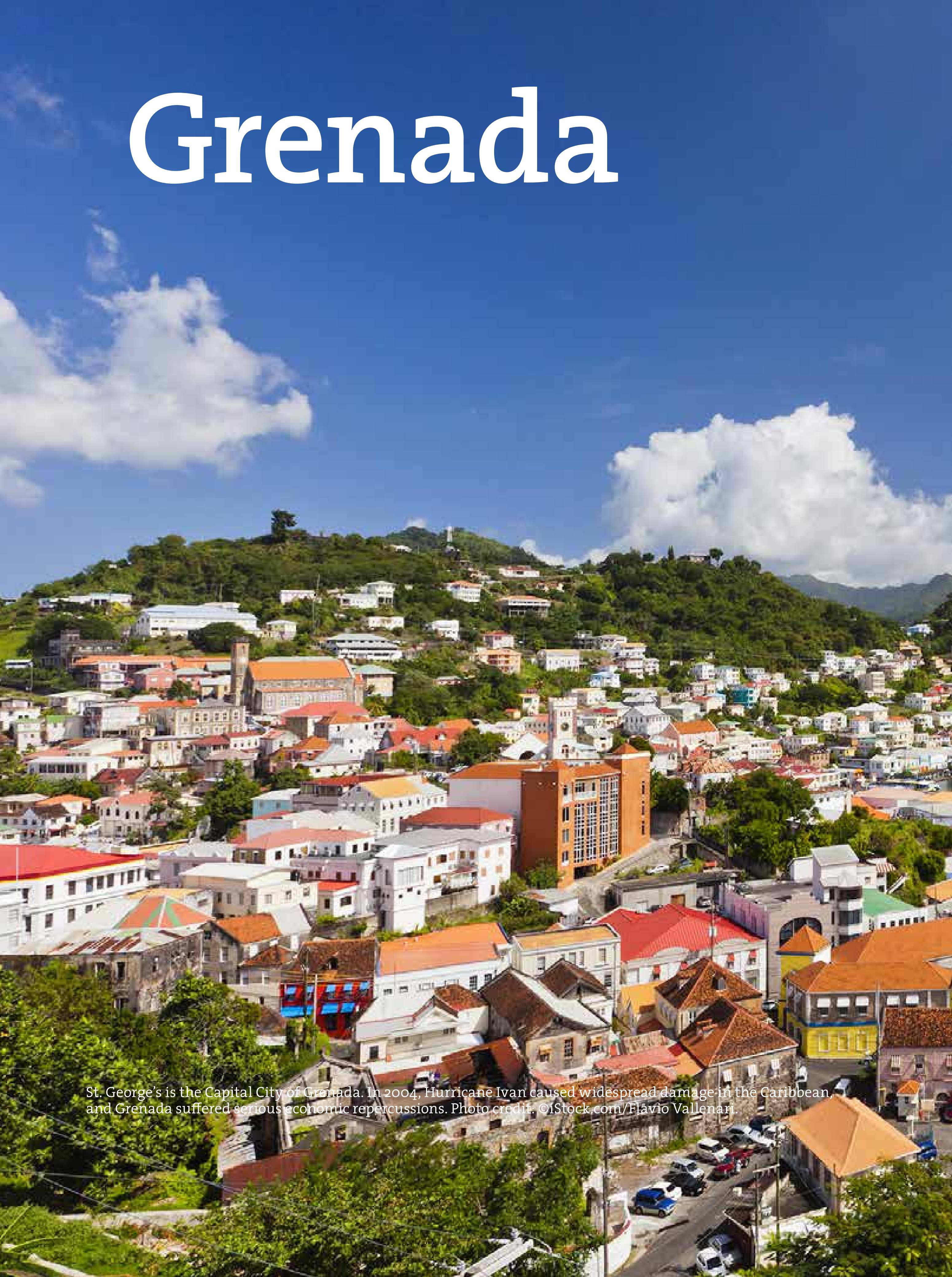
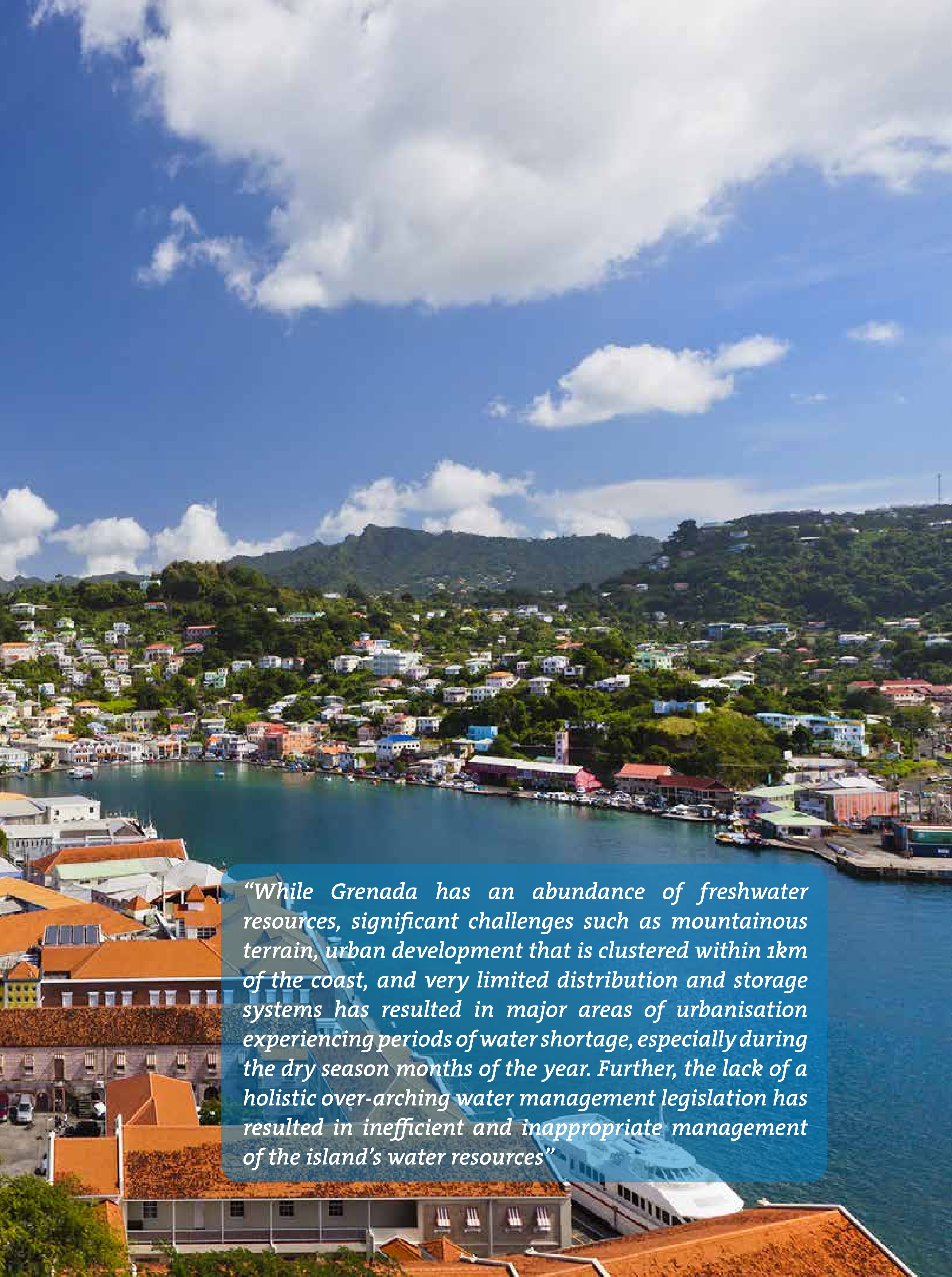
9. Acronyms

SSMA: San Salvador Metropolitan Area
ANDA: National Aqueduct and Sewer Administration
CDC: Center for Consumer Defense
DIGESTYC: National Center for Statistics and Census Data
EHPM: Home and Multi-Purpose Survey
ENCC: National Climate Change Strategy
FISDL: Social Investment and Local Development Fund
FOCARD-APS: Central American and Dominican Republic Forum on Potable Water and Sanitation
MAG: Ministry of Agriculture and Livestock
MARN: Ministry of the Environment and Natural Resources
METROPLAN: Metropolitan Planning 1980
MINSAL: Ministry of Health
NSO: Salvadoran Obligatory Standards
OMS: World Health Organization (WHO)
OPAMSS: San Salvador Metropolitan Area Planning Office
PAN: National Adaptation Plan
PLANDARH: Master Plan for the Development and Use of Water Resources - 1982
PLAMADUR: Master Plan for Urban Development 1996
PNCC: National Plan for Climate Change
PRISMA: Salvadoran Environmental Research Plan
SACDEL: Local Development Advice and Training System
SNET: National Territorial Studies Service
UCA: Universidad Centroamericana José Simeón Cañas

Grenada



St. George's is the Capital City of Grenada. In 2004, Hurricane Ivan caused widespread damage in the Caribbean, and Grenada suffered serious economic repercussions. Photo credit: ©iStock.com/Flavio Vallenari.



“While Grenada has an abundance of freshwater resources, significant challenges such as mountainous terrain, urban development that is clustered within 1km of the coast, and very limited distribution and storage systems has resulted in major areas of urbanisation experiencing periods of water shortage, especially during the dry season months of the year. Further, the lack of a holistic over-arching water management legislation has resulted in inefficient and inappropriate management of the island’s water resources”

Impact of Development on Water Supply and Treatment in Grenada

Martin S. Forde and Brian Neff

Summary

Urbanization is not a phenomena limited to developed countries but is also occurring in many developing nations such as Grenada which is located within the Caribbean region. While defining clear-cut urban areas for an island that has a population of approximately 100,000 spread over a very small area (312 km^2) may be somewhat challenging, clear evidence of increasing rates of development and clustering of human activities can be identified on the main island of this tri-island country. Two parishes in particular on the main island –St. George's and St Andrew's– can be considered as 'urban' parishes since about 60 percent of the population lives in these two parishes.

Fundamentally, Grenada has an abundance of freshwater resources, however, several challenges currently exist in the management of these resources. As a result, water supply problems exist and prove challenging to resolve. Key challenges associated with managing a growing presence of urban centers, particular in the south of the main island, range from legislative (e.g. no holistic over-arching water management legislation currently exists) to administrative (the sole water provider is also responsible for evaluation of water provisioning services) to difficult geographic realities (e.g., piping water from sources in the North to areas in the South where the demand exists over mountainous terrain).

1. Introduction

Urbanization is not limited to developed countries but is also occurring in many developing nations including those located within the Caribbean region. Indeed, the Caribbean is one of the most urbanized regions in the world with approximately 69% residing in urban settings. By 2015, the Caribbean is expected to see an absolute urban population increase of 4 million.

It should be noted that the highest rates of urbanization are not taking place where the largest cities are located but rather in previously remote or sparsely populated areas. This may be due to national policies which encourage the development of certain areas for tourism purposes.

Among the many reasons why those who live in Caribbean islands are choosing to live in urban areas is the greater availability of public utilities such as piped water, which may be limited or even unavailable in rural areas. The resulting increased demand on water utilities to supply an ever increasing amount of potable water to these growing urban areas can and does impose challenges on water utility providers as they strive to meet this demand while at the same time not compromising on the continuous availability or quality of water delivered.

The Caribbean region consists of a heterogeneous mix of islands that can be differentiated by language, geographies, land geologies, levels of economic development and political history, and culture. Rather than try to present a chapter detailing the impact of urbanization on water resources for the whole Caribbean, this chapter will focus on one English-speaking Caribbean country, Grenada. The issues and challenges experienced by this very small island will obviously not be fully representative of other much larger islands (e.g., Trinidad, Jamaica), however, much of what is discussed here in this chapter for Grenada will also be seen in many of the other English-speaking small island states located in the Caribbean.

1.1 Location of Grenada

Grenada, located between latitude 110 59' and 120 20' North and longitudes 610 36' and 610 48' West, is the most southerly island of the Windward Islands (Figure 1). The country comprises of three main islands: Grenada, Carriacou, and Petite Martinique. Grenada is the largest of the three islands (312 km^2), followed by Carriacou (34 km^2), which is located 24 km to the North East of Grenada, and Petite Martinique (2 km^2), which lies east of the Northern section of Carriacou. Thus the total area of the island country is approximately 348 km^2 and the total length of the coastline is 121 km. Administratively, the island of Grenada is divided into six parishes. Carriacou and Petite Martinique are administratively managed as the seventh parish.

Figure 1. Map of Grenada, Carriacou, and Petite Martinique

Source: wikipedia.org

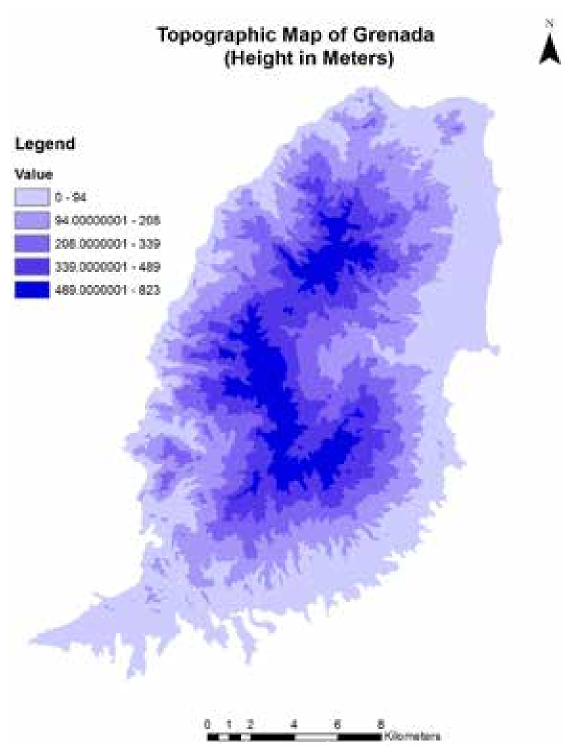
1.2 Geology and Geography

Grenada is located in the Lesser Antilles, which is a long arc of volcanic islands in the Caribbean Sea (Figure 1). Of the three main groups of which the Lesser Antilles is sub-divided into, Grenada belongs to the Windward group of islands, which starts with Dominica in the North and then continues down to Martinique, St. Lucia, St. Vincent & the Grenadines, and finally Grenada in the South.

Grenada is mostly of volcanic origin with a mountainous center which quickly descends towards the flatter coastline (Figure 2). The islands of Carriacou and Petite Martinique are also of volcanic origin and represent the exposed summits of peaks on a single narrow bank of submerged volcanic mountains.

Approximately 70% of the mountain slopes in Grenada have a gradient greater than 20° which predisposes terrestrial resources to rapid water runoff and land degradation. The highest peak is Mount St. Catherine at 840 m. Steep mountain peaks, sharp ridges and deep narrow valleys sloping towards the coastline thus characterize the topography of the main island of Grenada. Seventy-five percent of the total land area lies below 305 meters while 23.4 percent lies between 305 meters and 610 meters and 1.6 percent lies above 610 meters. Further, due to the very short 10 km average distance from the mountain peaks to the coast, there is low soil water holding capacity. Clay loams (84.5%), clays (11.6%) and sandy loams (2.9%) are the main types of soils found in Grenada. The coastline itself is ringed by extensive coral reefs.

Figure 2. Topography of Grenada



Source: Government of Grenada

1.3 Climate

Grenada experiences a semi-tropical climate within the Atlantic northeast trade wind belt characterized with an average temperature range from 24°C to 30°C. The average temperature is 28°C. Temperatures at sea level are generally high with little diurnal or spatial variation due to the effect of the adjacent ocean.

Seasonal shifts in the trade winds give rise to two main seasons –a dry season, which runs from January to May, and a wet season which runs from June to December. Approximately 77% of the annual rainfall occurs in the wet season.

The marked spatial variation in rainfall pattern across Grenada is due to the difference in orthographic elevations (Figure 3). The high mountainous areas are cooler compared to the low coastline areas which are warmer. Annual evapotranspiration has been estimated to vary from 1000 to 1500 mm. High rainfall intensities are common and this leads to severe soil erosion on the sloping lands. Mountainous areas can experience an average of about 3,880 mm whereas lower areas along the northern and southern coastline can experience a much lesser average of 1,125 mm annually.

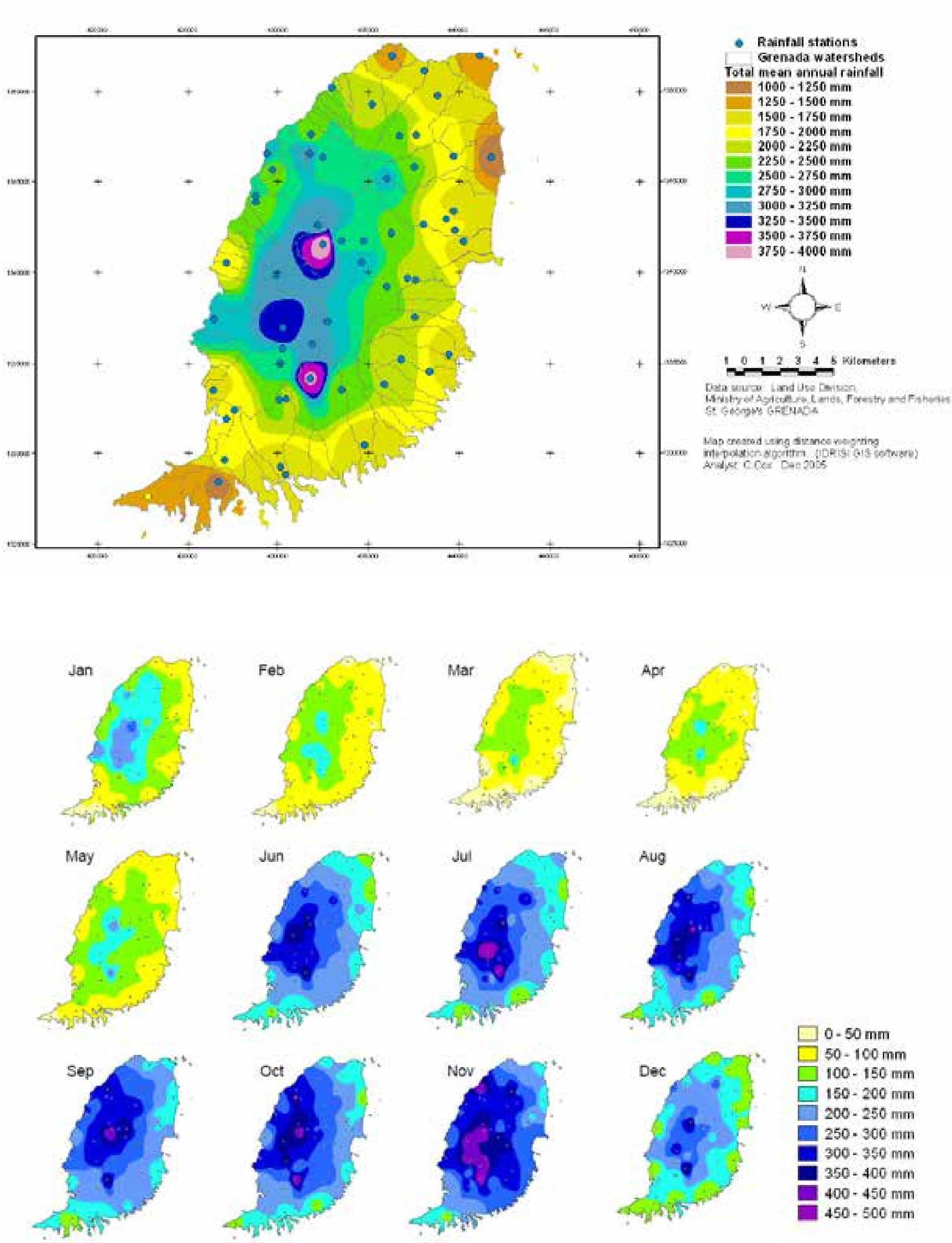
This gives rise to different climatic zones as depicted in Figure 3. Thus, some parts of the island experience moderately warm temperatures between 20°C and 22.5°C, no dry season, and rainfall in excess of 4000 mm whereas other parts of the island are characterized by very warm temperatures over 27.5°C, a long dry season, and rainfall ranging between 700 mm and 1000 mm.

For Carriacou and Petite Martinique, due to their small size and relatively low elevations, both of these islands are significantly drier than Grenada with annual rainfall being only around 1,000 mm. In all three islands, however, extended dry periods and extreme drought conditions during the dry season are not uncommon and indeed over the past decade have become more pronounced.

1.4 Land Use

Grenada's total land area is 31,334 ha. Land use in Grenada is closely linked to its agrarian history as a primary commodity producer of sugar in the

Figure 3. Climatic zones - Grenada



Source: (CEHI, 2006a)

recent past to now where more tree crop products such as nutmeg, cocoa, and bananas are cultivated. Additionally, a lot of subsistence farming now takes place with the land that is being used for such cultivation moving more and more from the lower areas up and onto the mountainsides. As a result, the amount of forest acreage has steadily declined since the 1960s to the present.

Although it is difficult to determine the exact magnitude of land use change over time in Grenada due to unavailable data, over the past two decades, several significant land use changes have been observed. Firstly, the rate of abandoned cropland dramatically increased from 144 ha in 2000 to over 2,428 ha in 2009, which is equivalent to a 1685% increase in the amount of lands abandoned from use for crop cultivation (Roberts, 2013). Secondly, land characterized as urban and built-up areas increased by almost 25% from 1,825 ha (5.8%) in 2000 to 2,267 ha (7.2%) in 2009 (Roberts, 2013). Especially following the passage of Hurricane Ivan in 2004, the rebuilding efforts which followed witnessed a massive expansion of construction activities and conversion of abandoned agricultural estates and pastures in coastal areas into tourism, commercial and residential use. This still ongoing increasing trend in urbanization with its attendant increased demand for land for housing and non-agricultural purposes continues to lead to further encroachment on remaining agricultural lands and key watershed areas.

In Grenada, as well as most other small Caribbean islands, small farmers undertake a significant percentage of the agriculture industry. With the exception of the Grand Etang Forest Reserve, most of the historical large plantation estates have been sold and subdivided into smaller lots allowing for mass private ownership. The typical size of most lands used for agriculture is less than 5 hectares. Nearly 75% of the farm sizes in Grenada are less than 0.8 ha in size. However, this represents less than 15% of the agricultural lands with approximately 50% of the agricultural lands being held in holdings varying from 1 to 10 ha. The FAO in 2007 estimated that though forested land in Grenada has declined to 12% and agricultural land to 35%, only 2% of total land area is designated as protected areas.

Other major land use problems observed in Grenada are listed below:

- Illegal developments and squatter settlements;
- Land use conflicts among the agricultural, tourism and construction sectors;
- More settlements vulnerable to disasters including flooding, land slides and rising sea levels;
- Environmental management concerns;
- Inappropriate and inadequate land tenure arrangements and institutional capacity for land management; and
- Lack of adequate legal and regulatory frameworks.

1.5 Demographics

The island of Grenada is administratively divided into six parishes with the other two islands –Carriacou and Petite Martinique (PM)– being administratively treated as one parish (Table 1). Based on 2011 census data, Grenada's population is estimated to be 105,539 persons with a gender split of 51% females and 49% males. Annual population growth averaged 0.6% annually for the period 1981 to 2001. The current population density is about 307 persons per km^2.

Given Grenada's mountainous terrain, most of the population resides within 1 km of the coastline with many settlements located around the mouths of rivers. The southern parish of St George, where most of the industrial and tourism activities are located, accounts for 36% of the population. The largest parish, St Andrew, accounts for 24% of the population with the rest of the population being fairly evenly distributed among the other parishes (Table 1).

The Grenada population is relatively young with about 50% of the population under 25 years old. The labor force now stands at approximately 42,000 persons. A recent poverty assessment survey (Government of Grenada, 2007b) revealed that 37% of the population is deemed to be poor with 53% of the population deemed to be economically vulnerable.

1.6 Urbanization in Grenada

Two parishes –St. George's and St Andrew's– can be considered as 'urban' parishes since about 60 percent of the population lives in these two parishes. It is estimated that for the period 2001 to present the annual population growth rate was 0.7%. The parish

Table 1. Geographical Distribution (2011 census) and Population Density by Parish

Parishes	Population					
	1991	2001	2011	Land Area (km^2)	2011 Density ($/km^2$)	2021
St. George (town)	4,621	3,628	3,100	1	3,100	N/A
St. George (Rest)	27,373	27,951	34,304	64	536	40,726
St. John	8,752	9,374	8,404	35	241	13,382
St. Mark	3,861	4,676	4,346	25	174	4,654
St. Patrick	10,118	11,537	10,461	42	250	12,218
St. Andrew	24,135	27,114	26,433	99	267	28,508
St. David	11,011	12,637	12,858	44	293	9,891
Carriacou/PM	5,726	6,219	5,633	34	166	6,982
Total	**95,597**	**103,136**	**105,539**	**344**	**307**	**116,361**

Source: Ministry of Finance, 2014

with the fastest population growth is the parish of St. George, which is most likely due to the fact that most of the island's tourism activities are located in this parish and the tourist industry in expanding. The population density for the parish of St. George is approximately 570 inhabitants/km^2 which is significantly higher than the national average of 307 inhabitants/km^2.

In general, the majority of Grenada's 300 towns and villages are located in the coastal areas with linear inland extensions along valleys and ridges. The main urban centers in Grenada are the capital, St. George's, Grenville in the parish of St. Andrews, and Gouyave in the parish of St. John. In Carriacou, the largest settlement is Hillsborough. All of these urban centers are located in coastal areas and are predicted to grow to contain over 60% of the country's population by 2050.

1.7 Water Management in Grenada

In Grenada, although the responsibility for supplying, producing and distributing water throughout the tri-island state has been assigned to the National Water and Sewage Authority (NAWASA), management functions are very fragmented. The responsibility to preserve and protect all water catchment areas has also been given to NAWASA. It should be noted that while NAWASA has a nominal presence in Carriacou and Petite Martinique, both of these islands predominantly rely on self- or communal supplies of water. Water governance and reform efforts are discussed further in Section 3.4.

2. Water Sources and Problems Caused by Urbanization

2.1 Overview of Water Sources in Grenada

The island of Grenada is reasonably well resourced with respect to fresh water (Figure 4). There are many rivers, streams, and lakes on the main island which contrasts with Carriacou and Petite Martinique where no perennial fresh water rivers or streams exist.

Grenada has 71 distinct watersheds of which the largest watershed, the Great River catchment comprises 4,521 ha whilst the smallest is the Crayfish catchment, 27 ha (Figure 5). Most of these watersheds have perennial flows, however, flows can drop significantly during the dry season. Of the 71 watershed catchments, 23 are utilized for water supply.

Carriacou has 20 watershed areas. No differentiation is made for Petite Martinique due to its small size. There are no permanent streams or springs in both of these very small islands. Water supplies in Carriacou and Petite Martinique depend almost exclusively on the harvesting of rainwater in

Figure 4. Rivers, streams and watersheds in the six parishes of Grenada

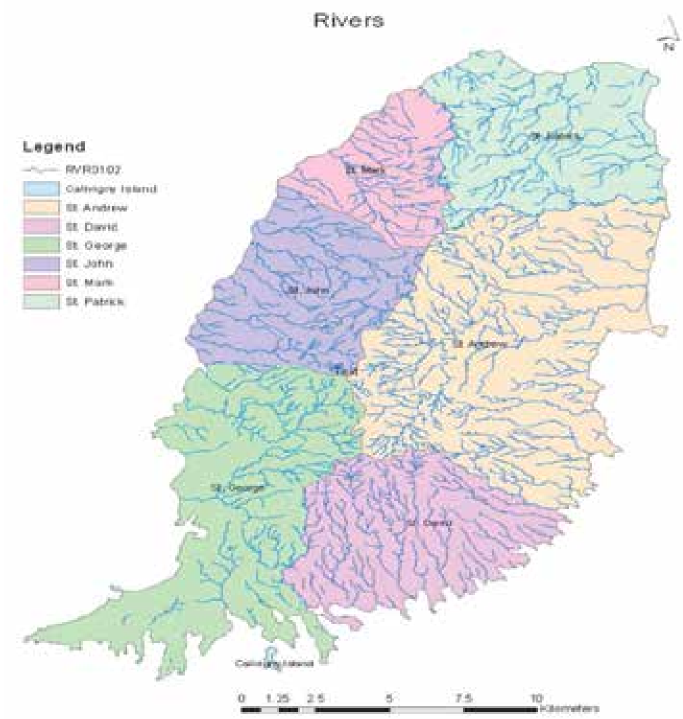


Figure 5. Watersheds in Grenada

Source: Government of Grenada

cisterns, while water for agriculture and livestock comes mainly from the withdrawal of groundwater and surface water stored in ponds. A 2001 water supply study for Carriacou concluded that island-wide community rainwater collection systems totaling 15 ha with provision for a total of 22,000 m^3 of storage is sufficient to meet to the island's water needs.

Although there are estimates of the mean yield from the watersheds used for water supply, consistent, accurate data or a comprehensive assessment of surface water resources is not available. Additionally, there is very little long-term, consistent stream-flow data, especially for low and high flow periods.

2.2 Surface Waters

Arising out of its volcanic past, there are three crater lakes –Grand Etang Lake (8 ha), Lake Antoine (17 ha) and Levera Pond (23 ha)– the most important for providing water to the south of the island being Grand Etang lake, which is located in the center of the island. The natural dry season outflow of the Grand Etang lake has been measured as exceeding 2,270 m^3/day.

Given the increasing demand for water particularly in the urban south of Grenada as a result of construction and investment in the tourism sector, the provision of adequate water supply has become very important particularly in the dry season when there is maximum usage and at the same time reduced stream flow. As a result, the Grand Etang Lake is used as a source in the dry season as well as bore holes located in the south and south east of Grenada. There is also a full time borehole facility in Carriacou.

2.3 Groundwater

Exploitable groundwater resources in Grenada lie in three valleys located in the south of the island: Woodland (448 m^3/day), Chemin Valley (1,648 m^3/day) and Baillie's Bacolet (917 m^3/day) giving a grand total of 3,013 m^3/day. Presently, only about 5-10% of current water demand is met from groundwater supplies, primarily during the dry season to help supplement surface water supplies. Although more groundwater could be exploited, water quality issues, in particular taste, as well as the costs in pumping this water to the surface mean that this source of water is used only on a limited basis.

Another concern regarding the increased use of groundwater is salt-water intrusion. A 2001 study, however, that was conducted to review the potential impact of sea-level rise as a result of global climate change found that this impact was minor when compared with the threat posed by over pumping of the aquifers. Again, as with surface water data, there is currently no consistent data collection program in place that would allow assessment of the quality, quantity, water balance, subsurface flows or outflows of potential groundwater supplies.

2.4 Water Production

NAWASA operates 23 surface water sources mostly located in upper catchment areas to supply the water needs for the island of Grenada. A 2006 review estimated that the rainy season yield of these sources was 54,600 m^3/day which dropped to a maximum of 31,800 m^3/day in the dry season. Again, it is noted that current reports do not provide consistent data which makes it very difficult to evaluate what is the true yield of each water source which, in turn, makes it difficult to design appropriate intake works, water treatment facilities, and pipeline transmission capacities.

A 2006 water deficit mapping exercise indicated that during the statistically driest month of March, the total raw water yields from the 23 catchments utilized by NAWASA were extremely low in cases where the mean monthly rainfall was close to or below the evapotranspiration losses. This fact is very significant since during the month of March the estimated daily national demand exceeds water from surface sources. While utilizing raw water storage, mainly water that has been storage in the Grand Etang Lake, helps somewhat to compensate for this shortfall, this situation highlights the water scarcity situation that prevails during the dry season months.

The same study mentioned above extended the water deficit analysis to generate spatial variation in the number of cases where evapotranspiration exceeds rainfall input and found that the northern and southernmost coastal areas of the island of Grenada have the longest water deficit periods. This is of particular concern since the greatest amount of development and urbanization is taking place in the southernmost coastal areas. Further, this problem is likely to get much worse before it gets better since this very same area is also where the 'tourist belt' lies. Current and projected future plans indicate that the tourism industry in going to continue to steadily expand both in this size and demands in the coming years.

In 1998, a 1,818 m^3/day desalination plant was installed in order to help augment the water supply to the southern communities. Similar but smaller plants were also installed in Carriacou (454 m^3/day) and Petite Martinique (136 m^3/day) but both are currently in various states of disrepair. Several large hotels in the south of the island also have installed their own small desalination plants to augment their water supplies. One institution, St. George's University, which is located on the southern tip of the island, has installed a large desalination plant which has a capacity to produce 908 m^3/day. Present consumption ranges from 340 to 450 m^3/day, which allows it to take care of all of its current water requirements.

As previously mentioned, rainwater harvesting supplies almost 100% of the demand to households in both Carriacou and Petite Martinique.

2.5 Water Supply and Demand

Currently, 97% of the urban population and 93% of the rural population has access to potable water. Per capita consumption values for Grenada have been estimated to range from 130 L/day to 150 L/day; in Carriacou and Petite Martinique consumption rates are estimated to be 100 L/day. Unaccounted for water (UFW), also referred to as non-revenue water, has been estimated to be 33% of production.

Water demand estimated for the year 2010 for the north and south of Grenada indicate an average daily demand (ADD) of 31,877 m^3/day, or annual demand of 11.6 million m^3 (Table 2).

The 23 surface water and 6 ground water supply facilities in Grenada produce 12 million gallons per day (mgd) in the rainy season which drops to a minimum of 8 mgd in the dry season (Figure 6). The demand for water in the rainy season is 10 mgd which rises to 12 mgd in the dry season. Assuming

Figure 6. Monthly surface and groundwater supply (mgd, stacked bars) and demand (line)

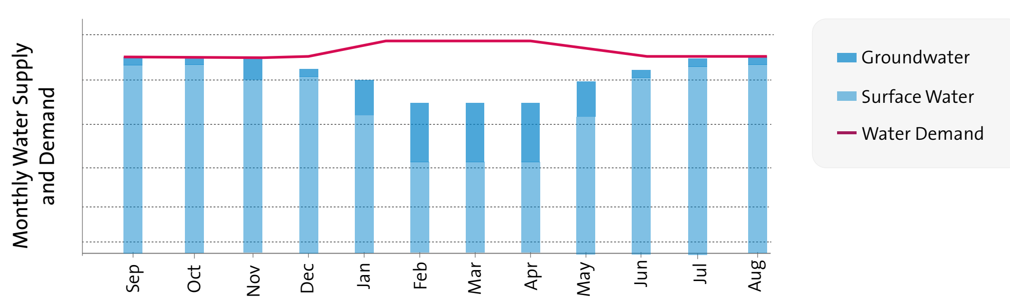


Table 2. Water demand estimates for Grenada 2010

Area	Total Cons. (m^3/d)	UFW (m^3/d) *	ADD (m^3/d)	Water Production (driest week 1999/2000) (m^3/d)	Water Production (avg. annual 1999/2000) (m^3/d) **
Northern Grenada	9,094	4,479	13,573		8,835
Southern Grenada	12,076	6,228	18,304	16,540	20,761
Total	**21,170**	**10,707**	**31,877**		**29,596**

Sources : Stantec (2001), Witteveen+Bos (2001). Notes: * Unaccounted for water (UFW) 33% of production for northern Grenada, and 30% for southern Grenada. ** For northern Grenada, plant capacity in 2001.

that no significant change takes place with respect to NAWASA's water production capacity, it can then be concluded that there will be, in particular for the southern region of Grenada, a significant shortage of water during the dry season months of the year.

One way NAWASA is trying to mitigate this shortfall is by increasing water storage capacity. Based on a 2007 (Government of Grenada, 2007b) review of Grenada's water sector, available water storage capacity in the rainwater catchments can just meet the 100-day minimum requirement for dry season demand from the present human population, but the water available from ponds and dug wells can meet only 80% (80 days) of demand from the livestock.

2.6 Problems Caused by Urbanization on the Water Sector

Urbanization, and more generally ongoing economic development, particularly in the tourism industry, coupled with continued demographic growth have led to rising demand for potable water and challenges in managing Grenada's water resources. Over the past 30 years, maintenance and needed upgrades to water resource infrastructure has not kept pace with the demands that have been placed upon them. As a result, the present water supply system is not adequately resilient to ensure that supply for good quality water in the quantities required are met, especially in the dry season. This situation in further compounded by poor enforcement of water resource management regulations and the very weak financial position of the agency, NAWASA, who is mandated to provide and maintenance adequate water resources to the public.

A review of Grenada's water sector done in 2007 identified four key challenges for the sustainability of integrated water resources management and water services:

1. **Financial Sustainability:** The government of Grenada's historically poor and limited access to financial resources has meant that it has been very difficult to source sufficient funds to finance the necessary capital investments needed to ensure the adequate provision of infrastructure for water resources, as well as find the funds to carry out needed maintenance and eventual replacement of water resources as these suffer wear and tear.
2. **Institutional Sustainability:** In Grenada, the same agency –NAWASA– that supplies water to the country also regulates itself. There is thus a need to establish an independent water resources management unit that can do water mapping, demand projection, and water quality assurance testing.
3. **Operational Sustainability:** This is contingent of the pricing of water services to recover full costs and investing the capital raised in operation and maintenance to provide better service standards. As it currently stands, the government sets what rates NAWASA can charge which do not match the costs incurred to produce and deliver to the local population.
4. **Technical Sustainability:** While a range of solutions made be available, these need to be carefully reviewed to ensure that they are financial feasible and meet the needs of the local population taking into account that any solution usually involves behavioral adaptation and therefore it must be cultural acceptable.

The main threats to the fresh water ecosystem are listed below:

- Improper domestic solid waste and liquid disposal
- Over exploitation of species
- Unsustainable agricultural practices including the use of weedicides and pesticides
- Saline intrusion
- Deforestation
- Introduction of alien invasive species
- Extensive use of fresh water for domestic and commercial purposes

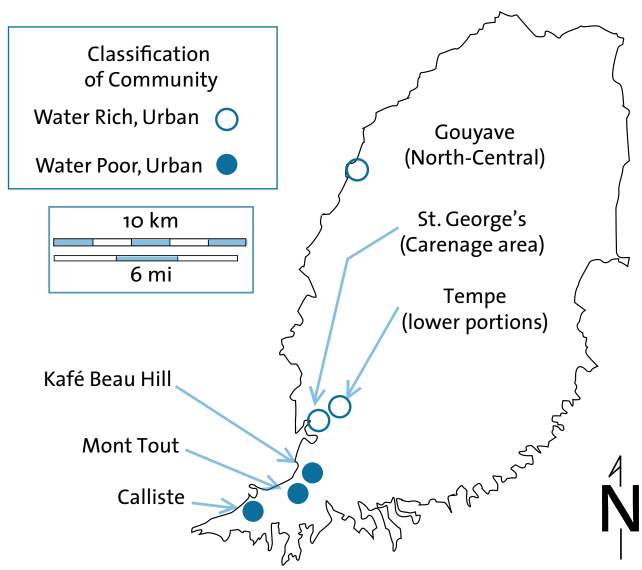
3. Water Supply Services in Urban Areas

Recent statistics indicate that 98% of Grenadian residents have access to improved sources of water and 97% have access to improved sanitation (World Health Organization and UNICEF, 2014). The World Bank parses these data further in their online

Table 3. Description of community classification and communities surveyed

Classification	Description	Community Surveyed
Water Rich	Urban communities with a stable, high quality water supply	St. George's (Carenage area)
		Tempe (lower portions)
		Gouyave (North-Central)
Water Poor	Urban communities with water rationing and/or frequent water quality problems	Calliste
		Kafé Beau Hill
		Mont Tout

Figure 7. Map showing locations of surveyed communities



Base map of Grenada provided by d-maps.com, http://d-maps.com/carte.php?num_car=1707&lang=en

database of world development indicators, which states that as of 2012, 99% and 97.5% of urban residents have access to improved sources of water and sanitation, respectively (World Bank, 2014a). Despite these numbers, many urban residents experience substantial turmoil due to water service irregularities such as intermittent service, poor water quality, and poorly regulated water pressure. The resilience of residents to these water supply challenges is variable, and depends largely on wealth and empowerment.

3.1 Characterization of Water Service

Data have not been published to quantify the proportion of residents who experience water supply problems in Grenada. Although many publications exist which describe various aspects of water management in Grenada, data describing water service is uncommon. One recent survey study, however, of water management in Grenada done by Neff (Neff, 2013) provides a detailed insight into the range of resident experiences with water service in both urban and rural areas. This study utilized surveys of residents in 6 urban neighborhoods, three being classified as having 'good' water service and three as having 'poor' water service (Table 3 and Figure 7).

Key findings from the Neff 2013 survey of residents living in these six communities are listed below:

- Residents reported experiencing several water related problems such as water service interruptions, episodes of 'dirty water,' and other resident-perceived service problems. Data showed that even residents in 'water rich' neighborhoods experienced water service problems, suggesting that some degree of water service problems are likely widespread.

- Water service cutoffs were usually short-term (less than a full day) and ranged from occasional to chronic (Figure 8). Most cutoffs occurred as a result of water rationing or shortage when water demand exceeds water supply. However, during drought conditions, water cutoffs lasting weeks to months, and requiring NAWASA to deliver water by tanker truck, were reported.
- Many residents reported experiencing episodes of receiving 'dirty water' through their taps. The severity of dirty water ranged from slight discoloration to being described by residents as being "like mud" (Figure 9). As a frame of reference, Figure 10 shows a jar of water collected that would be classified as "severe" but not quite "like mud." Dirty water often occurs after breaks in distribution pipes or following intense precipitation events. In the later case, rapid runoff flushes sediment-laden water into water treatment plant intakes.
- One third (33%) of survey respondents identified one or more additional issues with their water supply in both water rich and water poor locations (Figure 11). The most common problems reported by residents other than water service disruption and dirty water were excessive chlorine smell and/or taste, low and high pressure at the tap, and health concerns.
- Health concerns related to potable water were expressed by 12% of the urban residents surveyed. Concerns were spread over such factors as microbial contamination, perceived adverse gastrointestinal reaction to 'heavy' borehole water or excessive chlorine, and general suspicions of the safety of the water.
- Survey participants that elaborated on their concerns over water pressure described episodes of low water pressure during daytime which interfered with water usage and high pressure at nighttime which commonly broken water fixtures.

Figure 8. Days of water supply interruption per year reported by residents

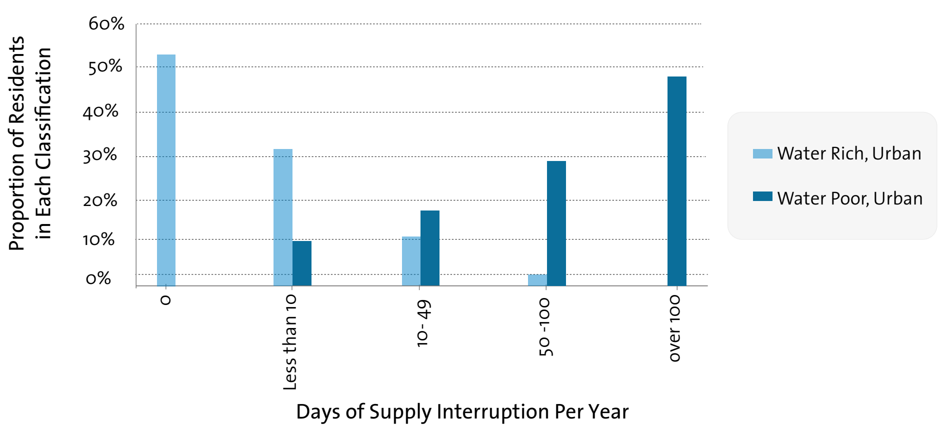
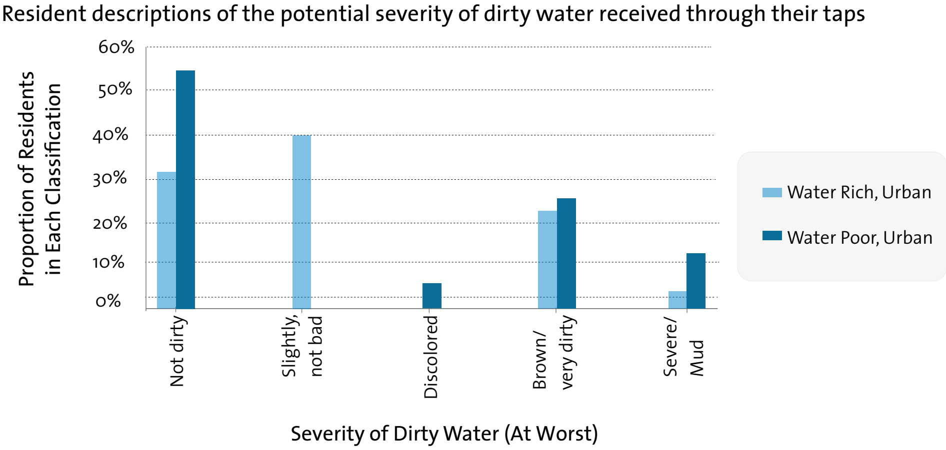


Figure 9. Resident descriptions of the potential severity of dirty water received through their taps



- Despite the shortcomings in water service, residents were generally satisfied with the water service provider NAWASA with a majority perceiving the water supply situation as being either stable or improving over time. Notably, 63% of residents surveyed in urban communities with poor water service reported that water supply interruptions are decreasing over time.

3.2 Poverty and Resilience to Water Service Irregularities

Options exist for Grenadians to reduce or eliminate the impact of water service problems on their daily lives. For example, residents may store water for use during water supply interruptions. Likewise, sediment filters can be installed to reduce or eliminate dirty water and pressure-limiting valves and water pumps can be installed to eliminate problems caused by poorly regulated water pressure. However, resident access to adaptation measures is variable and depends largely on the amount of financial resources available and empowerment.

Figure 10. Comparison of 'normal' piped water (left) and 'dirty water' (right) collected by Neff from a tap at his residence in Grand Anse, Grenada. The sample at right qualifies as 'severe'

Photo by Brian Neff, 2014.

In the case of water storage for use during service interruptions, different approaches can be taken with varying degrees of effectiveness. Crude storage systems capture and store rainwater using buckets and rain barrels and are not plumbed into the home (Figure 12a). More elaborate systems store piped water using elevated black polyethylene storage tanks of 500 gallons (1,890 L) or more and are plumbed to supply the home with water by gravity when water supply is interrupted (Figure 12b). In some cases, large cisterns, typically holding over 10,000 gallons (37,850 L), are located under the home and may hold either rain water or piped water and are plumbed to automatically supply the home during water service interruptions using a pressurized pump. With a sufficiently large tank and pressurization, residents may be unaware of water supply interruptions.

Data reported in Neff (2013) support the assertion that the ability of residents to adapt to water supply problems is strongly influenced by wealth and empowerment. While the frequency of water supply interruption was the primary factor determining if a household possessed a water storage tank of any type, the type of tank/system (e.g., plumbed/ not plumbed) installed was associated with the level of wealth the household possessed (Figure 13). This suggests that residents who need to store water for use during water supply interruptions do so, but relatively wealthy residents own large tanks plumbed into the home, while relatively poor residents rely on simple rain barrels which must be accessed from outside the home.

The lack of financial resources by several Grenadian residents is also an issue in the country. While NAWASA is required to be self-supporting and funds most of its operations with user fee, they try to be flexible with residents who communicate an inability to pay their water bill due to financial hardship and strive to prevent disconnections. Unfortunately, many residents do not take advantage of this flexibility and as a result do have their service disconnected. Nearly 9% of study respondents in urban areas surveyed in the Neff reported having their service disconnected in the past or being at risk of disconnection due to delinquent bills.

Figure 11. Other water service problems reported by residents

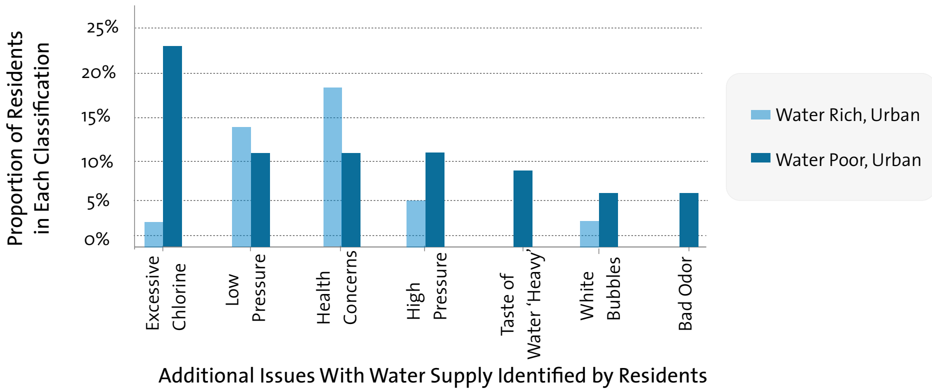
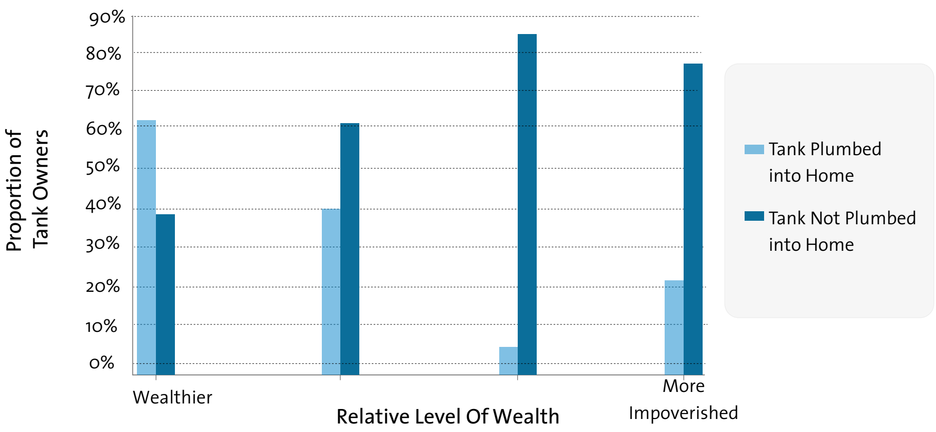


Figure 12. a) Left: Example of an elevated 500 gallon (1,890 L) black polyethylene storage tank plumbed into the home b) Right: Example of a rain barrel not plumbed into the home (Photos courtesy of Brian Neff, 2014)

Figure 13. Relation between poverty and the water tank installation used



3.3 Water Service Challenges and Solutions

Fundamentally, Grenada has an abundance of freshwater resources. In fact, a tropical rainforest exists at relatively high elevation within 10 kilometers of every residence. Urbanization, per se, does not pose a significant challenge for the Grenadian water service. Nonetheless, the management of these resources in Grenada poses several challenges and, as a result, water supply problems continue to exist.

Water is generally supplied to residents through a system of diverting source water from high-elevation streams to treatment plants and then distributing treated water to residents at lower elevations. A distinct advantage of this system is that it utilizes gravity to distribute water and greatly reduces the need for costly pumping. However, the quantity of water which may be withdrawn from streams is vulnerable to seasonal decreases in streamflow during dry season and during droughts. In addition, the rugged terrain also reduces opportunities for easy diversion or distribution of water from one watershed to another. Difficulties in diverting water around the island make areas with high populations, and thus high water demand, vulnerable to water shortages.

An added challenge is that sediment-laden water is frequently flushed into streams and water intakes after significant rainfall events. Most water treatment plants lack the ability to let heavy sediment loads settle out from water being treated. In these cases, plant operators have to choose between closing the treatment plant until the source water clears, which causes a supply disruption to residents, or supplying sediment-laden water to the distribution system.

The mountainous terrain of Grenada and deficiencies in the water distribution system combine to cause difficulty in maintaining consistent water pressure. Spikes in water pressure can rupture household fixtures and cause frequent breaks in the distribution system. This can further exacerbate water quality and quantity problems.

Technical solutions exist to overcome all of these problems, although obstacles exist to implementation. Expanding raw water storage capacity to supply treatment plants during precipitation events could prevent dirty water from entering the treatment and distribution system. If storage is sufficiently expanded, water could be stored during the wet season to supply water treatment plants through the dry season. The rugged terrain precludes easy distribution of water from any central location to other parts of the island, but the feasibility of constructing many moderate size dams or large storage tanks could be explored.

Other technical options to prevent water shortages exist. The water authority NAWASA could utilize additional streams or establish intakes and treatment plants farther downstream than presently located to expand source water supply. Expanding the use of groundwater could provide additional source water during supply shortages and NAWASA's 5-year plan contains plans to study the feasibility of this option (NAWASA, 2009).

Reducing water demand and improving resident resilience to water supply problems are also options for improving the present situation. One technical approach to reduce water demand is to reduce leakage of the present distribution system, as is the main objective of the Southern Grenada Water Supply Project. Policies can be devised and implemented to promote water use efficiency or persuade residents to collect and use rainwater (Box 1). Other policies could make it easier for residents to adopt better adaptation strategies to water supply problems.

3.4 Water Governance and Reform Efforts

In 2008, a formal national water policy for Grenada was ratified, however, the overarching legislation needed in order to replace the existing 14 pieces of legislation that govern water resources in Grenada and their management is still yet to be passed and implemented. This arrangement has led to a poorly coordinated approach to water management and generally to a top-down bureaucratic structure that provides separate agencies with relatively narrow mandates.

Beside the lack of coordination in the current governance structure, a more serious problem that exists is the absence of an over-arching strategic vision for the long-term (multi-decade) water future of Grenada. Long-range, multi-decade planning is not required under Grenadian water management laws and as a practical matter does not occur

Box 6

Rainwater Harvesting as an Urban Water Solution in Grenada

The potential of better implementing and utilizing rainwater harvesting (RWH) systems in Grenada are significant:

- Grenada experiences sufficient precipitation for RWH systems to prove to be economical and effective
- Even small-scale RWH can substantially improve resilience to water shortage
- RWH reduces demand for pipe-borne water and could be used to fill the gap between dry season water supply and demand in urban areas
- Residential RWH systems could be more cost effective in reducing water shortages than infrastructure improvements

Currently, the structure of Grenadian water management is fragmented with multiple silos of responsibility and a lack of an overarching, holistic management approach (see section titled Water Governance and Reform Efforts). No entity has the legal responsibility to consider tools such as RWH as part of a holistic water management strategy. In particular, the water authority, NAWASA, is mandated to supply water, not to reduce demand.

Within recent times, RWH has received renewed interest from NGOs and academics as a resident-driven means to augment or replace municipal supplied water (e.g. CEHI, 2006; Peters 2006; Neff, Rodrigo, and Akpinar-Elci 2012). Notably, the Caribbean Environmental Health Institute (CEHI) drafted and promoted the Grenada National Rainwater Harvesting Programme (CEHI, 2006). However, to date, no aspect of this plan has been adopted by the water authority (NAWASA, 2009). Worse, this program promoted a relatively expensive 'best practices' model of RWH and was ineffective at persuading residents to consider installing RWH systems at their homes.

Observing this setback, Neff, Rodrigo, and Akpinar-Elci (2012) attempted to delineate a potential role for RWH. These researchers concluded that the potential exists to expand the use of basic forms of RWH (e.g. rain barrels), but the best practices model is difficult to promote for several reasons, a conclusion which is consistent with the view of criteria specified by the United Nations Environment Programme (1999) for promoting RWH and conversations between the primary author and persons in the local water authority (Al Neptune, personal communication, 2011).

Ultimately, the use of RWH systems still remains an unrealized potential and a symbol of the limitation of Grenada's fragmented and incomplete water management system.

anywhere in the water governance structure. This situation is true even within the individual 'silos' of water management.

In 2007, the European Union (EU) offered Grenada a US$7.4 million grant to fund a much needed water infrastructure project on the condition that the government formulate and pass a new water policy. The Government of Grenada agreed and rushed toward a new water policy. A brief consultation period was held and consultants produced key documents which sought to identify the deficiencies in current water resources management, define a sensible water policy for future integrated water resources management, and chart a path to implementing the new policy (Government of Grenada, 2007c, 2007b, 2007a). In early 2008 the Grenada legislature approved the 2007 water policy and the EU released funding for the water infrastructure project.

It is one thing to draft and approve an idealistic visioning document describing good water governance with a US$7.4 million ultimatum hanging in the balance; it is quite another thing, however, to draft and enact legislation to supersede the 14 existing statutes and provide a blueprint for implementing such governance. To date, the legislation required to bring life to the 2007 water policy has not been implemented.

Of the 14 current pieces of legislation that govern water resources in Grenada and their management, the most comprehensive is the National Water and Sewerage Authority Act 1990, which vests the right to the use of every body of water to the National Water and Sewage Authority (NAWASA). Further, this Act specifies that one of NAWASA's functions is to provide the public a satisfactory supply of potable water for domestic purposes and provide a potable or otherwise satisfactory supply of water for agriculture, industrial and commercial purposes.

Although NAWASA has been granted the legal authority to manage all water resources within the state of Grenada, there is no single government department that exercises any oversight or responsibility for the formulation of water regulations and policies. The Ministry of Health, Social Security, and the Environment is responsible for waste management, the control/management of hazardous waste, formulating guidelines, regulations, legislations and other policies in relation to the environment. The Ministry of Agriculture, Lands, Forestry, Fisheries, Public Utilities and Energy though has responsibility for the oversight of NAWASA.

Finally, both the water service provision and the regulation of such service provision is vested in the same entity, namely NAWASA. In effect, in the absence of an independent agency that has oversight over NAWASA's water service provision function, NAWASA in essence self-regulates itself.

4. Treatment of Wastewater in Urban Areas

Currently, 96% of the urban population and 97% of the rural population has access to improved sanitation. Individual septic tanks and pit latrines handle the majority of sewerage with only 5% of the total population connected to one of only two sewerage systems located on the island of Grenada.

The two existing sewerage systems are both located in the south of the island of Grenada (Figure 14). The St. George's system is over 75 years old and serves mainly the capital, St. George's. The other sewerage system, the Grand Anse System, was commissioned in 1992, and serves mainly the hotels and residential areas located in the southwest tip of the island of Grenada. Both of these systems are only primary treatment systems that simply remove by screening large items from the sewerage with the remainder outflowed to two points on the west coast.

5. Effect of Climate Change on Urban Water Users

Forecasting the hydrologic effects of climate change is much different than forecasting the effect of climate change on urban water users. Both are critically important questions to address, but the latter is arguably of greater value to guide management of climate change adaptation. The potential effects of climate change on Grenadian urban water users will be impacted mainly by three factors: (1) the likely hydrologic effects of climate change; (2) the vulnerability of the present water supply system to those effects, and (3) the effectiveness of the current water management system to adapt to these changing conditions.

5.1 Hydrologic Effects of Climate Change

Climate change is likely to disrupt historical patterns of temperature and precipitation, with resulting cascading effects throughout the water cycle. The following discussion is divided into observed and projected changes in climate as they affect water management.

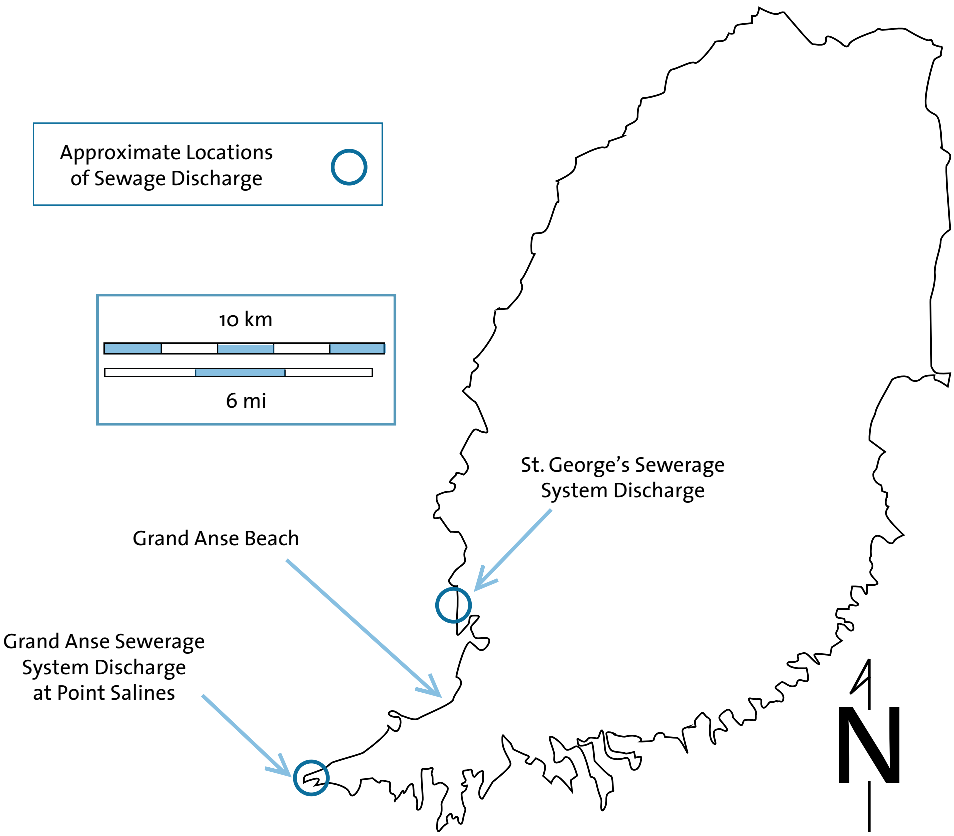
5.1.1 Observed Trends

Since 1960, mean air temperature in Grenada has increased approximately 0.6°C (McSweeney, New, and Lizcano, 2010). In analyses of Caribbean-wide climate trends, both Peterson (2002) and Stephenson et al. (2014) found an increase in the frequency of very warm maximum and minimum daily temperatures over the same time period. The Stephenson research group also found a corresponding decrease in cool days and nights. These observations are consistent with data describing increasing global temperatures (IPCC, 2007).

Since 1960, mean annual precipitation has increased slightly in Grenada, though the change is not statistically significant (McSweeney, New, and Lizcano, 2010). In analyses of Caribbean-wide climate trends, Peterson reported an increase in precipitation intensity and a decrease in consecutive dry days, indicating a more frequent rainfall during the dry season. However, a revised analysis by Stephenson et al. (2014) found that the trend in consecutive dry days had reversed since the late 1990's. In addition, these researchers found no trend in total precipitation in the past 50 years and confirmed the trend toward increased precipitation intensity observed in Peterson (2002).

The El Niño Southern Oscillation (ENSO) is an important wild-card in the discussion the effects of climate change on water supply. Climatic factors that create drought conditions in the Caribbean are complex and incompletely understood, but ENSO appears to be the largest factor (Giannini, Kushnir, and Cane 2000; Stephenson, Chen, and Taylor, 2008). Both the frequency and intensity of ENSO has been increasing since at least the 1500's and the trend appears to be accelerating (Gergis and Fowler, 2009), though this has not been attributed to climate change.

Figure 14. Sewage systems installed in Grenada



Base map of Grenada provided by d-maps.com, http://d-maps.com/carte.php?num_car=1707&lang=en

5.1.2 Projected Changes

Air temperature in Grenada is projected to continue increasing throughout the next century. The exact degree of warming varies depending on which model and climate scenario is used. For example, the 4th IPCC report predicts the Caribbean will warm 1.4°C to 3.2°C by 2100, with a median of 2.0°C (Christensen et al., 2007). The UNDP Climate Change Profile for Grenada projects warming of 0.7 to 2.6°C by the 2060's and 1.1 to 4.3°C by the 2090s (McSweeney, New, and Lizcano, 2010). The point is that widespread consensus exists to document substantial warming in Grenada in coming decades, most likely by approximately 2°C by 2100.

The significance of warming air temperatures to water supply is that evapotranspiration can be expected to increase concomitantly. As evapotranspiration increases, less of the water that falls as precipitation makes its way to the streams used as source water. Of particular interest, groundwater recharge is reduced, causing a reduction in groundwater discharge to streams (baseflow).

Change in total precipitation over the next century is highly uncertain in both global and regional climate models (Karmalkar et al., 2013). Overall, recent studies are tending toward a slight reduction in annual precipitation by 2100. The IPCC Fourth Assessment Report (IPCC, 2007, p. 912) states, "...most models project decreases in annual precipitation and a few increases, varying from –39 to +11%, with a median of –12% [by 2100]." McSweeney, New, and Lizcano (2010) report project annual precipitation deviation ranges between -61 and +23% by the 2090's, with a median of -13 to -21%.

Changes in the seasonality and intensity of precipitation are critical to water supply. Grenada lacks the ability to store streamflow from the wet season so that it can be utilized in the dry season. Total annual streamflow is far less important than daily streamflow, particularly during dry season conditions. Water supply in Grenada may be unaffected if the reduction in precipitation is isolated to the wet season, as some authors have suggested (Government of Grenada, 2011). In addition, McSweeney, New, and Lizcano (2010) project precipitation events will be less intense by 2100. This should enhance infiltration of precipitation, which tends to reduce flooding and increase baseflow in streams, potentially improving water supply during dry seasons and droughts. Reducing the intensity of precipitation events should also reduce erosion and sedimentation of streams, potentially reducing episodes of dirty water in potable supplies. Grenada lacks streamflow data that could be used to confirm these propositions. Other factors, such as land use changes in water supply catchments, will also affect the relation between precipitation, streamflow, sedimentation, and dry season baseflow.

As discussed in section 5.1.1, ENSO appears to be the largest factor driving severe drought in the southern Caribbean. Unfortunately, climate scientists offer little in projections for if and how ENSO will change in the next 100 years. Given the long-term acceleration in ENSO frequency observed by Gergis and Fowler (2009), it may be prudent to anticipate a potential increase in severe droughts, regardless of whether or not ENSO frequency is affected by climate change.

5.2 Water Management and Climate Change

The effect of climate change on water supply is not necessarily a question of hydrology; rather the real question is if and how water management responds to future water challenges. Grenada is blessed with great freshwater resources and water supply is fundamentally more sensitive to water management decisions than to forecast changes in the water resource. Options already exist to expand water supply or to reduce water demand through improving water use efficiency or increasing residential rainwater harvesting (Box 1; Caribbean Environmental Health Institute, 2006; Neff, Rodrigo, and Akpinar-Elci, 2012). The real question is if water managers utilize these options to maintain and improve water supply over the coming decades.

One option to expand water supply to the largest urban areas in Grenada is to divert and treat water from the Concord River, and transfer it 6 km south to the capital city of St. George's through the existing water distribution system. The Concord River is a relatively large stream in Grenada and is largely unused for water supply. There is evidence that the chronic dry-season water supply problems in the southwest part of the island could be easily corrected if this water source was tapped and brought on stream. NAWASA engineer's believes this one project could increase supply to the southwest part of Grenada by 0.8-1.0 million gallons per day (mgd), an increase of ~40% over the current 2.25 mgd capacity to supply this area.

Ultimately, Grenada possesses excellent options for coping with the effects of climate change on water supply. Grenada has an excess of water resources and management options already exist to greatly expand water supply. In addition, it is possible that improving the present system of water governance could illuminate new solutions that are less difficult and costly to implement. The degree to which Grenada implements these options depends largely on political leadership and will. If these two qualities can be found and nurtured, Grenada's resilience to deal with any water management challenges posed by climate change will be greatly enhanced.

6. Conclusions

As is true for many developing countries, the increasing development and expansion of cities and other urban centers in Grenada will bring more and more to the fore the need to significantly improve and enhance the infrastructure needed to deliver water of sufficient quality and quantity to these growing concentrations of population. While Grenada is blessed with adequate freshwater resources, the challenge of harnessing these resources, which currently are located in the mountainous areas of the island, and bringing them to where the key consumption areas are located will need to be addressed.

Additionally, besides improving physical water capture and delivery infrastructures, there is the need to completely overhaul and update the management structures that are in place to manage all water resources in Grenada. Specifically, there is an urgent need to reform and collate the current mishmash of legislative and statutory bodies that currently perform some part of this function into one holistic, over-arching policy and legal framework. It is unlike that needed funding to improve and replaced aging water delivery and storage infrastructures will be sourced under the current legislative and management framework.

Finally, in order to improve water security, especially during the dry season months, polices and programs should be developed that encourage locals, particularly those living in urban centers, to install rainwater harvesting (RWH) systems. RWH systems are a relatively inexpensive way to significantly improve the overall water storage capacity of the municipal system. Furthermore, RWH residential systems can help reduce the demand for water from the municipal system, especially during the dry season months.

7. Recommendations

Based on the experiences of Grenada in trying to provide both the quantity and quality of water for a growing urban population, the following recommendations are made:

1. For the proper and effective management of water resources, holistic, over-arching water-management legislation has to be passed and enacted.
2. The provisioning of water and the regulation of such a service should not be vested in the same entity. The latter needs to set up to act independently of the former to ensure proper oversight and effective monitoring of the quality of water that is being produced for the population.
3. Policies and programs should be implemented to help locals better utilize the potential of Rainwater harvesting (RWH) systems so that these can firstly help reduce the demand load for pipe-borne water, and secondly help provide increased water security to locals especially during periods of water shortage.

8. Acknowledgments

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10. Acronyms

ADD	Annual Daily Demand
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
L	Liters
mdg	Million gallons per day
NAWASA	National Water and Sewage Authority
NGO	Non-governmental Organization
RWH	Rainwater Harvesting
UFW	Unaccounted for Water
UN	United Nations
UNICEF	United Nations Children's Fund

Guatemala

Guatemala City. People rest and shop on the "Parque Central", fountain and the National Palace's monumental facade. Photo credit: ©iStock.com/mtcurado.

"In Guatemala, an integral approach to urban waters is incipient and related information that would make it possible to diagnose the types of impact caused by urbanization has been concentrated in the capital city and in the neighboring municipalities (the metropolitan area or MA)"

Urban Water in Guatemala

Manuel Basterrechea,
Claudia Velásquez, Norma de Castillo,
Jeanette de Noack, Ana Beatriz Suárez,
Carlos Cobos, and Juan Carlos Fuentes

Summary

In Guatemala, an integral approach to urban waters is incipient and related information that would make it possible to diagnose the types of impact caused by urbanization has been concentrated in the capital city and in the neighboring municipalities (the metropolitan area or MA).

The water supply for the Metropolitan Area and other urban areas presents two challenges: overuse of the aquifers, with the consequent increase in pumping costs, and access to new water sources that are found outside their jurisdiction, which creates conflicts. In the first case, the solution to the problem depends fundamentally on organizing how the aquifers are used through the different management institutions. To do so, the parties need to come to a consensus and encourage the infiltration and reuse of rainwater from areas that have been impermeabilized. In the latter case, assignment and compensation mechanisms will need to be considered. Urbanization has caused contamination of water sources due to a lack of wastewater treatment and the increase in flooding represents a risk to human lives.

1. Introduction

In Guatemala, an integral approach to urban waters is incipient and related information that would make it possible to diagnose the types of impact caused by urbanization has been concentrated in the capital city and in the neighboring municipalities (the metropolitan area or MA). The country's population is

14,061,666 inhabitants in an area of 108,000 square kilometers. The amount of water available annually is 97,120 billion cubic meters, of which 33,699 billion cubic meters are renewable groundwater. Figure 1 shows a map of Guatemala, depicting the country's hydrographic division with more water being discharged into the Pacific Ocean, followed by discharge into the Gulf of Mexico, and lastly, discharge into the Caribbean Sea.

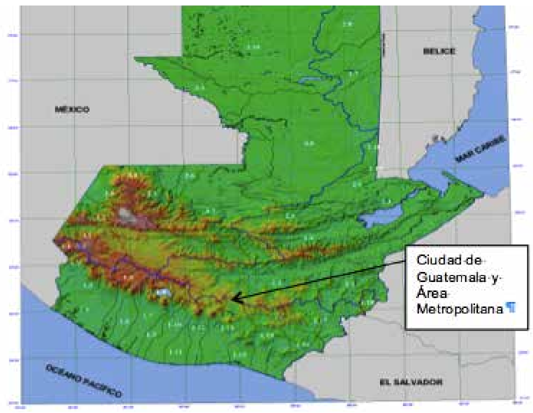
2. Water Sources in Urban Zones and the Types of Impact Caused by Urbanization

Since the country is located between two oceans and is crossed by the Sierra Madre and Cresta de Gallo mountain ranges, it has abrupt topography, with several cities being located in the *altiplano* (the high part of the watersheds) where the main source of water is underground. The rest of the municipal headwaters are located in the medium and low parts where there is more surface water available. Since it is contaminated by discharging untreated wastewater from the medium and high parts, however, groundwater is also a major source of water supply for the population.

Guatemala City and part of the rest of the Metropolitan Area are found on the water divide for the Pacific and Atlantic watersheds. Therefore, surface water is comparatively scarce and, as a consequence, the underground sources have had to be exploited. Urban growth in Guatemala City since it was created in 1776, but especially other municipalities in the MA in the last four decades, has caused a reduction in infiltration of water due to impermeabilization and overuse of the aquifer due to growing demand, as well as contamination of the surface and groundwater sources due to the discharge of untreated wastewater.

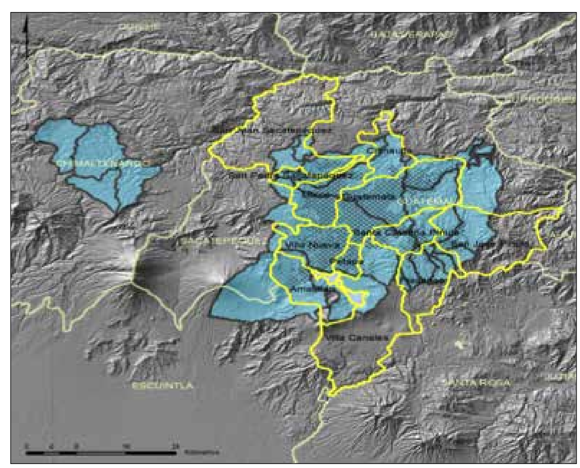
The MA is made up of 12 municipalities, running from San Lucas Sacatepéquez to Fraijanes and from Amatitlán to Palencia, encompassing 20 sub-watersheds and around 2 million inhabitants (INE, 2002), with an annual growth rate of 3.5%, occupying an area of 1,461.15 square kilometers. Figure 2 shows the municipalities and the watersheds in the MA.

Figure 1. Map of the Republic of Guatemala



Source: Instituto Geográfico Nacional, IGN.

Figure 2. Watersheds and Municipalities of the Metropolitan Area (MA)

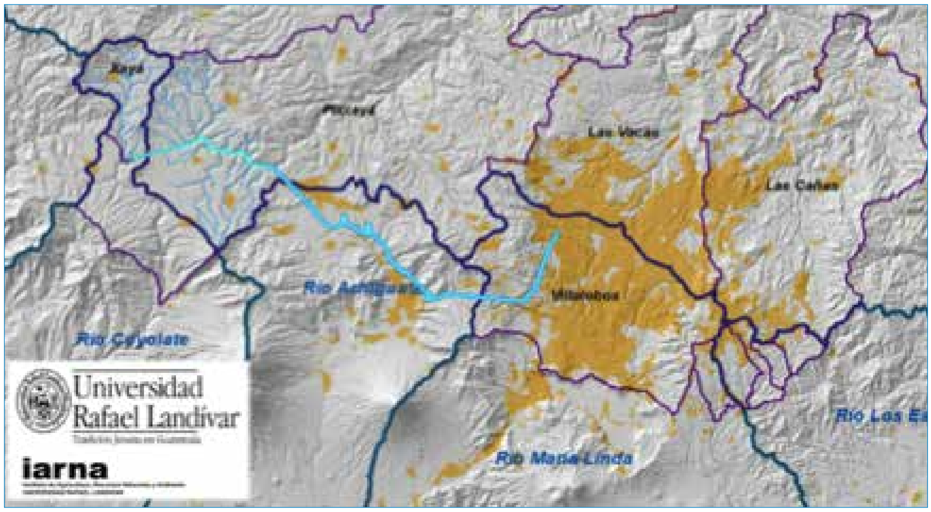


Source: IARNA-TNC 2012.

The IARNA-URL and TNC (2012a)[1] summarize the water situation in the MA as follows: "The water supply for the metropolitan area is based on five surface water systems linked to five hydrographic watersheds (Coyolate, Pixcayá, Las Vacas, Plátanos, and María Linda), as well as an undetermined number of mechanical wells that exploit the local aquifers. Water distribution is handled by the Municipal Water Company (EMPAGUA in Spanish) in Guatemala City and by the local governments and the other municipalities in the Metropolitan

1. Water availability in the Guatemala Metropolitan Area: Fundamental Bases for Water Management with a Long-Term Vision.

Figure 3. Water supply for the subwatersheds in the MA and Xayá Pixcayá



Source: IARNA–TNC 2012.

Table 1. Total Water Supply in the Metropolitan Area (millions of cubic meters)

Scenario	Metropolitan Area	Xayá Pixcayá
Base	1,611	298
To 2020	1,481 (-8.1%)	275 (-7,7%)

Source: IARNA-URL TNC (2012a).

Area. Some of them have hired companies such as Agua de Mariscal. Most of the urban developments and private companies (industry, hotels, shopping centers, etc.) are supplied by groundwater through their own mechanical wells. Currently, there are no regulations related to extracting water at the national level, much less at the metropolitan area level. The complexity and lack of regulation that characterize the water extraction system contribute to the unsustainability of the water system in the Metropolitan Area overall (supply and demand)."

Table 1 shows the results of the total water supply in the MA sub-watersheds and the area of Xayá-Pixcayá, as well as the trend out to 2020. Figure 3 shows the Metropolitan Area and the Xayá-Pixcayá sub-watersheds.

The IARNA-URL and TNC (2012b)[2] analyzed the groundwater situation in the MA and estimated the extraction of groundwater and characterized the aquifers in the zone. The report indicates that "initially, the upper or free aquifer is used and then, due to the increase in demand, the multiple aquifers found in the stratified volcanic landfills are used. The increase in usage of groundwater and the extension of the urban borders have had an influence on the drop in recharging these aquifers. This is made evident by the decrease in the levels of groundwater in the zone and has required deeper wells to be able to penetrate the aquifer being used farther and/or to search for deeper aquifers. Therefore, the regional aquifers that are found at a greater depth are used, which are recharged in the areas of the volcanic landfills in the zone and the geologic formations that cross the hydrographic watersheds. In general, these aquifers are in fractured volcanic rocks and in fractured sedimentary rocks and/or rocks with a degree of karstification. Currently, groundwater supplies part of the urban, rural, industrial, and irrigation zones and has been estimated to cover on the order of 60% to 70% of the demand in the zone of interest."

The IARNA-URL and TNC (2012b) indicate that, in the Metropolitan Area, "the wells in the Metropolitan Area are in the range from 80 feet to more than 2,000 feet deep depending on the aquifer or aquifers being captured."

The conclusions drawn by the IARNA-URL and TNC (2012b) are: "i) The Metropolitan Area, to supply

2. Analysis elements to characterize the status and estimate the consumption of groundwater in the Guatemala Metropolitan Area.

water for its different services (supplying water to the population, irrigation activities, and industry) is making use of the groundwater resource. In the preliminary estimates that were made, there are areas with intense use of groundwater from different aquifers. Over time, their reserves have decreased, which is reflected in the variance in the time for the groundwater level and requires the implementation of reforestation projects, artificial recharging that boosts infiltration, proper use of the resource, etc., and that involve using the resources sustainably. ii) Water extraction in most of the micro watersheds is much higher than the local estimated recharge, especially for the more urban watersheds. iii) Although the local aquifers may benefit from additional recharge coming from outside the micro-watersheds that were studied, the conclusion may be drawn that using groundwater is an unsustainable trend in the Metropolitan Area, since the amount that is extracted is more than what is recharged."

The types of impact in the country are similar to the types of impact in other cities in the world. They include: impermeabilization of the soil due to unplanned urban growth, recharge zones are not preserved, water infiltration has dropped and aquifer feeding has been reduced. Runoff and the discharge, are also generated by intense rains, causing damages to the infrastructure and representing a risk to human life as well as the fact that the minimum yearly water flows are lower. In addition, unlike other countries where wastewater is treated, in Guatemala the percentage that is treated is minimal, causing a deterioration in the quality of surface and groundwater (absorption wells) and limiting its use downstream.

The sources of contamination in the country are similar to the sources of contamination in other cities in the world. The predominant sources of contamination include the discharge of domestic wastewater; however, in the Metropolitan Area there are also relevant industrial and agro-industrial sources of contamination. In the Metropolitan Area, it has only been recently that wastewater treatment has been mandatory based on the issuance of Government Agreement 236-2006. Even so, water that is discharged from the municipal drains that have been collecting wastewater from housing and industry since before the promulgation of the government agreement is still not treated.

For a long time, the country has faced problems with the water quality in the urban areas but still has not been able to solve them. An example is the deterioration the quality of the water in Lake Amatitlán (1,080 meters above sea level). Since Amatitlán is located downstream from the southern part of Guatemala City and from some municipalities in the MA (1,500 meters above sea level), it receives untreated wastewater that have taken it to a state of hypereutrophication. In addition, due to the inadequate soil and water management in Amatitlán's watershed, the lake is also experiencing silting. For the last bathymetry taken in 2012, silting caused its useful life to be 110 years (AMSA, 2012). In the 60s, the lake was conceived to be able to be a water reservoir to supply the MA; at this point in time this would require a multimillion dollar investment.

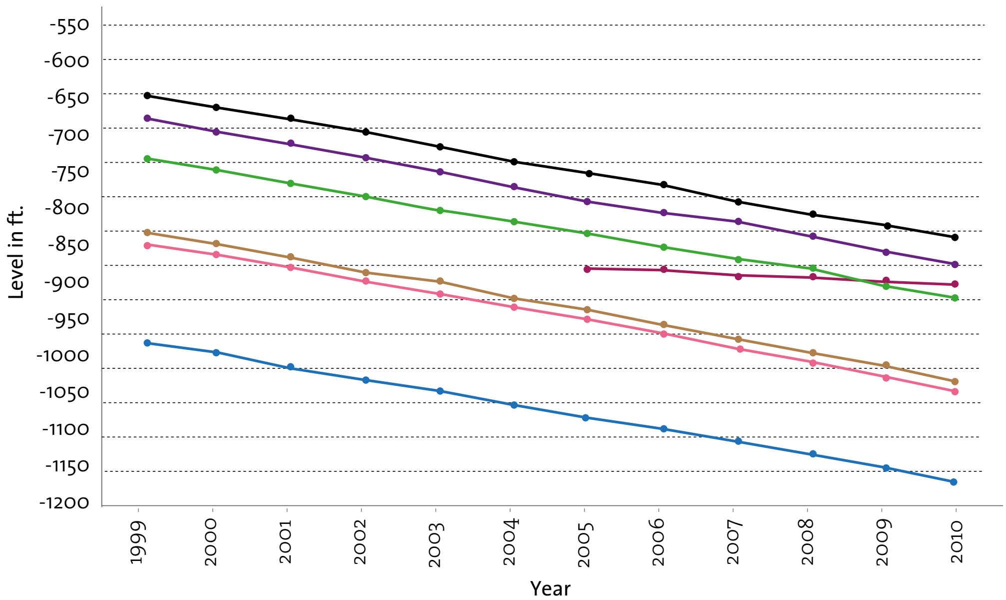
It is interesting to mention that, in the 60s, Guatemala City, built collectors in the high part of the Lake Amatitlán watershed on counterslopes to keep the wastewater from being discharged into Lake Amatitlán. The plans were for industries to be located in one specific sector (Petapa) so wastewater from the different industries could be treated together in the future. However, due to the lack of planning and compliance with the functions by the municipalities in the MA, most of the wastewater is not treated, which causes surface and ground water to deteriorate.

In the MA, the ground has been covered (impermeabilized) due to the advance of urbanization without any compensation to boost natural or artificial recharge.

Until the 60s, there were several lagoons in Guatemala City and the neighboring areas such as the one located in the Industry Park and in El Naranjo. There were also springs such as the swimming pools at Lo de Bran and Ciudad Vieja. They dried up when the water table dropped and water was no longer supplied. Furthermore: the prehispanic population at Kaminal Juyú settled there (west of Guatemala City) due to the availability of surface water, since there were some lagoons in existence.

The output from the mechanical wells has decreased from 1,246 liters per second to 701 liters per second and the water table levels have dropped from 450 feet to 1,700 feet deep. This situation has caused the fact that water has to be extracted from deeper in the wells with lower output, increasing

Figure 4. Drop in groundwater levels at seven monitored wells, the Northern Limestone Aquifers (1999-2010)



Source: IARNA-URL and TNC, 2012b.

the cost. For example, in 2010, the average cost to produce a cubic meter at the Lo de Coy plant (gravity fed) was 0.50 Quetzals, but for a surface source that is pumped, such as at Las Ilusiones, the cost varies between 3.00 and 5.00 Quetzals.[3]

As an indication of the variance in the groundwater level over time, IARNA-URL and TNC (2012b) performed a 10-year analysis for six 12-inch wells at 1,300 feet deep and another analysis of a well for five years at 1,700 feet located in the northern limestone. Figure 4 shows the variance in the water levels measured in the wells. The trend is for the water level to drop over time. This indicates that more water is being extracted than is being recharged into the aquifer; six wells show a drop of 16 feet per year, while the remaining wells show a drop of four feet. The latter is because the extraction is deeper.

Due to the lower relative availability of surface water in the high part of the MA and due to urban growth, the government planned and built the Xayá Pixcayá pipeline in the 70s. The pipeline captured 1 m^3/second when water levels were low, 60 kilometers from Guatemala City. From its inauguration to today (35 years), transporting this water has contributed to around 400,000 people having water in the city (216 liters/inhabitant/day). Even more so, from its inception, planners designed the pipeline to be able to conduct water up to 3 m^3/second. The planners had a vision and foresaw that additional water could be added from other surface and underground sources. There is another version that indicates that the pipeline was over-dimensioned. Currently, despite more volume could be possibly transported with the current infrastructure, it has not been feasible to add this flow due in part to the lack of the financial retribution instrument (payment) and social conflicts. In part due to that situation, EMPAGUA (2012) has seen the need to purchase approximately 20% of the water that it distributes to private companies; that figure will probably continue to grow.

In the 12 municipalities that make up the Guatemala Metropolitan Area, a total of 553.4 million cubic meters of water is consumed per year, which is the equivalent of an average of 189 m^3 per capita per year. Some 91% of the water that is consumed comes from the aquifer mantles where the Las Vacas and Villalobos micro-watersheds provide 67% of the total (which denotes at the same time the intensity of extraction from those watersheds) and 9% from

3. One American dollar is the equivalent of 7.70 Quetzals, the currency in Guatemala.

the Xayá and Pixcayá watersheds (51.1 million m^3) (URL-IARNA and TNC, 2012b).

The job opportunities that the MA offers has induced people to migrate. This has caused some municipalities to have a growth rate of up to 10% annually and has also caused municipalities such as Guatemala, Mixco, and San Miguel Petapa to be totally urbanized. Depending on the income of the people in the MA, they settle in peripheral urban zones and informal settlements, always in the MA.

The lack of planning and exercise of functions by the municipalities has caused a proliferation of informal settlements, mainly in the marginal zones, where the natural threats and their vulnerability represent a high risk to people's lives. These settlements get their water from tank trucks, whose quality is questionable and whose price is higher than the municipal system's price.

In peripheral urban zones made up of residential developments, water is supplied by mechanical wells. The municipality does not have any control over these wells in relation to overexploitation of the aquifer and means of recharge. Likewise, there is no evaluation of the efficiency of wastewater treatment in the neighborhoods and its effect on the surface and underground sources of water.

Recently, an initiative promoted by The Nature Conservancy (TNC) was initiated. It is known as the "Fund for Water Conservation in the Guatemala Metropolitan Region" (FONCAGUA). An alliance also exists in Latin America that is made up of 25 initiatives by eight countries in the Americas, including Guatemala. In June 2013, the Second Meeting for these initiatives was held in Panama. Its purpose is to be a financial mechanism for investing in green infrastructure (protecting the soils, forest, and water; best production system practices; water collection and hydric recharge infrastructure; strengthening governance and institutionalization; education on saving water) (Juan Carlos Godoy con. per.).

Water funds are efficient mechanisms that are self-sustainable and able to generate resources to pay for conserving the water production areas. As was indicated previously, for every 1m^3/second of water drawn off for the last 35 years, the Xayá and Pixcayá River watersheds have not been paid back anything for conserving the natural resources of their watersheds. The model predicts that large water users are willing to put up financial resources to strengthen the fund to ensure the water quantity and quality in the future at a lower cost. The funds are institutional mechanisms with multiple stakeholders. Their objective is to provide financing resources to protect key territories in terms of the production of ecosystem services and in particular, water. Success for these funds lies in an accurate quantification of those services as well as in adopting sustainable financial mechanisms with transparent management. Some of the documents used to prepare this chapter that were in turn prepared by IARNA-URL and TNC are technical studies that are necessary to design the fund (Juan Carlos Godoy, con. per.).

To design and start operations for FONCAGUA, a promotion group has been created with the participation of private enterprise, public authorities, local governments, academic institutions, and NGOs. Actions have already been taken such as reforestation of 150,000 hectares in the Xayá Pixcayá watersheds with the participation of the Agrobosques company and TNC (Juan Carlos Godoy, con. per.).

The Fund's objectives are: i) Ensure, in the mid-term, the water quality and quantity for the inhabitants and institutional and business users in the MA; ii) Improve environmental management of the watersheds and water recharge zones (private reserves, community forest, and municipal forests in the MA greenbelt; iii) Increase the citizen awareness in the MA in relation to sustainable use and consumption of water and its implications for environmental costs; and, iv) Contribute to being able to govern the water and strengthen institutions for water management (Juan Carlos Godoy, con. per.).

IARNA-URL and TNC (2013)[4] did a study of the demand and consumption of water in the Metropolitan Area and established the economic value that forests possess due to their contribution to the hydrologic cycle in the zone. In the study, an environmental assessment is used to estimate the value of the forest for water production and conservation in the Metropolitan Area of Guatemala City, i.e., it estimates the value of the ecosystem service that forests provide to supply the vital liquid to the population in the central Guatemala

4. Analysis of the demand for water and evaluation of the environmental value in the water recharge zones in the Guatemala City Metropolitan Area.

metropolis. That involves elements for creating a fund that promotes conserving the forest to ensure provision of water to the population.

URL-IARNA and TNC (2012a) estimated the water balance sheet for the MA by "calculating the total incoming flow is the equivalent of 2,211 million cubic meters of water, of which precipitation comes to 86%, storage in the soil represents 12% and infiltration coming from irrigation is 2%."

URL-IARNA and TNC (2012b) show that "water extraction from the aquifer mantle is the main source of supply for consuming the liquid in the Metropolitan Area, which has been estimated to be 91% of the total consumption in the zone. In that regard, a claim may be made that a major component in water management lies in correctly balancing infiltration and extraction of water from the aquifer mantles."

URL-IARNA and TNC (2012b) show that "61% of groundwater extraction is for domestic purposes, 31% for municipalities, 7% for industry and commerce, and 2% for irrigation. These figures suggest, therefore, that homes are the main consumers in the Guatemala Metropolitan Area."

3. Potable Water Service in the Urban Zones

At a national level, there is a coverage deficit in Guatemala. Besides, the services for the network are intermittent and the quality of the water is deficient. According to ENCOVI (2011), coverage for homes with water service for human consumption was 75.3%. Figure 5 shows the water supply service coverage trend.

What may be observed in Figure 5 is that, according to information from ENCOVI (2006), water coverage for human consumption was 78.7%, which represents a step backwards with respect to 2006 of 2.4% as of 2011. The cause for this decrease is not known. It may be assumed to be due to damages caused by extreme hydro-meteorological events that occurred in the country in the last few years (Tropical Storm Agatha in 2010) and the increase in access to services, so it has been lagging behind in relation to the population growth. For 2002, urban coverage was 89.4%, representing 50.2% of the total homes at the national level.

In reference to intermittent services in the grid, a study prepared by the IDB[5] in 2008 estimated that 80% of the systems in the country worked intermittently, providing between 6 and 12 hours of service per day. In relation to water quality, it is estimated that just 15% of the water supplied by the systems is purified and that just 25% of the municipalities at the urban level have purification systems. Data from the National Water Quality Oversight Program, PROVIAGUA of the MSPAS, show that, of the 10,277 water systems that are registered,[6] just 17% have water purification.

In relation to sanitation services, according to ENCOVI (2011), national sewage system coverage is 38%. The rest of the population meets its needs for domestic sanitation by using a latrine, a blind well (41% of homes), a flushable toilet (7% of homes) and a toilet connected to a septic tank (6% of homes). Figure 6 shows the coverage trend.

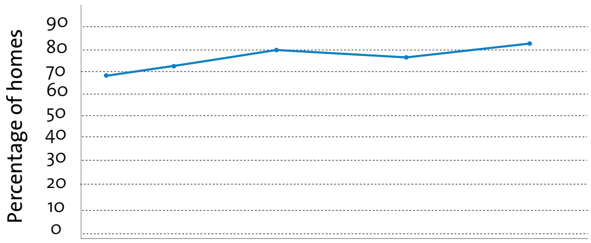
The water supply in Guatemala City is the responsibility of the Municipal Water Company (EMPAGUA) and private companies that have their own mechanical wells. The other municipalities in the MA supply just a small percentage of urban users. Hotels, industry, and other users that demand comparatively large volumes of water install their own wells to ensure quantity and continuity. However, a high percentage of the urban population that lives in marginal areas obtains its water by purchasing from private tank trucks at elevated prices compared to what is paid for the EMPAGUA service, for example, and the quality is questionable.

In addition, the water supply service rates do not meet the operating and maintenance expenses except in certain sectors of Guatemala City (EMPAGUA, the Agua Mariscal company and companies that supply private residences). The result of this has been a deterioration in the existing infrastructure, subsidies for urban areas, and expansion of services by means of alternate systems (tank trucks). As indicated previously, they are of dubious quality and the cost is higher. The

5. Samper, Olga (2008). Informe Final: Plan Estratégico del Sector Agua de Agua Potable y Saneamiento (Final Report: Strategic Plan for the Potable Water and Sanitation Water Sector). Guatemala: The International Development Bank. Washington, D.C.

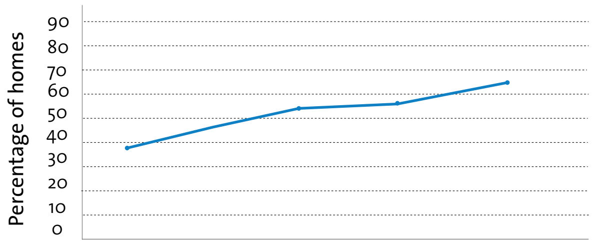
6. Information coming from the system inventory for water transferred to PROVIAGUA during the workshop with Sanitation Directors and Supervisors of Health Areas, June 2012.

Figure 5. Homes with improved access to sources of a potable water supply: homes with water supply connected to pipes inside or outside the home and public water supply



	1994	2002	2006	2011	Goal by 2015
Improved access to sources of a potable water supply	66.0	74.6	78.7	75.3	81.5

Figure 6. Homes with improved sanitation services: homes with a toilet connected to the drainage network, a toilet connected to a septic tank, and a flushable toilet



	1994	2002	2006	2011	Goal by 2015
Percentage of homes with improved sanitary services	35.20	46.89	54.50	55.96	66.00

Source: Presentation: "The 7C Goal in the ODM", SEGEPLAN, 2012.

municipality of Villa Nueva (a municipality in the MA) provides a monthly subsidy to users in the amount of 1.0 million Quetzals (around US $125,000). The average price per cubic meter charged by EMPAGUA is 1.80 Quetzals, when the production cost is 3.50 Quetzals. The EMPAGUA rate is 2.90 Quetzals per cubic meter for usage between 1 to 20 cubic meters. Q. 3.71 per cubic meter for usage between 21 and 40 cubic meters; Q. 4.45 per cubic meter for usage between 41 and 60 cubic meters; and, Q. 8.90 per cubic meter for usage between 61 and 120 cubic meters.[7]

Another relevant indicator is the percentage of losses in the water service systems. In urban areas, the losses reach 50% while in the rural area they are 10%.

7. Free Press.

The water supply for the Metropolitan Area and other urban areas presents two challenges: overuse of the aquifers, with the consequent increase in pumping costs, and access to new water sources that are found outside their jurisdiction, which creates conflicts. In the first case, the solution to the problem depends fundamentally on organizing how the aquifers are used through the different management institutions. To do so, the parties need to come to a consensus and encourage the infiltration and reuse of rainwater from areas that have been impermeabilized. In the latter case, assignment and compensation mechanisms will need to be considered.

4. Water Treatment in Cities

In the municipalities located in the Lake Amatitlán watershed, which encompasses part of the MA, there are 79 wastewater treatment plants. Table 2 shows that 58 of the plants are municipal and the rest are private in the charge of residential committees.

Table 3 shows that the treated volume for the 79 wastewater treatment plants in the municipalities in the Lake Amatitlán watershed is 126,201 m³. The projected population in 2014 for the Lake Amatitlán watershed is 1,147,540 inhabitants. They will produce around 137,705 m³ of wastewater per day so 91.6% of the wastewater could be treated.

However, as shown in Table 4, few of the plants are functioning properly. In addition, when 47 of the 79 wastewater treatment plants were evaluated, seven were reported to no longer be functioning, 14 were totally abandoned, eight function at minimum capacity, eight function at medium capacity, nine are functioning at their maximum capacity, and one is in the construction phase. No treatment plant has an operator; they just have guardians.

EMPAGUA invests US$392,000 per month to treat raw water and make it potable, which is the equivalent of US$4.7 million per year (P. Alvarado, con. per.). A percentage of this investment is due to the fact that the raw water is contaminated by wastewater.

5. Water and Health in the Cities

In general, the information to analyze and make decisions comes from national censuses and surveys, but this information is not generated in a systematized, continuous form.

As of 2010, the general mortality rate was three deaths for every 1,000 inhabitants and the infant mortality rate was 30 for every 1,000 births. In

Table 2. Number of Wastewater Treatment Plants

Municipality	Municipal	Private	Total
Amatitlán	4		4
Fraijanes	2		2
Guatemala	4	4	8
Magdalena Milpas Altas	2		2
Mixco	13	1	14
San Bartolomé Milpas Altas	1		1
San Lucas Sacatepéquez	2		2
San Miguel Petapa	5	5	10
San Pedro Sacatepéquez	3		3
Santa Catarina Pínula	3		3
Santa Lucía Milpas Altas	1		1
Villa Canales	1	2	3
Villa Nueva	17	9	26
General Total	58	21	79

Source: AMSA, 2013.

Table 3. Volume of Wastewater in Treatment Plants

Municipality	Volume (m³ / día)
Amatitlán	2,246.40
Fraijanes	604.80
Guatemala	18,489.60
Magdalena Milpas Altas	259.20
Mixco	24,114.24
San Bartolomé Milpas Altas	1,728.00
San Lucas Sacatepéquez	345.60
San Miguel Petapa	40,617.50
San Pedro Sacatepéquez	518.40
Santa Catarina Pinula	518.40
Santa Lucía Milpas Altas	86.40
Villa Canales	3,231.36
Villa Nueva	33,441.12
General Total	126,201.02

Source: AMSA, 2013.

Table 4. Status of Wastewater Treatment Plants

Municipalities	01 - Land	02 – Under construction	03 – Rehabilitation	04 – Normal Operations	Capacity			08 – Structures S-Destroyed	09 – Structures Destroyed	10 – No Plant	11 - Unknown	General Total
					05 – Maximum	06 – Mean	07 – Minimu:					
Amatitlán					1	1		1	1			4
Fraijanes	1				1							2
Guatemala						5		1	2			8
Magdalena Milpas Altas				2								2
Mixco		1	1	3		1	2	2		4		14
San Bartolomé Milpas Altas								1				1
San Lucas Sacatepéquez		1			1							2
San Miguel Petapa					1	2	4	3				10
San Pedro Sacatepéquez								3				3
Santa Catarina Pinula		1			2							3
Santa Lucía Milpas Altas				1								1
Villa Canales					1	1	1					3
Villa Nueva			3	6	3	1		6	3		4	26
General Total	1	3	4	12	10	11	7	17	6	4	4	79

Source: AMSA, 2013.

children five years old, the main causes of mortality included infectious diseases and parasites (66 for every 100,000) and conditions originating in the perinatal period (37 for every 100,000).[8]

Data from the Health Information Management System (SIGSA in Spanish) indicate that, during 2011, the events that occupied the greatest number of first consultations for morbidity (4,490,279 consultations) related to health services, in all age groups, were acute respiratory infections with 48%, followed by intestinal parasites with 10%, gastritis with 9%, infections of the urinary tracts with 7%, and other acute diarrhea related diseases with 6%, which represents 80% of all consultations.[9] The top 10 causes of general morbidity at the national level are shown in Table 5.

During 2011, 378,602 cases of diseases transmitted by food and water were reported. The reported cases included diarrhea, hepatitis, food poisoning, and other costs. The whole country had 2.6% of the total population affected, which, compared to 2010, represented a decrease of 29% in registered cases.[10]

Table 5. Top 10 Causes of General National Morbidity for 2011 - January to November

Diagnostic Description	Female	Male	Total
Acute Respiratory Infections	1,234,579	903,224	2,137,803
Intestinal Parasites	304,699	147,003	451,702
Gastritis	254,182	145,667	399,849
Urinary Tract Infection	242,913	61,754	304,667
Other Acute Diarrhea Related Diseases	144,398	126,247	270,645
Anemia	119,751	41,521	161,272
Cefalea	126,755	32,942	159,697
Conjunctivitis	54,029	38,491	92,520
Dermatitis	53,092	38,125	91,217
Unspecified Allergy	51,214	32,338	83,552
Total	2,745,294	1,744,985	4,490,279

Source: The Ministry of Public Health and Social Assistance National Health Diagnosis. March 2012.

8. The Ministry of Public Health and Social Assistance National Health Diagnosis. March 2012.

9. Ibidem

10. Ibid.

In relation to rotavirus, 724 cases in children younger than five years old were reported in 2011, compared to 2010 (5,932 cases), which represented a decrease of 88%. In a time series, the effect that the introduction of the vaccine had on this event may be observed. The vaccination that is applied currently contains the viruses that have circulated in the last three years. The departments that reported the most cases were Escuintla (160 cases), Quiché (134 cases), and Huehuetenango (113 cases). There was no significant difference by gender.[11]

During 2011, 3,281 cases of dengue were reported, of which 78% were clinical, with 687 confirmed, and 29 cases of hemorrhagic dengue. There were 11 deaths attributed to dengue. Compared to 2010, 2011 was not an epidemic year for this event.[12]

In 2011, during the 52 epidemiological weeks, there were reports to the SIGSA of 2,664 confirmed cases of malaria at a rate of 22 x 100,000 inhabitants, with *Plasmodium vivax* being the most frequent at the national level, with 98% of the total recorded cases. Note that, in comparison to 2010, only one-half of the cases were recorded, which is a trend that has been observed over the last several years.[13]

When a correlation is done with the indicators developed by the World Health Organization (WHO) in relation to the impact of investments in potable water and sanitation on health, for every dollar invested, at least a 10% reduction in diarrhea related diseases is able to be achieved. In other words, for every dollar that is invested, a reduction of five dollars could be achieved in the Ministry of Health's budget.

6. Variability and Climate Change, Its Impact on Water Resources in Cities

Guatemala is highly susceptible to extreme hydro-meteorological phenomena, especially great magnitude floods. In the last decade, Hurricane Stan in 2005 and Tropical Storm Agatha in 2010 caused losses to the country of more than US $1.9 billion, of which US $745,000 directly affected the infrastructure.[14] In the Department of San Marcos alone, 331 water supply systems were damaged. In the case of Agatha, it was the effect of the storm combined with the eruption of the Pacaya volcano. Hurricane Mitch in 1998 affected a broader area and also presented damages of more than US $115 million in infrastructure;[15] the number of water systems damaged was 237.

With the effects of climate change and variability, this type of event is predicted to be increasingly more frequent. As a developing country, the costs of investment in damaged infrastructure implies sidetracking resources into reconstruction, which limits the construction of new work. This is a financial cost that affects the country's whole economy and not just the place that was specifically affected.

Although Guatemala is highly vulnerable due to the threat of hydro-meteorological phenomena and their high indices of at-risk populations and infrastructure, there is very little that can be done to actually reduce the effects of greenhouse gases. The reason is that the large industrialized countries emit more than 80% of the gases worldwide, so the media for adaptation to reduce vulnerability needs to the concentrated.

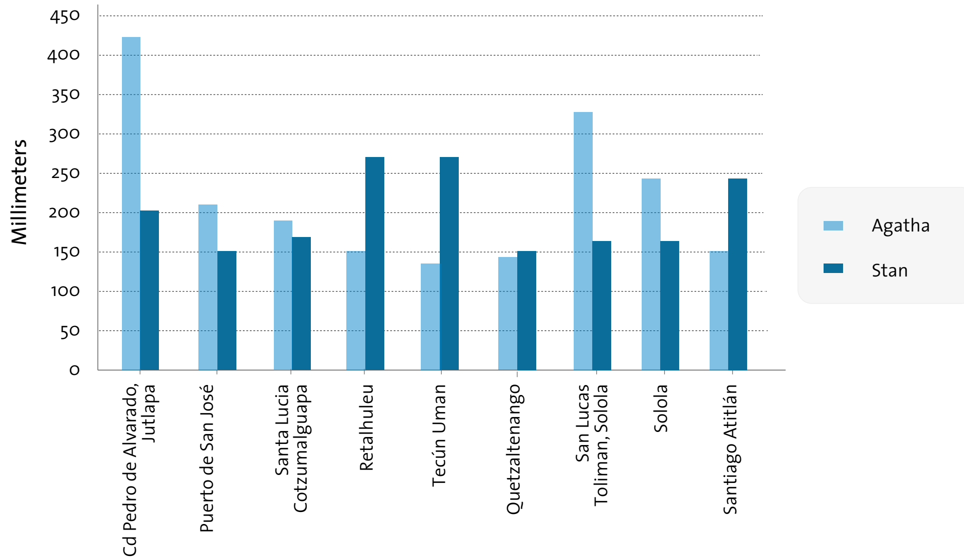
The main effect of climate change in the urban zones consists primarily of flooding, in addition to the droughts that mostly affect the availability of water for the supply systems. Flooding is due to the increase in intensity or magnitude of storms, as well as the rising trend in their frequency. In other words, storms occur with a greater intensity and they occur increasingly closer to each other. This is confirmed by the fact that, in the last 15 years, three events of a great magnitude have occurred, represented by hurricanes Mitch and Stan, as well as Tropical Storm Agatha. Figure 7 shows the 24-hour precipitation during Stan and Agatha in different parts of the country.

Fuentes (2013) quantified the effect associated with urbanization during the water cycle, principally on the components of precipitation and surface

11. Ibidem
12. Ibidem
13. Ibidem

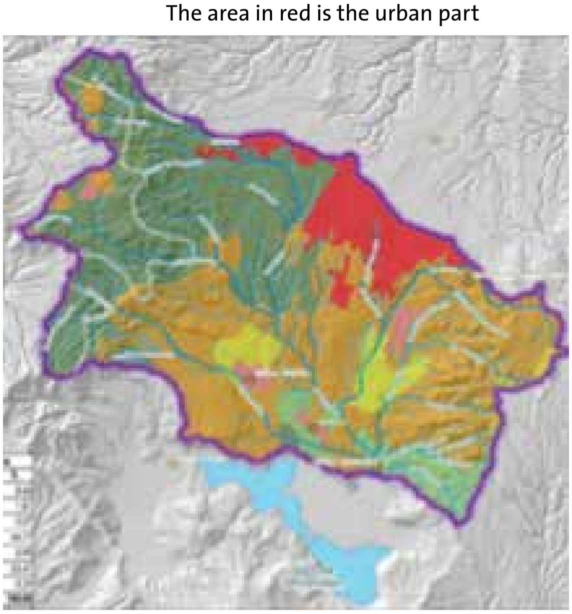
14. Reports by the CEPAL about Stan (2005) and the SEGEPLAN report (2010) on Agatha.
15. CEPAL report on the evaluation of damages caused by Hurricane Mitch (2004).

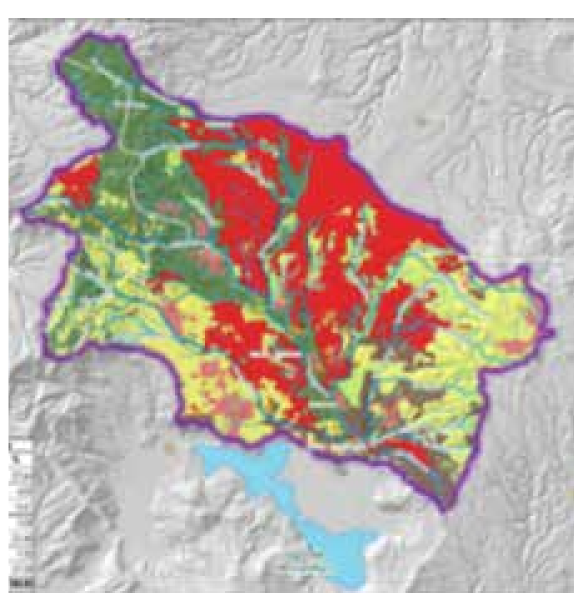
Figure 7. Comparison of 24- hour rain data for Tropical Storm Agatha (25-30 of May, 2010) versus Hurricane Stan (1-10 of October, 2005)



runoff in the Villalobos River sub-watershed, where a part of the MA has been settled. The analysis indicated that two groups of seasons were clearly established: those located in areas exposed to the urbanization process and those where the process is lesser. In addition, the annual and maximum series (of daily rainfall and maximum annual daily rise) show a significant positive uptick. To estimate the impact on surface runoff, the hydrogram was modeled for the most extreme event that occurred (Tropical Storm Agatha) for urbanization conditions in 1972 and 2012 (Figures 8 and 9).

Figure 8 and 9. Land use in the Villalobos River Sub-Watershed in 1972 (above) and 2012 (below)
The area in red is the urban part





Source: J. C. Fuentes, 2013.

The increase of urban areas in the last 40 years (approximately 22% of the total area of the Villalobos River-Late Amatitlán sub-watershed) has caused significant increases in the hydrogram components, peak water flow, and surface runoff primarily, only decreasing the concentration over time since the sub-watershed is in a continuous urbanization process. The results show that there is actually a considerable impact on the hydrological cycle (Figure 10).

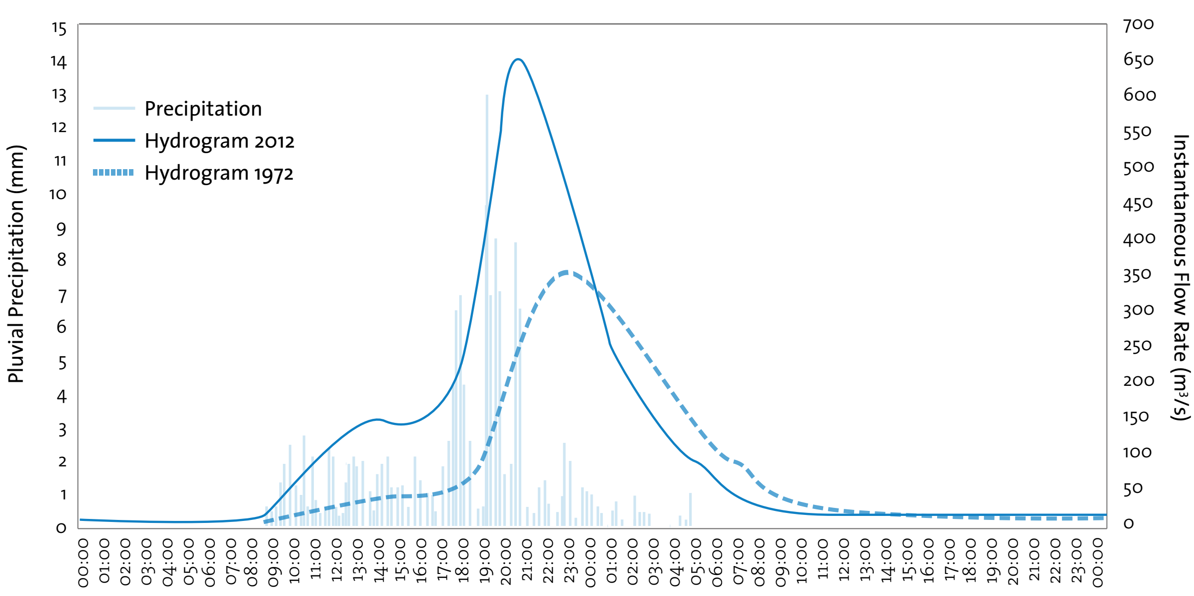
AMSA (2013) issued a contract for a bathymetry study for Lake Amatitlán and sediment carried by the Villalobos River. The study results indicated that between the last bathymetry in 2001 and the bathymetry in 2012, 14.5 x 106 m^3 of sediments were deposited. During that period, around 9% of the lake's total volume was lost (Figure 11). In addition, the sedimentation rate is doubled during extreme climate events, such as Agatha in 2010.

The URL-IARNA and TNC (2012a) reported that "forests provide the best conditions for water infiltration in the aquifer mantles and identify the areas that should be conserved and those that should be reforested to improve the water supply in the metropolitan area. The current forest coverage in the Metropolitan Area in Guatemala is 21,244 hectares and contributes to the infiltration of 214.5 million cubic meters of water per year into the subsoil. In addition, reforestation of 39,831 hectares was considered, which would infiltrate some 206.7 million additional cubic meters annually."

In the near future, due to climate change, "less rain is expected in the metropolitan area. If the current coverage (21,244 hectares) is conserved, in 2020, 195.6 million cubic meters will be infiltrated, which would represent 10% less than what is infiltrated today. If, in addition to conserving the forest, a total of 39,831 hectares is reforested, 206.7 million cubic meters would be infiltrated, which would represent a decrease of just 5%."

Thus, the urban areas are conditioned, first of all, on progress in the urban zone or densification. These changes are extremely rapid due to migration and development that are caused by how attractive urban centers are as sources of employment, study, and culture. In addition to this progress, the effects of climate variability with more intense, more frequent rainfall have to be taken into account. These all represent worrisome challenges for the municipal structure for managing urban water. Faced with progress in the urban area and climate variability, municipalities generally outdo themselves in providing services, especially when it comes to rainwater drainage, sanitary sewers, and providing potable water.

Figure 10. Hydrogram in the Villalobos River Sub-Watershed in 1972 and 2012



Source: J.C. Fuentes, 2013.

In that regard, there is a need to seek mechanisms that make operating public systems viable. One alternative is to internalize the impact of water on new developments in relation to municipal public services. Once the types of impact are defined, mitigation measures should be suggested that will decrease them. The municipalities can achieve this by regulating new developments to reduce their impact. If they are not willing to do so, they should pay for the infrastructure that is required to properly manage water.

Thus, the impact of water that any new development produces are the following:

- Impact due to lack of infiltration;
- Impact due to increase in demand;
- Impact on the sanitary system;
- Impact due to contaminated discharge;
- Impact due to run-off produced; and
- Impact due to intervention in riverbeds.

Figure 11. Volume of Sediment Deposited in Lake Amatitlán between 2001 and 2012

Source: AMSA, 2012.

The municipality of Guatemala has undertaken some measures such as harvesting rain water in reservoirs for schools and housing in the peri-urban areas as well as holding tanks, etc., with the participation of the beneficiaries.

7. Conclusions

Guatemala City and part of the rest of the Metropolitan Area (MA) are situated on the water divide for the Pacific and Atlantic watersheds. Therefore, the surface water is relatively scarce and, as a consequence, underground sources have had to be exploited. The MA is made up of 12 municipalities, 20 sub-watersheds and around 2 million inhabitants with an annual growth rate of 3.5% in an area of 1,461.15 km^2.

Urban growth in Guatemala City since it was created in 1776, but especially other municipalities in the MA in the last four decades, has caused a reduction in infiltration of water due to impermeabilization and overuse of the aquifer due to the growing demand, as well as contamination of the surface and groundwater sources due to the discharge of untreated wastewater.

The increase in urban areas in the last 40 years (approximately 22% of the total area of the Villalobos River sub-watershed) has caused significant increases in the hydrogram components, peak water flow, and surface runoff primarily, only decreasing the concentration over time and evidencing that there actually are considerable types of impact on the water cycle.

Recent study results indicate that between the previous bathymetry in 2001 and the bathymetry in 2012, 14.5 million cubic meters of sediments were deposited. During that period, around 9% of the lake's total volume was lost. In addition, the annual sedimentation rate is doubled during extreme climate events, such as Tropical Storm Agatha, which occurred in May 2010.

In the near future, due to climate change, less rain is expected in the metropolitan area. If the current coverage (21,244 hectares) is conserved, in 2020, 195.6 million cubic meters will be infiltrated, which would represent 10% less than what is infiltrated today. If, in addition to conserving the forest, a total of 39,831 hectares is reforested, 206.7 million cubic meters would be infiltrated, which would represent a decrease of just 5%.

8. Recommendations

The water supply in the MA requires a coordinated effort by the municipalities due to the fact that using groundwater so far is unsustainable if infiltration is not boosted naturally and artificially and the demand is improved (lower consumption), along with the supply (fewer leaks and illegal connections). The Municipality of Guatemala recently began projects to harvest rainwater and set up holding tanks.

The Metropolitan Area's Water Fund initiative is an attempt to have financial mechanisms to conserve forests and to provide an incentive for changing how the recharge areas are used. The purpose is to attain a sustainable balance between supply and demand now and in the future for the water supply in the Metropolitan Area. The initiative should be supported by both the public and private sectors.

Another line of coordinated action between the municipalities in the Metropolitan Area is to treat all wastewater. The multimillion dollar investment required should be shared by the generators. The contamination in Lake Amatitlán due to the discharge of untreated wastewater coming from the Villalobos River watershed is evidence of how serious the matter is.

Investigation into the causes and effects of urbanization in the Metropolitan Area and the measures to be taken should be promoted by research centers and universities since recent studies carried out by IARNA-URL, TNC, and AMSA, and the master's thesis in hydrology by Engineer Fuentes have been the first ones to evidence the effects of urbanization on the water resources in the Metropolitan Area.

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10. Acronyms

MA
Metropolitan Area

AMSA
The Authority for Sustainable Management of the Lake Amatitlán Watershed

EMPAGUA
Municipal Water Company of Guatemala

ENCOVI
National Housing Survey

FONCAGUA
Fund for Water Conservation in the Guatemala Metropolitan Region

IARNA Institute of Agriculture, Natural Resources, and the Environment

IGN
National Geographic Institute

INE
National Statistics Institute

MSPS
The Ministry of Public Health and Social Assistance

MDG
Millenium Development Goals

WHO
World Health Organization

PROVIAGUA
Program for Water Quality Oversight

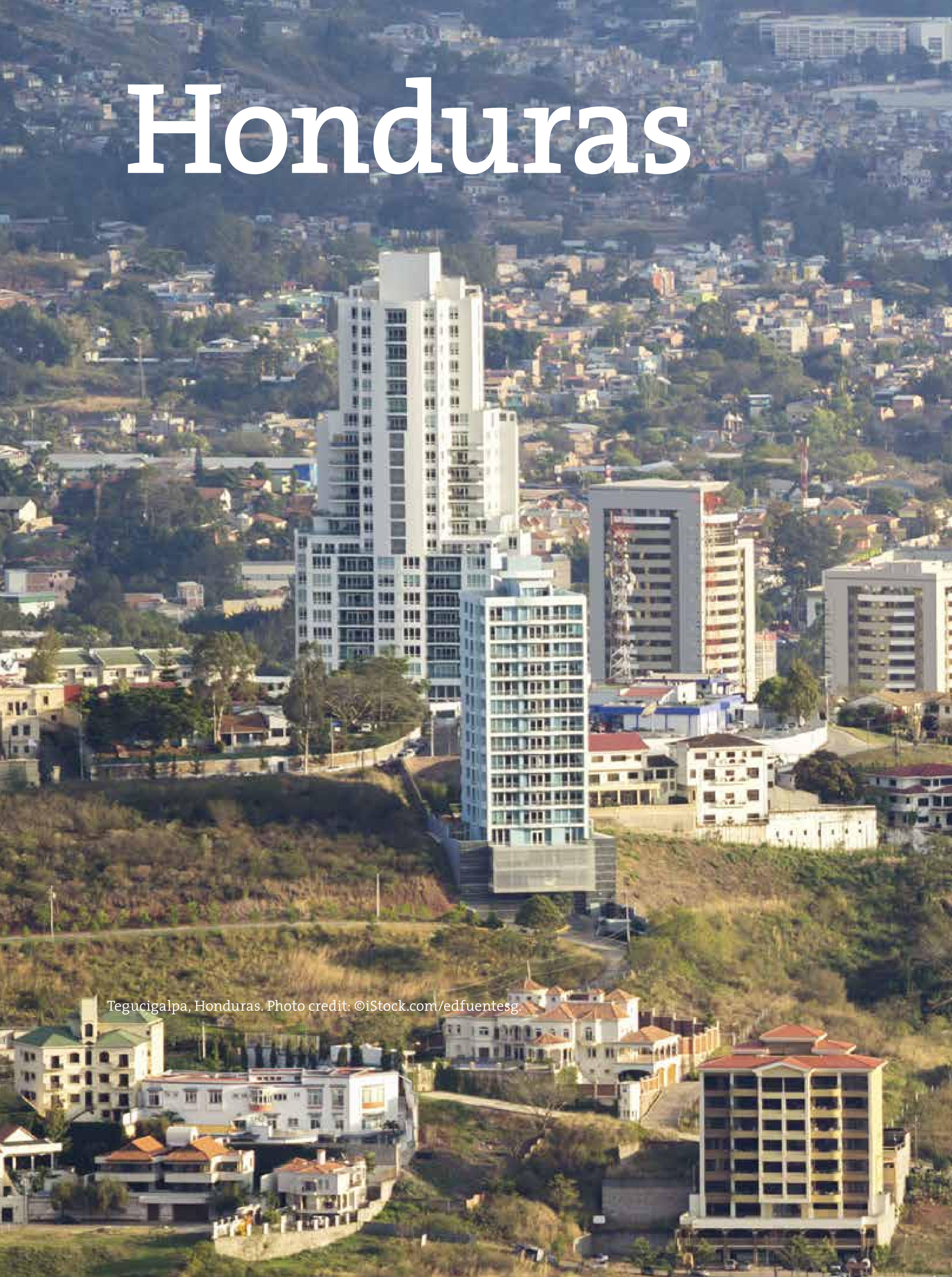
SEGEPLAN
General Planning Secretariat

SIGSA
Health Information Management System

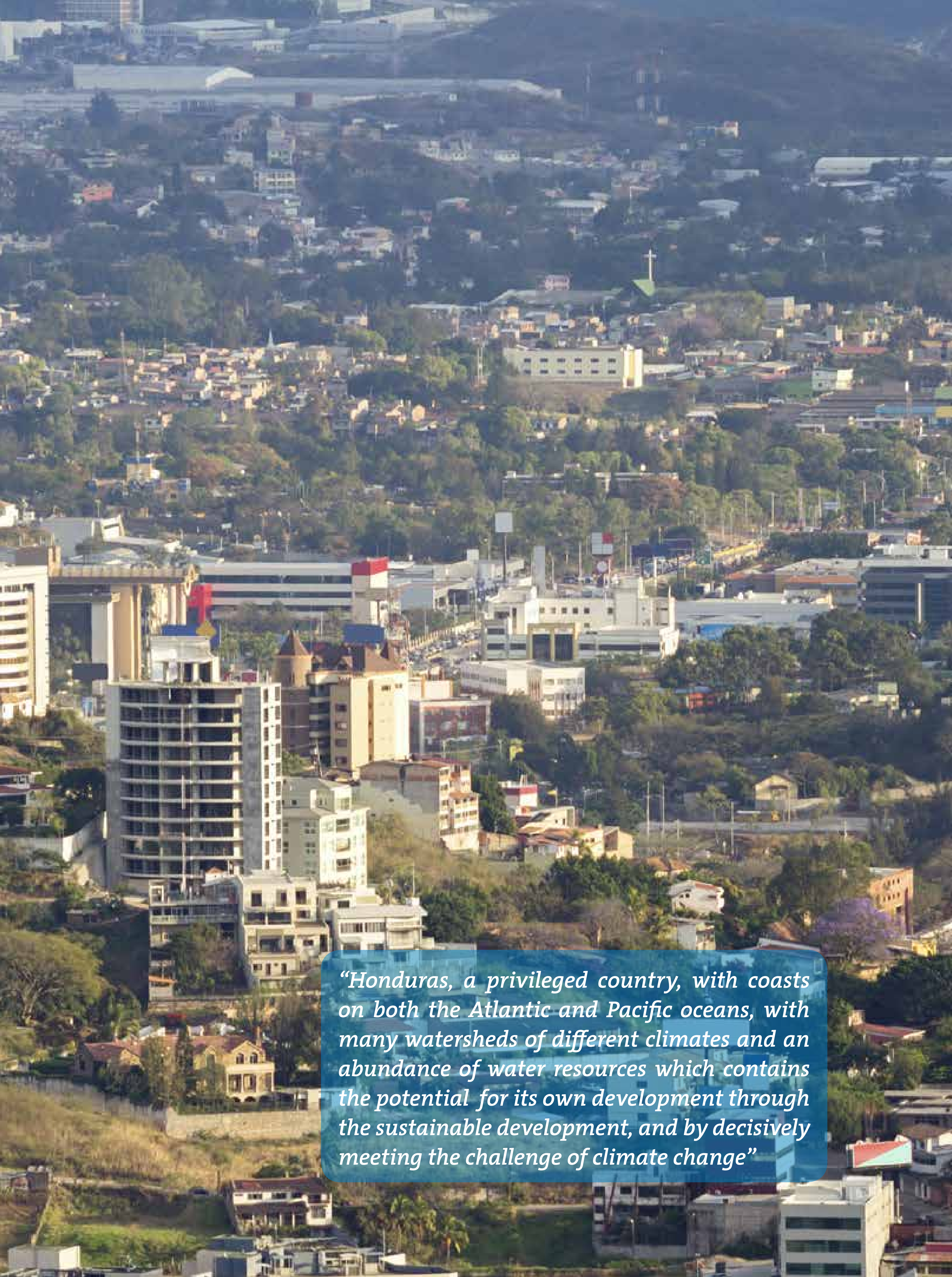
TNC
The Nature Conservancy

URL
Universidad Rafael Landívar

Honduras



Tegucigalpa, Honduras. Photo credit: ©iStock.com/edfuentesg.



"Honduras, a privileged country, with coasts on both the Atlantic and Pacific oceans, with many watersheds of different climates and an abundance of water resources which contains the potential for its own development through the sustainable development, and by decisively meeting the challenge of climate change"

Urban Water Management in Honduras. The Case of Tegucigalpa*

Marco Antonio Blair Chávez
Manuel Figueroa

Summary

Honduras is a privileged country with coastlines on the Atlantic and Pacific oceans, a varied climate ranging from tropical, hot and humid on the Atlantic coast to dry, temperate and tropical in the central-western area, and tropical savannah on the Pacific coast, with abundant, unevenly distributed water resources, since the Atlantic slope basin has a greater number of rivers, lakes and lagoons.

Despite this abundance of water resources, the country faces serious problems of water supply to the population, which has three salient characteristics: 1) a very young population (55% under 25 years); 2) the population in rural areas is greater, and 3) the female population is larger.

The problem of water supply in the capital of Honduras is replicated in other cities in the country, with the exception of the city of San Pedro Sula, where the drinking water supply has positive indicators of quality of service and quality of product, reflected in the good level of overall public health and individual health of the population in particular.

The influence of climate change is noticeable, which, added to man's actions through frequent forest fires and deforestation, has caused variability in natural resources such as modifications in rainfall patterns, extreme temperature changes, siltation of waterways by erodible material and frequent floods.

The government has taken action by defining strategies and policies for the rational use of resources, giving priority to water by declaring it a social good and an important factor in the alleviation of poverty.

*A Chapter developed thanks to the support of the Global Water Partnership GWP

1. Introduction

Honduras has a surface area of 112,492 km^2 and is hydrological divided into 22 watersheds that drain into two slopes: the Atlantic slope with 16 major watersheds and the Pacific slope with 6 river basins. It has a population of 8.5 million, with approximately 50% living in urban areas. Until 1950, the population of Honduras' major cities accounted for a mere 10% of the current population. Population growth has led to rapid, disorganized urbanization, especially in Tegucigalpa, where it has had substantial impacts on water availability for human use.

Although water resources are abundant, water infrastructure is extremely limited, since the implementation of new works for incorporating more water supply sources has failed to keep pace with population growth, resulting in a severe water shortage during the dry season, causing strict rationing of the water service system, whereas during the rainy season, the city is affected by frequent floods and landslides. Moreover, deforestation and uncontrolled urban encroachment in watersheds near the metropolitan area threaten the quality of surface and groundwater, which is compounded by the lack of treatment for most of the wastewater in the capital. This is also associated with weaknesses in water governance related to the lack of enforcement of the legislation related to the issue, especially as regards institutional reforms.

The water supply problem is particularly acute in the outlying neighborhoods around the Central District, located in unstable, rugged terrain without access to the conventional piping system for water supply. This issue negatively impacts the quality of life of disadvantaged populations, reflected in diseases, economic and social costs and environmental degradation.

Despite significant advances in the Water and Sanitation Sector, current water management practices for the main urban area of Honduras have proved unable to solve existing problems. The country is currently striving to enforce the Framework Law on the Drinking Water and Sanitation Sector, enacted in 2003, which provides for the decentralization of services to the national firm SANAA and the General Water Law, which envisages the creation of a National Water Authority.

This paper presents a diagnosis of the state of water resources in urban areas, focusing on the metropolitan area of the Central District. Its contents are divided into five chapters addressing urbanization, the state of drinking water service, water treatment, impact on human health and climate variability and change. The information contained in each of the chapters was gathered through the analysis and consultation of various national and regional studies as well as data provided by the relevant government institutions.

The preparation of this document was made possible by the collaboration between the Academy of Sciences in Honduras and GWP Central America, in an effort to contribute to generating useful information for determining the status of urban water management, and making decisions on the actions required for its use and sustainable management.

2. Water Sources in Urban Areas and the Impacts of Urbanization

This chapter contains a diagnostic summary of Tegucigalpa, the capital of Honduras, on the various water sources as well as information on the quality and quantity of the water used in the urban area corresponding to the Metropolitan District. It also studies problems that arise when population distribution does not correspond to the availability of water sources and critical problems in specific zones, such as informal settlements and periurban areas.

The physical characteristics of the Central District where Tegucigalpa is located are shown in the Table 1 (INE, May 2013; Wikipedia, May 2013).

On the basis of the description by the Administrative Division, the Central District Metropolitan Area is a conurbation (INE, 2001), since it meets the characteristics of this definition: "Region comprising cities, large towns, urban villages, which, through population growth and spatial expansion, may be integrated into a single system."

2.1 Drinking Water Service in the Municipality of Distrito Central

Tegucigalpa and Comayagüela, like most Latin American capitals, have a rapidly growing population in their metropolitan area, which requires an increase in basic service coverage, including water and sanitation services.

According to the Population and Housing Census 2001 and the Permanent Multiple Purpose Household Survey (EPHPM) 2013, both conducted by the National Statistics Institute (INE), until 2013, the population of the urban area of the city capital was 1.11 million, corresponding to 13% of the national population, estimated at 8.5 million, characterized by being a young population, since 55% are under the age of 25, as shown in the accompanying figure.

According to records from the National Autonomous Service of Aqueducts and Sewers (SANAA, 2014) in the urban area of the Central District, the institution provides water service to 120,204 users, representing almost 50% of the urban population, distributed among 424 districts and neighborhoods. SANAA rations service, with constant interruptions due to network failures and pressure constraints, which must be controlled by special operating tasks. This is also linked to restrictions on water availability.

A large section of the population, mainly in the periurban areas, equivalent to approximately 38% of households, self-supplies water by purchasing it from tanker trucks that sell it in barrels, equivalent to 42 gallons.

Figure 1. Population by Age Ranges and Sex

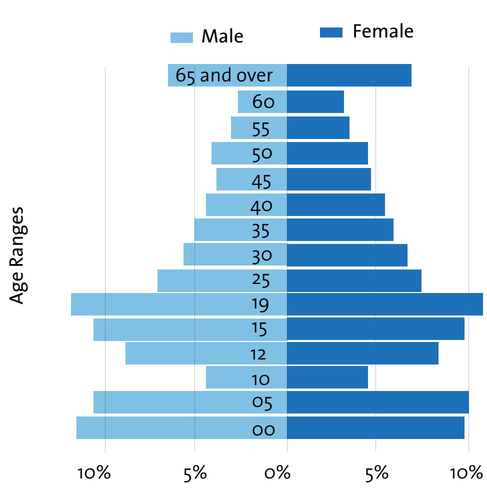


Table 1. Municipality of Distrito Central

1. Administrative division	2 Cities: Tegucigalpa y Comayagüela 44 Villages 291 Hamlets
2. Territorial size	1.514.6 km²
3. Urban area	150 km²
4. Mean altitude	1,100 masl
5. Population	Urban: 1,101,900 Rural 100,900
6. Housing	Urban: 249,945 Rural: 22,422

Source: Prepared by the authors, based on INE, May 2013 and Wikipedia, the free encyclopedia, May 2013.

Given the current population, current water demand (2014) for the Central District is 3.66 m^3/s. This means a theoretical water deficit of 0.37 m^3/s in winter time and of 1.92 m^3/s in the summer. However, considering unaccounted water, estimated at 45%, the actual deficit is 1.58 m^3/s and 2.54 m^3/s for the two seasons respectively (SANAA, 1986).

Figure 2.2 shows the projected water demand until 2040, which will require the incorporation of new sources to provide over 600,000 m^3/d.

2.2 Type of Supply Sources

The water supply system in the capital city comprises surface and groundwater sources, with surface water accounting for 96% of the total. The systems are therefore gravity-based.

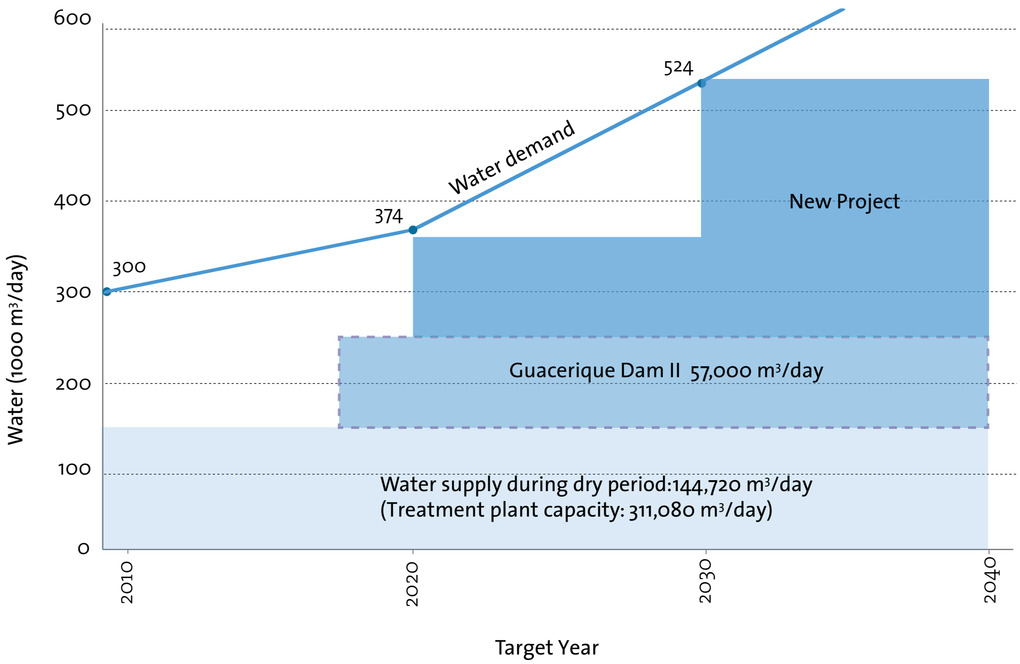
Existing water supply sources constituting the supply of water by SANAA are shown in the following table (SANAA, 2014 and 1986).

2.3 Impact of Urbanization

Urban development is one of the main factors affecting water quantity and quality. Some of the impacts of urbanization include erosion and sedimentation, urban runoff, contaminant refuse, and sewage spills, which have a direct impact on water quality.

The main problem of the capital is that it went from being a small town to a large city, with a consequent increase in population due to urbanization

Figure 2. Water demand for the Municipality of Distrito Central



Source: SANAA/KOICA, Tegucigalpa, 2012. Estudio de Factibilidad para la Construcción de Presa Guacerique II.

and industrialization. Water in the outskirts of the city has been affected by the development of industrial and commercial activities, so that nearby available water resources are reduced or degraded due, inter alia, to deforestation, forest fires and wastewater discharges.

Deforestation is caused by logging, which is largely illegal. It is practiced for the commercial exploitation of timber, firewood use or for converting forests to farmland, affecting vast amounts of forest with a deforestation rate of 62 thousand hectares/year (Suazo Bulnes, July 2010), and in the specific case of the Central District Municipality, it is carried out prior to the construction of new urban areas. Forest fires, most of which are thought to be intentional, average between 400 and 650 a year (*La Tribuna*, 2014) across the country, and of these, at least 50 fires occur in the Central District Municipality *(El Heraldo*, 2014).

As a result, the capital's water supply basins are being degraded, causing an increase in the cost of developing new water supplies, since the sources available for exploitation are increasingly distant, and require more treatment for their purification due to poor water quality.

2.4 Pollution of Water Sources

The open discharge or improper disposal of urban and industrial wastewater and the lack of treatment thereof, contributes to the deterioration of water quality in potential drinking water sources. This is the case of the Central District Municipality, where the wastewater load is approximately 260,000 m³/d, of which only 22.7% is treated, equivalent to 59,000 m³/d. The remaining wastewater is freely discharged into the Choluteca River through its various tributaries: rivers, streams and winter creeks that cross the city. The problem becomes more severe because of the constant expansion of the urban area due to continued urbanization, the opening of large malls and new industrial zones, which discharge into the existing sewerage network, which has yet to be expanded. Once its capacity is exceeded, the system necessarily discharges its surplus into the environment at the lowest, most fragile points.

Waterproofing urbanized areas by paving streets and parking lots in addition to roof areas considerably modifies urban hydrology, causing runoff volumes with higher peaks that cause waterlogging in the streets and frequent floods.

Table 2. SANAA Water sources for the Capital

Source	Production (m^3/d)	
	Winter	Summer
1. Surface sources	**286,244**	**151,340**
1.1 San Juancito-El Picacho	78,624	30,240
1.2 Concepción Reservoir	129,600	95,040
1.3 Los Laureles Reservoir	64,800	21,600
1.4 Tatumbla-Sabacuante-Miraflores	6,480	2,160
1.5 El Lindero	6,740	2,300
2. Underground sources	**12,960**	**8,986**
2.1 Various wells	12,960	8,986
Total	**299,204**	**160,326**

Source: Prepared by the authors based on SANAA, Department of the Metropolitan District, May 2014.

This instant runoff with short periods of concentration constitutes one of main sources of nonpoint pollution, since it carries polluting matter into riverbeds. The improper, illegal practice of connecting sewage systems to rainwater systems means that the systems are overloaded in the rainy season, causing sewage overflows into the streets. This wastewater is carried along with garbage and other surface contaminants, creating a highly polluted mix that damages natural receiving bodies comprising rivers, streams and winter riverbeds located within the urban area.

Street cleaning, where inlets are used as rubbish deposits is another of the specific problems exacerbating the problem of pollution, since the waste deposited in inlets produces obstructions, pushing out the trash that has been dragged along, together with soil and granular material. Due to the irregular geomorphology of the capital, floods occur in the lower parts of the city with highly polluted water. This bad practice leads to public health problems associated with environmental pollution, as well as reducing opportunities for recreation and domestic and international tourism.

2.5 Supply System Features

In addition to the National Autonomous Aqueduct and Sewer Service (SANAA), water supply service in the Central District Municipality is provided through Water Management Boards and tanker trucks.

The SANAA Metropolitan Division is responsible for the metropolitan aqueduct as well as the sewerage system. Within the Central District Municipality, there are 245 Administrative Boards registered to operate legally, and it is estimated that there are approximately 50 unregistered Boards. As for water trucks, SANAA has units that provide water service at affordable prices to users who, for whatever reason, have a shortage of water, whether temporarily or systemically. There are approximately 60 private tank trucks engaged in the sale of water purchased at SANAA's facilities for this purpose, while a similar number obtain their water from other private providers. These tanker trucks meet water demand in developing neighborhoods, particularly those which lack a SANAA supply network.

SANAA has three water treatment plants, meaning that the water distributed is of good quality and suitable for domestic use. Due to the characteristics of the water, the unitary processes in the three plants include coagulation, flocculation, sedimentation, filtration and chlorination for final disinfection, which makes it suitable for human consumption.

It is worth mentioning the case of the El Picacho system, which consists of 24 mountain intakes, originally with good quality water. However, population growth in the vicinity of the intakes has created pressure on land where agricultural, livestock and poultry operations have expanded, leading to the degradation of watersheds and affecting water quality. Thus, the old water treatment plant, which consisted of a chlorination system, was replaced by a conventional rapid filtration treatment plant.

In order meet the water demand of the population of the Central District Municipality, in 1980 SANAA established the Master Water Plan for Tegucigalpa with a 2020 horizon (SANAA, Nov. 1980a), which envisages the construction of four new dams. However, the Master Plan has not been implemented according to schedule. Only one reservoir has been built, which was incorporated into the system in 1992, and since then, the water supply has not increased. The existing system is therefore subject to constant rationing to meet demand partially, with supplies by area and set times.

2.6 Available Water Sources

The sub-basins near Tegucigalpa have a combined production capacity of 225.4 million m^3/year. The largest and those with the highest capacity are the sub-basins of Río del Hombre and Guacerique, located to the west and southwest of the Central District, accounting for 77.2% of the city's water supply.

The following table provides a summary of SANAA's water supply from the main sources it currently exploits.

Water produced in the sub-basins is stored in four major subsystems, equipped with: two reservoirs with storage capacity of 48 million cubic meters of water called Los Laureles and Concepción, the El Picacho subsystem, which captures 24 surface sources within the La Tigra National Park on the San Juancito mountain and the Miraflores aqueduct, comprising the sources of the Sabacuante and Tatumbla rivers.

The total water supply of the Central District basin system located south-east and west of the capital is estimated at 7.14 m^3/s, of which SANAA currently operates approximately 3.31 m^3/s during the rainy season and 1.74 m^3/s in the dry season.

2.7 Protection of Water Sources

SANAA has a Watershed Department, responsible for watershed management. Actions include monitoring pollutant discharges into headwaters to permit the rapid intervention of the competent authority to solve the problems; prevention and fighting fires and illegal logging within the basin, particularly in the reserve areas. The point is also to control the spread of urbanization, which should not even reach the basin's buffer zones.

SANAA's Master Plan for Tegucigalpa also established the corresponding Master Sewer Plan for Tegucigalpa, which includes the development and expansion of the collection system and 100% wastewater treatment in order to minimize pollution of water sources by direct discharges of raw sewage into rivers, streams and natural winter waterways.

3. Drinking Water Service in the Distrito Central Urban Zone

The Central District, where the capital of Honduras is located, has a complex geomorphology with extremely irregular topography and steep natural slopes, as shown in the figure comprising the isometric view and profile of the central area of Tegucigalpa.

As shown in the profile, the city has variations in altitudes from 910 masl in the center of the city to 1,300 masl at Cerro Picacho, located 1.7 km northeast of the city.

This situation requires finding solutions adapted to the context of the city, and in the particular case of the drinking water system, its infrastructure has been designed to adapt to this extreme variation in altitudes. Thus, the Metropolitan District water distribution system comprises eight networks: seven being pressure networks and one a network outside them. Each network, designed to withstand pressures of up to 40 mca, is described below:

Evaluation of the service, administration and regulation that determines the water supply and availability of water for the capital of Honduras, which has a higher average density of population with a high demand for water, is undertaken in the following sections.

Table 3. Water supply of the main water sources near the Distrito Central

Name of the Watershed	Area	Production (LPS)
(Km²)	Production	2.66
(LPS)	140.0	0.99
Sabacuante	80.0	0.27
Tatumbla	64.0	0.35
Río del Hombre	343.0	2.85
Totals	837.0	7.14

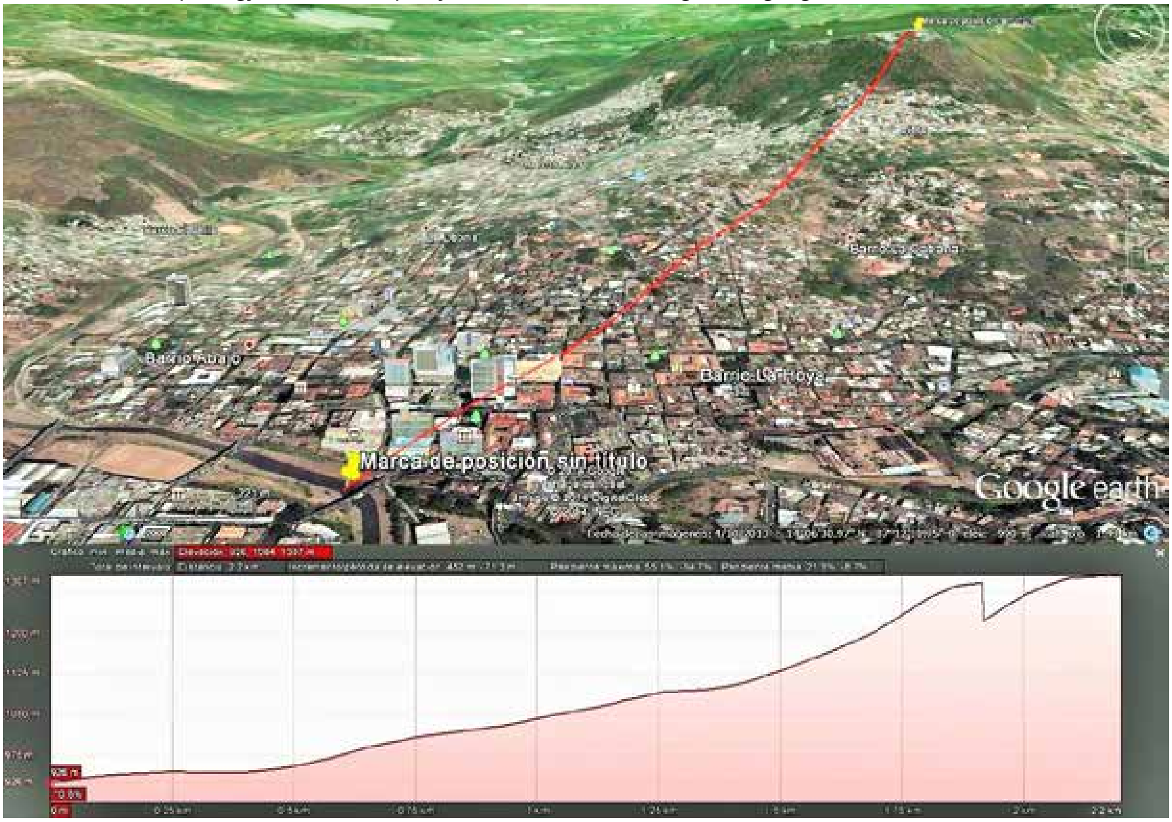
Source: Prepared by the authors based on the Funding Request for the Expansion and Improvement of the Tegucigalpa Water System, Tegucigalpa Master Plan, 1986.

Table 4. Water network distribution in the Distrito Central

Pressure Network	Pressure Range (Masl)	
1. Low Network	910	950
2. Intermediate Network	950	990
3. High Network	990	1030
4. Upper Network I	1030	1070
5. Upper Network II	1070	1110
6. Upper Network III	1110	1150
7. Upper Network IV	1150	1190
8. Network Outside Upper Network IV	1190	and above

Source: Prepared by the authors based on the Funding Request for the Expansion and Improvement of the Tegucigalpa Water System, Tegucigalpa Master Plan, 1986.

Figure 3. Geomorphology of the Municipality of Distrito Central (image from google earth)



3.1 Systems Administration

Administration of water supply systems for the population in the Metropolitan District urban area poses a number of problems due to its unequal population density, sharp socioeconomic contrasts, and developing neighborhoods with a high density population with a corresponding high water demand.

The National Autonomous Aqueducts and Sewer Service (SANAA) is the official decentralized institution of the Central Government, established by Legislative Decree No. 91 on April 26, 1961, to construct and administer potable water and sewage services throughout Honduras (National Congress of Honduras, 1961).

The population growth and urban expansion of the Central District Metropolitan Area has caused a serious problem, since water project development has failed to keep pace with urban expansion or population growth. Therefore, in the 1980s and 1990s, these services began to be delivered through Water Administration Boards (JAA) as a means of meeting the demand for water services and sanitation of the city's newly urbanized areas.

Since SANAA found a good ally in the communities, especially in the Developing Neighborhoods, through these JAA, it supported the community participation model by providing technical and administrative assistance. These JAA succeeded the Neighborhood and District Board of Trustees in the management of such services, having created an institutional structure governed by Water Boards Regulations promoted by SANAA (ERSAPS, July 2006).

Water demand is so high and supply so low that there has been a proliferation of Water Boards and water trucks selling water. However, many Water Administration Boards have a proper institutional structure, together with support from national and international NGOs to develop their own supply sources, which are mostly groundwater through boreholes, a supply network and storage tanks.

In the Central District Metropolitan Area, SANAA remains the institution responsible for water and sanitation service management, involving a total of 183 water boards, operating mostly in Developing Neighborhoods. In remote, in accessible zones and periurban areas, water trucks owned by SANAA and the Central District Municipal Town Hall (CDMA) provide water for residents, while approximately 150 private water trucks sell water indiscriminately to any neighborhoods, districts or dwellings that so request.

3.1.1 Modernization of the sector

Legislative Decree No. 118-2003 created the Framework Law for the Drinking Water Sector and its Regulations (National Congress of Honduras, January 2004) to promote the provision of water and sanitation services under the principles of quality, equity, solidarity, sustainability, generality, environmental respect and citizen participation. The overall objective of the Framework Law is to establish "the rules applicable to the drinking water and sanitation in the country as a basic instrument for promoting the quality of life among the population and strengthening sustainable development as a generational legacy."

The Framework Law establishes the National Water and Sanitation Council (CONASA) as the official representative of the Government of Honduras with regard to drinking water and sanitation both nationally and internationally, and sets the policies, strategies and plans for the sector. It also creates the Drinking Water and Sanitation Service Regulator (ERSAPS) as a decentralized institution with functional technical and administrative independence, responsible for the regulation and control of potable water and sanitation provision within the country.

Within CONASA, it hierarchizes responsibility for water and sanitation system management, recognizing the Municipal Authority as the leading authority, followed by the Water Administration Boards.

The Framework Law and the Municipal Law provide that the Municipal Authority may administer services directly, or through a Drinking Water and Sanitation Service Provider (EPS-APS), a decentralized municipal entity. Both cases involve Municipalization of Services. It may also delegate administration to a private firm through Service Concession. In the latter type of administration, assets and infrastructure remain the property of the Municipality. Lastly, there is the Administrative Board, which may assume responsibility for the administration directly as a municipal agency or as a decentralized unit of the municipality.

The Framework Law does not in any way permit or contemplate the provision of drinking water and sanitation services within the concept of "privatization".

As part of the implementation of the Framework Law, a maximum of five years was proposed from the time of the implementation of the law, so that SANAA would transfer all the systems under its administration to municipal governments, with the commitment to support them in their technical and administrative organization under the management model chosen by the municipality in question. To date, 27% of the systems have yet to be transferred and are therefore still managed by that organization. The remainder are administered by municipalities, decentralized units of the municipality and municipal companies.

The Framework Law therefore regulates the strengthening of the planning and governance of the water and sanitation sector, given the existence of a large number of national and foreign institutions involved in the development of projects with local or external funding.

In 2009, the General Water Act was passed, which regards the basin as a water management unit and provides for the establishment of River Basin Councils as regional bodies tasked with the coordination of actions between public and private stakeholders who live in and administer a basin. These organizations are tasked with proposing and implementing programs and activities to improve water management, water infrastructure, and the protection, conservation and preservation of water resources in the basin.

3.1.2 Regulation of institutions

The Framework Law establishes the need to readjust the legal and institutional framework for the water and sanitation sector in order to improve service planning, regulation, control and delivery as part of the state's decentralization policy. It also forms part of the modernization of its institutions, assigning a key role to municipal governments and the need for the broad participation of social sectors, which involves establishing mechanisms to promote joint participation by the municipal authorities and citizens (ERSAPS, May 2013). This vision is achieved through the creation of the Municipal Water and Sanitation Commission (COMAS) with jurisdiction throughout the municipality.

The Framework Law also clearly states that for the performance of its control functions, ERSAPS must have the support of regional and municipal bodies and citizen participation in a clear acknowledgement of the role that the law grants municipal governments in the provision of water and sanitation services, and of the limitations that a centralized body may have regarding the delivery of fully decentralized services. ERSAPS has therefore adopted a decentralized control model, yet one that is oriented and directed from the central level, resulting in regulatory instruments with sufficient latitude for municipalities to adopt and adapt the models commonly used in the country to the specific conditions of each (ERSAPS, September 2009). This vision is achieved through the creation of Local Supervision and Control Unit (LSCU) with jurisdiction over the entire municipality.

a. COMAS, comprising city councilors and representatives of users, is a body that ensures genuine participation by the Municipal Government and sectors of society in the dissemination and ongoing dialogue regarding the contents of the sectorial analyses, municipal water and sanitation policies, investment programs and other issues of national importance that must be based on the local analysis of each community. COMAS also serves as a coordination mechanism between municipal authorities and citizens, to provide advice to the municipal corporation and assist citizens in decision-making through the socialization of decisions.
b. The LSCU has a directory of honorable citizens from the municipality, who provide their services pro bono. These people can contribute their knowledge and experience in key areas that must be reviewed to ensure compliance with aspects concerning health, legal and client care. Directors do not receive fees, but they may incur costs for travel expenses and accommodation at events involving training and the exchange of experiences. Since the LSCU board consists entirely of citizens, it must have close links with the Municipal Commissioner, who is assigned similar general functions in the municipality.

c. The interrelationship between COMAS and LSCU states that COMAS is a body that serves the Municipal Government in an advisory capacity in regard to issues related to the policies, planning and coordination of activities related to the water and sanitation sector. It is tasked with compiling the register of governmental and non-governmental organizations that operate within the municipal sphere. Meanwhile, LSCU must maintain a close, continuing relationship with COMAS, since it is the body through which reports on the sectorial situation are submitted to the Municipal Corporation. This makes it an official, updated, permanent source of knowledge of the state of service delivery, the identification of problems that require preventive or corrective actions by the service provider, which COMAS must consider in the sectorial planning proposals it submits to the Municipal Corporation.

   Thus, the LSCU must identify situations where deviations occurring in a municipal provider's performance of functions warrant intervention to ensure that they are undertaken in accordance with the Framework Law, regulations, bylaws and statutes established in the legal status of the provider.

3.2 Service Coverage

Drinking water access is a crucial part of attempts to decrease the frequency and risk of diseases associated with fecal contamination. It also provides information on human development when associated with other indicators, particularly those of a socioeconomic nature. Its spatial analysis reveals the degree of equity of access to the service within a given territory.

Access to water in general and drinking water in particular has quite dramatic aspects in the Central District Metropolitan Area, with a distinction needing to be established between easy access and no access to water. Easy access to water means that a person has to walk a daily maximum distance of 200 m to fetch a basic amount of water, estimated at one barrel, equivalent to 40 gallons or 125 liters, regardless of whether it is potable; whereas in the case of no access to water, water may be available at larger or smaller distances, but the person does not have access to it for a variety of reasons.

Due to the varied biophysical, socio-economic and socio-cultural conditions, water service coverage scenarios in the Central District Metropolitan Area include the following systems.

3.2.1 Conventional systems

Conventional systems generally focus on domestic connections, through which the water supply to each house or apartment is allowed through an individual connection to the municipal network administered by SANAA. This type of access provides direct drinking water service for a person in the comfort of his own home. In other words, he will have sufficient quantity and quality of water for human consumption and for performing daily activities such as bathing and washing food and personal items.

3.2.2 Non conventional systems

Non-conventional systems include conditions of easy access to water, which occur in the following situations:

a. Tanker Trucks. SANAA provides water supply service to developing neighborhoods, which have a storage tank and network. Tanks are filled by the Water Board, and water is subsequently supplied by gravity to the dwellings connected to the network. It also supplies water to the homes of very poor people who have some type of container or basin where they can store at least a small amount of water.
b. Public key banks. Public key banks still exist in certain developing neighborhoods, providing service with water from the municipal network administered by SANAA, indicating that it is good water.

   Public key banks operate as collection centers, where there is a person who keeps the access key to the taps, opening at times agreed on by the community of residents.

   At times of crisis, the Fire Department, government trucks and CDMA provide support in distributing water to the poorest sector of the population. Since the water they supply is taken from the SANAA municipal network, the water supplied is considered to be of good quality.

In the case of the Central District Municipality, the systems are currently being transferred from SANAA to CDMA. This has been a slow process, due to the complexity of the systems, both administrative and operational, and the fact that the Administrative Division of Metropolitan Area comprises two major cities with their own characteristics. This includes the establishment of the administrative model, which has yet to be defined, the creation of COMAS and LSCU.

c. Free water sales. A fleet of trucks fitted out with makeshift tanks belonging to people who sell water, supplying water to all kinds of housing located in any neighborhood or district, although most clients are residents of developing neighborhoods on the periphery of the city, where there is no water supply network.

   Water is sold to slum inhabitants using the barrel as a unit of measure, while dwellings from a higher social stratum are sold the entire contents of the tank.

   The average cost of a barrel is US$ 2.14, while the average cost of a 400-600 gallon tank is US$ 35.71.

d. Lastly, there is a totally destitute sector of population, which has no form of access to water and so goes to rivers or streams, where it uses the water, regardless of the quality. In some cases, these people take advantage of the rains to collect rainwater in containers, which serves as a palliative during the rainy season.

The following table summarizes the water supply situation in terms of access to water by the population.

According to the table above, crossing information from INE and SANAA, both official information sources, showed that drinking water coverage totaled 53.2% of all the households registered on the basis of EPHPM in May 2013.

SANAA records state that the Metropolitan Area has 120,204 subscribers, in other words, households with individual household connections.

An analysis of the information from both institutions shows that the coverage reported by SANAA refers, in percentage terms, to the users within its service area. In other words, of the total number of subscribers, 80.9% have direct connections in their homes, while 19.1% are served by non-conventional systems. In fact, the issue of coverage has different interpretations, but a more accurate picture is provided when both INE census figures and SANAA records are taken into account.

On the other hand, nationwide coverage is more optimistic, since the city of San Pedro Sula, together with the city of Puerto Cortés, has high coverage rates that increase average figures to approximately 80%

3.3 Coverage Expenses

The per capita cost incurred by service delivery according to the degree of coverage does not establish a differential ratio depending on the economic level of the client. It only considers four categories based on water use and consumption, based on the simple rule, "Whoever uses more should pay more."

Consumption categories are as follows:

1. Domestic
2. Commercial
3. Industrial
4. Government
5. Boards of Trustees and Water Boards

The domestic category includes four segments based on residential level, as shown below:

a. Segment 1, which applies to the population of developing neighborhoods; the cost of the basic water quota for 20 m³ is the lowest and residents are exempted from paying the fixed cost for connection.

b. Segment 2 applies to the lower intermediate population; the cost of the basic water quota for 20 m³ is 106.2% higher than the cost for Segment 1, while the fixed cost per connection is US $ 1.19 per month.

c. Segment 3 applies to the upper intermediate population; the cost of the basic water quota for 20 m³ is 178% higher than the cost of Segment 1, while payment for the fixed cost per connection is US $ 3.33 per month.
d. Segment 4 applies to the population in the higher social sector; the cost of the basic water quota for 20 m³ is 345% higher than the cost for Segment 1, while the fixed cost per connection is US$ 7.14 per month.

Although the cost of producing good quality water does not differentiate or discriminate according to whether the centralized supply is intended for the upper class, middle class or the poor, for use in public sources or by traveling salesman that transport water in tanker trucks for sale even to the privileged class who suffer the same inconvenience of rationing and lack of water, this differentiation is considered in the tariff structure, as one can see in the SANAA Current Rates approved for 2010, shown in the following table.

Analyzing the examples of payment for one month's service included by SANAA in the rates table, and replicating this calculation for each segment, considering only the use of the basic amount of water, shows that the following amounts would be payable:

a. Segment 1 L. 41.25 (US$ 1.96)
b. Segment 2 L. 108.50 (US$ 5.16)
c. Segment 3 L. 182.00 (US$ 8.67)
d. Segment 4 L. 328.50 (US$ 15.65)

The Table 7 includes a summary of SANAA's commercial invoice, with the items comprising the commercial invoice for each of the four categories of use served by this institution. The Board of Trustees and Water Boards Categories are not included.

Taking into account the number of users by category, the cost of production per category ranges from US $14.57 for a domestic user to $1055.52 for a government user.

A comparison of the previous unit cost of US $14.57.98, with estimated costs for the consumption of the same amount of water in the four segments of domestic category shows that only clients in Segment 4 cover the cost of service of the commercial invoice. Rates are lower for the remaining clients, resulting in a deficit in the commercial invoice (SANAA, 2013).

Evaluating the cost for commercial, industrial and government categories, based on consumption of 20 m³, is that the values that should be paid are US$15.49, US$29.77 and US$25.05, respectively. A comparison of the latter values with those calculated in the table above reveals a disproportionate subsidy for consumers in these three categories.

Table 5. Access to Water in the Municipality of Distrito Central

Description of Provider	Subscribers		
	Partial	Amount	%
SANAA Municipal Service		120,204	
Direct connections (80.9 %)	97,263		38.9
Direct connections (19.1 %)	22,941		9.2
Tanker Trucks		7,687	3.1
Public key banks.		744	0.3
Other means		4,215	1.7
Total dwellings with access		132,850	53.2
Total dwellings in urban areas		249,946	

Source: Calculations based on SANAA, Sales Department, June 2014.

Table 6. Cost of Water Supply in the Municipality of Distrito Central

National Autonomous Service of Aqueducts and Sewers SANAA, Commercial Department, Approved rate, December 2007

Domestic Category Range	Range of m^3 / month	Minimum water consumption per segment Lps / month	2003 Rates Lps m^3 / month	2010 Rates Lps m^3 / month	Variation	Fixed cost per connection	Sample calculations Domestic Category per Segment
Segment 1	0-20	31.80	0.85	1.59	0.74	Exempt	**For a consumption of 20m^3 Segment 1** Range of (0-20) Lps. 1.59 per m^3 Potable water 20m^3 = L 1.59=L 31.80 Sewerage L 31.80 x 25% = L 7.95 Meter maintenance = L 1.50 Fixed cost per connection (exempt) L 0.00 **Total amount due 41.25 L**
	21-30		1.70	3.17	1.47		
	31-40		5.20	5.23	0.03		
	41-50		6.80	9.10	2.30		
	51-55		8.50	12.92	4.42		
	56 and over		12.90	16.11	3.21		
Segment 2	0-20	65.60	0.85	3.28	2.43	25.00	**For consumption of 25m^3 Segment 2** Range of (21-30) Lps. 4.05 per m^3 Potable water 25m^3 x L 4.05 = L 101.25 Sewerage L 101.25 x 25% = L 25.31 Meter maintenance = L 1.50 Fixed cost per connection L 25.00 **Total amount due L 153.06**
	21-30		1.70	4.05	2.35		
	31-40		5.20	6.18	0.98		
	41-50		6.80	10.54	3.74		
	51-55		8.50	13.12	4.62		
	56 and over		12.90	16.79	3.89		
Segment 3	0-20	88.40	0.85	4.42	3.57	70.00	**For consumption of 35m^3 Segment 3** Range of (31-40) Lps. 7.37 per m^3 Potable water 35m^3 x L 7.37 = L 257.95 Sewerage L 257.95 x 25% = L 64.49 Meter maintenance = L 1.50 Fixed cost per connection L 70.00 **Total amount due L 393.94**
	21-30		1.70	5.23	3.53		
	31-40		5.20	7.37	2.17		
	41-50		6.80	11.40	4.60		
	51-55		8.50	14.42	5.92		
	56 and over		12.90	18.24	5.34		
Segment 4	0-20	141.60	0.85	7.08	6.23	150.00	**For consumption of 50m^3 Segment 4** Range of (41-50) Lps. 13.58 per m^3 Potable water 50m^3 x L 13.58 = L 679.00 Sewerage L 679.00 x 25% = L 169.75 Meter maintenance = L 1.50 Fixed cost per connection L 150.00 **Total amount due L 1,000.25**
	21-30		1.70	8.90	7.20		
	31-40		5.20	10.93	5.73		
	41-50		6.80	13.58	6.78		
	51-55		8.50	16.86	8.36		
	56 and over		12.90	19.42	6.52		
Commercial category	0-20	119.00	5.50	5.95	0.45	175.00	
	21-30		6.00	7.96	1.96		
	31-40		8.00	12.17	4.17		
	41-50		9.00	16.03	7.03		
	51 and over		12.00	22.48	10.48		
Industrial Category	0-20	299.60	9.00	14.98	5.98	250.00	
	21-40		12.00	19.67	7.67		
	41 and over		16.00	29.12	13.12		
Government Category	0-20	299.60	9.00	14.98	5.98	150.00	
	21-40		12.00	19.67	7.67		
	41 and over		16.00	29.12	13.12		
Trustees and water boards category	0-40	116.00	1.00	2.90	1.90	Exempt	
	41 and over		1.40	2.90	1.50		

To calculate the value to be billed monthly, the following is added to the value of the water: 1) sewerage charges, equivalent to 25% of the invoice value of water, 2) meter maintenance, charged at Lps 1.50 per month when a meter exists; 3) Fixed connection cost, applicable to each segment, published in the Official Gazette on September 17, 2007.
Source: SANAA, Sales Department, June 2014.

3.4 Supply Typology

In the particular case of the Central District Metropolitan Area, the type of water supply system is influenced and determined by its geomorphology, as described above. Additionally, according to research conducted by SANAA, the existence of groundwater in sufficient quantities for commercial exploitation to provide water for the population is extremely low. Despite this constraint, there are water boards that have small decentralized systems, whose intake sources are groundwater through wells drilled and fitted with their respective pumps.

3.5 According to the law (Ley Marco, Honduras)[1]

According to the Framework Law, the time limit set for the transfer of services prompted the search and creation of new organizational models for service delivery, including municipalization, concession and water boards, mentioned earlier.

The prevailing model is the Water and Sanitation Service Provider Body (EPS-AS), a decentralized municipal unit with extensive outsourcing of administrative services such as surveillance, among others, and some operation and maintenance services (Secretariat of Finance, March 2011).

1. Ley Marco Sector Agua Potable y Saneamiento

In the case of the Central District, SANAA remains the provider agency services while the transfer process of the systems that it administers, the management is still in process.

3.6 Characteristics

The characteristics of services in terms of continuity, water quality, pressure, leakage from the drinking water network, among others, have been evaluated by the ERSAPS, whose model with certain values is shown in the following table.

For the purposes of partially illustrating the ERSAPS model, only six elementary indicators have been selected to support the assessment of service management (Secretariat of Finance, March 2011).

3.7 Water Use

Water use in the Metropolitan Area of the Central District comprises the categories described below:

a. Domestic use. Intended for residential use.
b. Commercial use. Intended for the use of malls, stores, hotels, restaurants, public offices, academic centers and business centers.
c. Industrial use. For the use of metalworking and non-metalworking industrial centers. The water required and provided for agroindustrial centers must meet the same water standards

Table 7. SANAA Commercial Invoice

Item	Consumer Billing by Category (US $)			
	Domestic	Commercial	Industrial	Government
1. Clients	41,777	4,633	319	578
2. Consumption (m³)	54,819.76	15,418.90	1,515.81	16,841.62
3. Water consumption (L.)	372,041.76	304,773.00	42,103.27	487,094.48
4. Sewerage	91,996.27	75,996.66	10,582.09	118,657.79
5. Meter Maintenance	1,983.29	296.93	15.14	41.29
6. Retiree's Discount	13,132.85	3.57		
7. Fixed Cost	96,914.76	38,608.33	3,797.62	4,128.57
8. Interest in the event of overdue payments	32,651.47	26,570.82	5,317.34	170.74
9. Invoice value	608,720.40	446,249.31	61,819.46	610,092.87
Cost per Client	**14.57**	**96.32**	**193.79**	**1,055.52**

Source: Calculations based on SANAA, Sales Department, June 2014.

as those for residential consumption. However, in some metalworking industrial centers, good quality water is used for the type of industry, but not necessarily with the same features as that for residential consumption, except for the water intended for personnel. There is no water recycling.

There is no recycling of water for industrial use, only a SANAA wastewater treatment plant that discharges a certain amount into the river, estimated at 30% of the wastewater of the population located in the southern area of the city.

d. Public use. Intended for the use of civic government centers, government offices, hospitals, penitentiary centers, military and police barracks. The water required is supplied through SANAA's municipal network, meaning that it is good water, in other words, it meets the same standards as water for residential consumption.

In Honduras there are no regulations concerning the use of water saving or low consumption devices. The Ministry of Health promotes the use of low-cost sanitation units, although they are not water-saving devices. In general, the Ministry of Health and SANAA only promote sporadic water saving campaigns.

SANAA establishes prohibitions on wasting water, imposing sanctions ranging from fines to the suspension of service for the user who violates these prohibitions, which include the following: not using a hosepipe to water green areas, washing the floors and walls of houses or washing vehicles.

3.8 Problems

The ongoing water supply problem, for the population connected to SANAA's municipal network, is related to the rationing of water supply, which is exacerbated in the summer. The situation is worse in periurban areas and high areas of the city, which water is unable to reach due to pressure problems in the network.

This is linked to the lack of water infrastructure, which makes it impossible to meet the water demand of the growing population of the city. There are proposals for new reservoirs at the sources that supply water to the capital, but some of them have yet to be built, mainly due to the large amounts of financing required for public works on this scale.

4. Water treatment in cities

The demand for good quality water in large cities with high population density raises the need for water treatment for use in human activities, especially those intended for domestic use, which may include residential and commercial use. Within this context, water purification entails a series of individual processes that should culminate in the final disinfection process to ensure that water is safe for human consumption.

4.1 Water Treatment Coverage for Water Purification

Treatment coverage for water purification from the municipal network administered by SANAA is 100%. The network comprises four subsystems, each equipped with its own water treatment plant (see Table 9).

Groundwater sources are chlorinated in pipes, and at the El Lindero Center, chlorination is applied in the tank, which functions as a contact tank.

In the colonies or neighborhoods that are not supplied by SANAA, there are individual solutions that can be from both surface and groundwater sources. Although water is mainly used for domestic purposes, residents resort to buying bottled water for human consumption in order to ensure they consume good water.

4.2 Treatment Coverage by Economic Level

In the municipal network managed by SANAA, treatment coverage for water purification is widespread and there is no difference by the economic status of the population to be served. In short, the costs for this item are automatically included in the rates.

Likewise, water distributed through the network does not distinguish between the economic status of users, who may belong to the residential

Table 8. Characterization of drinking water indicators

Description	Amount	Source
1. Water and wastewater quality. Monthly samples of.		
• Potable water analyzed	329	2013, water treatment plant
• Treated wastewater analyzed	154	2014, wastewater plant
• Treated water that meets the standard	328	271 physico-chemical analysis; 328 bacteriological analysis
• Treated wastewater that meets the standard	133	2014, wastewater plant
2. Quality of service. Monthly records.		
• Complaints about lack of water	340	2011,SANAA, Internal report
• Complaints about incorrect billing	1,300	2011,SANAA, Internal report
• Complaints about sewerage system failures	250	2011,SANAA, Internal report
3. Monthly billing, US$, billing and revenue		
• Income for drinking water	158,730.16	2013, SANAA, Internal report
• Income for water source conservation service	0.00	2013, SANAA, Internal report
• Income for sewerage service	808,333.30	2013, SANAA, Internal report
4. Personnel		
• Number of employees in drinking water	2,116	2014 Human Resources SANAA
• Number of employees in sewerage	634	2014 Human Resources SANAA
5. Incidence of faults		
• Number of faults in drinking water system/month	372	2013, Maintenance SANAA
• Corrective actions in drinking water/month	504	2013, Maintenance SANAA
• Length of drinking water pipe, Km	3,000	2013, Maintenance SANAA
• Number of faults in the sewerage system/month	511	2011, SANAA, Internal report
• Corrective Actions for sewerage/month	511	2011, SANAA, Internal report
• Length of sewer pipe, Km	486	2011, SANAA, Internal report

Source: Calculations based on MOF/BM/ERSAPS, Manual para la identificación e implementación de acciones de tercerización, marzo de 2011. Tegucigalpa.

or commercial, industrial or public and government sector, regardless of the inputs used in the processes to purify the water distributed.

4.3 Cost of Treatment Systems (Expenditure per capita)

As mentioned in previous chapters, SANAA administers the municipal drinking water and sewerage service systems of the Central District, which are larger in size and more complex, due to the city's geomorphology.

Both systems have treatment plants that involve operating and maintenance costs, meaning that each case must be analyzed separately.

4.3.1 Water Treatment

Treatment plants for water purification systems are conventional systems that include individual processes of coagulation, flocculation and disinfection, in which the use of chemical inputs is required.

According to the water quality, sources in the El Picacho Distribution Center are those that require the fewest inputs. However, SANAA declares that the average daily cost of treating water for purification is L.0.50 (US$0.024) per capita, representing a total average cost of L.258,439.00 (US$12.307) per day for the population connected to the system.

Table 9. Water treatment plants in the SANAA system

Sub-system	Plant Type	Capacity (LPS)	
		Minimum	Maximum
1. Concepción	Rapid filtration	1,100	1,500
2. El Picacho	Rapid filtration	350	910
3. Los Laureles	Rapid filtration	250	750
4. Miraflores	Rapid filtration	25	75

Source: Calculations based on SANAA, Metropolitan Division, June 2014.

4.3.2 Wastewater Treatment

Since the issue of wastewater treatment plants is explained in section 4.51., this section will focus on analyzing the cost of wastewater treatment by SANAA.

Treatment plants for purifying wastewater from a sector of the sewerage system in the capital city are aerobic, oxygen being the only input required for operation. The average daily cost estimated by SANAA, of wastewater treatment is L.0.37 (US$0.018) per capita, equivalent to an total average cost of L.92,500.00 (US$4.405) per day for the population connected to the system.

4.4 Water Reuse

Within the Central District Metropolitan Area, there is no reuse of wastewater by state institutions.

There are some isolated cases of factories with wastewater treatment plants, whose effluents are used for landscape irrigation.

4.5 Graywater Treatment

The problem of high water demand in a small space in cities with high population density can be solved by the high amounts of used water, which can either be treated for reuse or simply purified for their reintegration into the ecosystem.

4.5.1 Treatment Processes

Wastewater treatment may involve two stages: the first is a purification process, which is the most common; and, second, a treatment process, when the water is to be subsequently used for an activity involving humans.

a. **Wastewater treatment.** The treatment is intended to reduce pollutant values to the typical values found in fresh water in nature, for their reincorporation into the ecosystem with no danger of pollution. The plants are known as wastewater treatment plants (WTP). For example, typical values of DBO5 in the surface waters of rivers, lakes and ponds are usually 30 mg/l, and it has been proven that with values of up to 50 mg/l BOD5, the content of fats and oils in rivers and lakes is zero mg/l.

   Honduras has the "Technical Standards for Wastewater Discharges into Receiving Bodies and Sewerage," which have regulated the values of liquid effluents for WTP since 1997.

   The presence of nutrients such as organic and ammoniac nitrogen, sulfates and phosphates, among others, is desirable in natural waters, since they contribute to the growth of trees and flora in general. These nutrients are found in high concentrations in wastewater, and therefore, through the treatment process, are reduced to values that are not harmful to the environment but beneficial to flora. The Honduran Technical Standards for Wastewater Discharges into Receiving Bodies and Sewerage regulate the limits for discharges into receiving bodies (Ministry of Health, 1997).

   The treatment processes typically include pretreatment or preliminary treatment, primary and secondary treatment, this flowchart being the one most commonly used in the Central District Metropolitan Area.

b. **Wastewater treatment.** Is applied when a tertiary treatment process is introduced for the purpose of making the treated water a suitable source of water supply for domestic use.

   At this stage, it is possible to add a water treatment plant to produce water for human activities that include residential, commercial and industrial use. This type of treatment is not yet used in Honduras.

4.5.2 Central District Actions

The Tegucigalpa, D.C.Master Sewerage Plan (SANAA, November. 1980) envisages the construction of two wastewater treatment plants (WTP), with the capacity to handle 25% and 75%, known as WTP 1 and WTP 2, respectively.

WTP 1 was strategically planned to be built in the Las Vegas sector, where SANAA currently has two WTPs, in order to process the largest possible volume of wastewater generated by the population in the southern sector of the Central District Metropolitan Area, representing 30% of the total volume of the entire population of the urban area of the Central District, as shown in the accompanying figure (Villafranca et al., 2009).

SANAA currently operates two WTPs, which together handle a daily volume of wastewater estimated at 50,000 m³ produced by an estimated 250,000 inhabitants. The population in the catchment area is approximately 380,000 inhabitants, meaning that a significant amount of wastewater remains untreated.

In the private sector, there are several neighborhoods that have small sewerage purification plants but due to poor operation and maintenance, these plants have collapsed, becoming sources of environmental pollution.

4.6 Reintegration of Water Into the Environment or Ecosystems

The main use of effluents from the SANAA WTP installed in the La Vega sector is the reintegration of the volume indicated above into the Choluteca river, for the following purposes:

a. Establish an ecological baseflow in the Choluteca River to preserve the two main features of fresh water: colorless and odorless. The river flow has been reduced due to the reservoirs built upstream in the headwaters of the basin.
b. Reduce the degree of pollution by diluting the high content of wastewater, and facilitate the excellent self-purification capacity of the Choluteca River due to its steep slope, which has a sufficiently fast flow to achieve this.
c. Ensure public health in the capital, by eliminating the unpleasant odors that often emanate due to the condition of septicity that can reach the river water during the hottest days in summer.
d. Reduce the pollution that can spread through the streams and rivers crossing the city, whose waters are used by a sector of the population, especially the one located on the riverbanks.

5. Water and Health in Honduras

Water, vital for human health factor, is also a vehicle for illness and death. Both extremes occur in Honduras: on the one hand, there is a water shortage, in both the urban and rural zone and on the other, there are floods caused by hurricanes and tropical storms. Both scarcity and abundance affect the health of Hondurans.

This becomes more dramatic in large cities such as Tegucigalpa and San Pedro Sula, the former with 1.11 million inhabitants and the latter with 677,000 (INE, 2013). Both cities have experienced rapid population growth over the last 50 years due to migration from the countryside to the city in search of better living conditions.

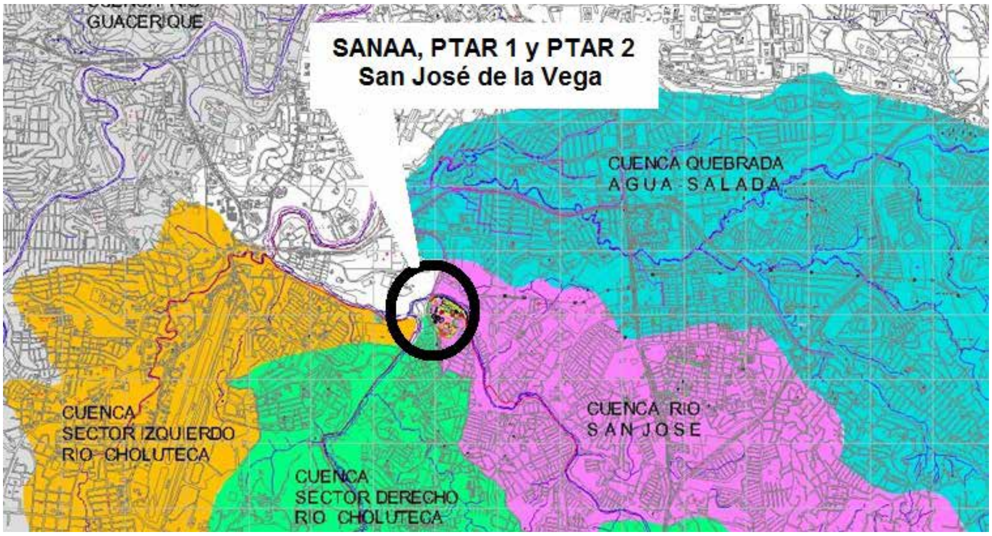
Tegucigalpa, located between hills in the interior of the country, is the more disorganized city and less prepared for this human wave, which requires water, food, health, housing, education, and transportation among other services. Each year, the city increases at a rate of 100,000 new inhabitants (Central District Mayor's Office, 2013), most without livelihoods, building homes classified as huts in hills where there is a lack of water, sanitation and roads. The city has nearly 900 neighborhoods and districts, of which over 400 are the result of urban encroachment (El Heraldo, May 14, 2014).

In the specific case of the Central District Metropolitan Area, two major rivers cross the urban area: the Grande or Choluteca River and the Chiquito River, and more than ten tributary streams that feed into it, flowing through numerous neighborhoods and districts located mainly in the upper parts of the city. In the headwaters of the Choluteca River, in the far south, two major rivers flow into the Choluteca River: the San Jose or Jacaleapa River and the Guacerique River.

Due to the growing demand for water, the population, especially those with the lowest income, often use the waters of these heavily polluted rivers.

The Choluteca River runs through the center of the city and serves as a dividing line between Tegucigalpa and Comayagüela. The river is heavily polluted due to the discharge of sewage it receives on its journey through the city, either directly or through leaks in the SANAA sewage sub-collectors, the majority of which have collapsed. The city's main markets are located near the edge of the left bank of the river. Due to the high pollution load of wastewater discharges it receives, the river become totally septic, in other words, the dissolved oxygen content is zero, meaning that it is devoid of aquatic life. During floods, the river has brought disease and death to thousands of residents (Rivera, 1967). For example, during Hurricane Mitch (1989), much of the commercial area of the city of Comayagüela, including markets, lay under three meters of water.

Figure 4. PTAR 1 and PTAR 2 Coverage Area



Additionally, the sewerage system in the lower areas of the city collapsed.

The city has two regulation dams: Concepción and Los Laureles, which store water from the Concepción and Guacerique rivers. Water from these dams is purified before being distributed in the city. Outside these reservoirs, there is another major source of water for the city, which comes from Mountain San Juancito, specifically La Tigra National Park. La Tigra National Park is a rainforest with significant biodiversity and through the El Picacho Distribution Center, supplies water to part of the Upper Network and the Higher Networks of the city.

5.1 Situation in Developing Neighborhoods

What do residents of neighborhoods set in the hills where there is no drinking water or sewerage do? For these people, water is a precious liquid for which they have to pay exorbitant prices to vendors driving around in tanker trucks. Although SANAA distributes water once a week in summer, it is impossible to cover all the neighborhoods. People must, in any case, reserve water for essentials: bathing at least once a week and washing one's hands before meals becomes a luxury. Since many homes lack sanitation or even latrines, sewage is washed away by rain to the neighborhoods below, polluting the streets before reaching the nearest creek.

5.1.1 Morbility

The health consequences are obvious. Childhood diarrhea is the leading cause of death in children under 5. Intestinal parasites, including amoebiasis, are common in children and even adults. The Hepatitis A virus, acquired in early childhood, goes unnoticed in most cases. Fortunately poliomyelitis has been controlled by vaccinating children, but before 1989, when the last case was reported, it was often transmitted by contaminated water (Rivera, 1967). The same happened with cholera during the period from 1991 to 1995 (Burdeth, 1995).

Several studies have been conducted at the National Autonomous University of Honduras on the causes of childhood diarrhea. Most point to the contamination of water and food, lack of hygiene when preparing infants' food and the lack of water for washing hands before eating, all strongly influenced by poverty, overcrowding and marginalization.

5.1.2 Mortality

The mortality rate in Honduras is 19.85 per thousand births (Secretariat of Health, 2013), water pollution undoubtedly being one of the main contributing factors.

Among the bacteria causing diarrhea, various studies mention Salmonella, Shigella and toxigenic strains of Escherichia coli (Figueroa, 1990). Late last century there was also an outbreak of Vibrio cholerae, which affected all of Central America, causing high mortality, primarily transmitted through contaminated water.

Waterborne parasites often include Giardia lamblia; while the Rotavirus virus is one of the leading causes of diarrhea in children under four.

In the city, people prefer to drink water sold in bottles or pouches and there are several companies selling purified water. The controls periodically carried out by the Ministry of Health's Contaminants Laboratory suggests that the quality of this water is acceptable. However, the outside of these bags is not clean and since the bags have to be opened with the teeth or nails, contamination may occur.

5.1.3 Floods and Storms

As a result of hurricanes and tropical storms, dengue and malaria thrive in flooded areas causing illness and death. Rains leave puddles and ponds where Aedes aegypti and Aedes albopictus mosquitoes, dengue-transmitting vectors, proliferate. In 2013, 29,500 cases of fever due to dengue were reported, together with 26 deaths from hemorrhagic dengue (Secretariat of Health, 2013). The most severely affected cities are obviously Tegucigalpa and San Pedro Sula, which have the highest population density. Cases of malaria, transmitted by mosquitoes of the genus Anopheles, also tend to increase in the wake of storms and hurricanes. Sporadic cases were registered of leptospirosis, an infectious disease affecting the liver, which is transmitted by water contaminated by rats' urine (Ministry of Health, 2010).

5.2 Other Pollutants

Chemical contaminants are unimportant in Tegucigalpa, since there are very few factories, and as in the agricultural field, these are small-scale operations. Pollution of the Choluteca River is mainly due to organic matter from the city sewers. Decomposition of organic matter by bacteria and algae causes loss of oxygen from the water and therefore the death of fish and other aquatic life.

In the 1940s and 1950s, DDT was widely used in the campaign to eradicate malaria, and undoubtedly contaminated the water. The campaign was successful across the country, but once the possibility of carcinogenic effects was realized, the program was discontinued. Other possible chemical contaminants that may enter the water include PCBs from hydraulic fluids, coolants, transformers and paint. More recently, lithium from discarded batteries and radioisotopes used in medicine have been known to make their way into water. Nevertheless, chemical pollution of the water in Tegucigalpa remains low.

The health impact of water pollution in urban areas of the two main cities of Honduras has been highlighted. The same problem probably occurs in other cities and towns in Honduras. Public health would improve by 50% if it were possible to improve the quantity and quality of water consumed by residents and to reduce flood damage. Improving water quality would significantly reduce spending on hospitals and medicines, and therefore improve the quality of life for residents.

The solution to the water problem in urban areas is closely linked to other social problems, such as the lack of sustainable economic development, uncontrolled population growth, -Honduras grows 2.1% annually, one of the highest rates of America-rapid deforestation, which causes the loss of water sources, climate change and a gradual increase in the average temperature caused by the development of northern countries, and lastly, the lack of planning by national and local governments, particularly in urban areas with high development rates.

6. Climate Variability and Change

Prior to the analysis of the impact of climate variability and change on water resources in cities, with particular reference to the Central District Metropolitan Area, the basic concepts of climate change and its associated features will be analyzed.

6.1 Climate change[2]

Climate change is the modification of the climate in relation to its history on a global or regional scale. These changes occur with different time scales and above all, climate parameters, and may in theory be due to natural (Croles and North, 1988) or anthropogenic causes (Oreskes1, 2001).

2. INE, December 2010.

Climate studies show that constant climate change has existed due to natural causes, known as natural climate variability, but that this change has been influenced by man -anthropogenic climate change.

The United Nations Framework Convention on Climate Change uses the term "climate change" to refer to change due to human causes, in other words, a change of climate directly or indirectly attributed to human activity that alters the composition of the world atmosphere and contributes to the natural variability of the climate observed during comparable periods.

The earlier reference to the United Nations shows that greater emphasis is placed on anthropogenic climate change, and that the terminology is often used inappropriately to refer to climate change as synonymous with global warming.

Climate change has increased and will continue to increase the vulnerability of cities, as demonstrated by the capital of Honduras. Special measures are required in urban areas for the efficient use of water resources, including: prevention of an impact on quality, wastewater treatment, introduction of more water reuse projects, and runoff use, among others.

6.2 Cities in Dry Areas and How to Organize Supply

Ecosystems in dry land or zones are characterized by the lack of water.[3] Water shortage limits the production of crops, forage, wood and other ecosystem services.

There are four commonly accepted subtypes of dry lands: dry sub-humid, semi-arid, arid and hyper-arid, with a growing degree of aridity or moisture deficit.

The Central District is located in central Honduras, at an average altitude of 1,100 meters, and according to the above definition, does not classify as a dry area.

Due to its spatial location and altitude, it has a Tropical Savanna climate.[4] This type of climate has two seasons: a dry season that begins in January and ends in April, February being the driest month, and a rainy season beginning in May and ending in October.

During the rainy season, there is a short period between the months of July and August, during which it stops raining and a dry period. This period usually lasts a month and is known as the "mid-summer drought." [5]

Due to this behavior, 69% of the Central District water supply system, planned, managed and operated by the water authority, SANAA, relies on two regulating reservoirs: Concepción and Los Laureles, currently in operation, and three to be built within an estimated period of 25 years, in other words, by 2040.

6.3 Storm Water and Flooding Problems

The rainfall pattern is one of climate factors that has been most severely altered by climate change, causing serious problems in major cities. Consequently, storm water drainage systems are the most heavily affected, due to the increased incidence and intensity of precipitation.

The rise in heavy rainfall and stronger, more frequent and severe hurricanes may cause river and coastal flooding, and overcome the defenses of the city, if they exist, or reveal the extreme vulnerability of cities. Although the link between these events and climate change has yet to be proved, the flooding and destruction caused by Hurricane Mitch in Tegucigalpa and Comayagüela in 1998 serve as a reminder of the catastrophic impact of extreme weather events on urban areas and society in general.

6.3.1 Floods in Cities

The increasing frequency and intensity of rainfall means that runoff levels may exceed the capacity of storm drains leading into the drainage system, or cause flooding in conjunction with sewerage systems. These overflows can cause street

3. http://www.greenfacts.org/es/glosario/tuv/tierras-secas.htm

4. http://www.xplorhonduras.com/clima-de-honduras/

5. *Ibidem*

flooding, with the attendant health hazards due to contamination, but can also increase the cost of complying with the related regulatory requirements.

The overflowing of sewers is a problem linked to cross-connections commonly maliciously performed by builders of housing sewage systems to the urban drainage system, and from the roof and courtyard drains of houses to the housing drainage system and thence to the municipal sewerage network maliciously performed by builders of housing sewage systems.

a. This illegal crossing over of connections, in addition to the practice of using storm drains as public landfills, severely affects the urban areas of the Central District, since the amount of rainwater flowing through both systems in addition to surface runoff in the streets causes flooding due to overflowing, which is more common now in the rainy season. Additionally, heavy rains carry an enormous amount of trash combined with raw sewage, which they eventually discharge into the rivers crossing the city.
b. The cost of this recurrent problem of urban flooding is estimated by the authorities in terms of the participation of emergency service agencies, care for the population affected, and repairs to damaged infrastructure.
c. The most immediate actions to prevent this systematic occurrence of flooding in the Central District may include:
   - Conduct an intensive program to clean out the drains, manholes and discharge heads of the storm water drainage system.
   - Ensure strict supervision of all urban constructions in order to control illegal and clandestine cross connections between the sewer system and storm drainage by builders.
   - Establish monitoring mechanisms and incentives or penalties, as appropriate, to prevent the use of storm drains as trash cans. A health education program at the primary and secondary school level would be useful for training future citizens in the new culture of the effects of climate change on water resources.

6.3.2 New solutions in cities

Given the high impact of climate change on flooding problems in urban areas, it is essential to focus strategies on storm water management as part of urban water management policy.

The current water management infrastructure requires immediate, practical solutions to address changing circumstances, since climate change projections show that variability can change capacity requirements by region or season. The choice of sustainable systems for water management in urban areas designed to address variable and unpredictable conditions seems to be the best answer for planning new urban solutions and achieving the implementation of flexible, often decentralized options and technologies that take a range of future scenarios into account.

A flexible system is characterized by its ability to adapt to changing requirements. For example, possible responses by a flexible system to changing conditions would include reducing runoff through the use of Sustainable Urban Drainage Systems options, including:

- Green roofs
- Porous pavements
- Grassy Channels
- Rainwater Harvesting
- Detention ponds
- Retaining troughs

The design of a flexible system and the choice of options and technologies can and should be provided through the strategic planning process.

6.3.3 Decentralization and centralization

The flexibility of unconventional urban water systems is often related to decentralized solutions. Decentralization reduces vulnerability by spreading risk. In fact, it is easy to understand the greater risk faced by a city that relies on one or more large wastewater treatment plants compared with a city that operates several natural treatment systems on a small-scale located in various areas.

Moreover, decentralized solutions are often quicker to install and more cost-effective to build and maintain. These considerations are particularly important in the face of changing conditions, which can either facilitate major investments in new treatment facilities or be redundant in water supply infrastructure.

The condominial systems for sewerage systems are the latest innovation in decentralized systems (Mendoza, 1999). These systems have introduced innovations into design criteria, eliminated the maximum distance between two manholes, implemented new devices for the construction of singularities in networks, including pipe inspection and cleaning, terminal boxes and cleaning terminals.

a. The main advantages of condominial sewage:
   - Lower cost of excavation, due to shallow depths of condominial sewers
   - Lower cost of material for condominial sewerage, which is less extensive
   - Lower cost per manhole, fewer conventional manholes required.
   - Increased number of pull boxes to replace traditional manholes
   - Lower cost of household connections because depths are shallower and the length of the connections is shorter.
   - Easier implementation of household connections, even for houses sharing common walls
   - Greater use of regional materials in the construction of condominial sewers and household connections
   - Greater use of unskilled labor
   - It is easier to unclog condominial sewerage and home connections through simple, easy to use equipment.

b. The main advantages of condominial sewage:
   - Greater demand for preliminary, permanent work, including the following: health education and social assistance to involve the community in the construction, operation and maintenance of its condominial sewerage system
   - Possibility that problems may arise over rights of way, expropriation and expansion of built areas.

6.3.4 Structural and nonstructural solutions

Impacts of climate change will be felt transversally in the various elements of the urban water cycle, as well as in all sectors of urban management. Current guidelines for urban water management are often fragmented in regard to the design, construction and operation of the various elements, which are implemented in isolation, with very little coordination with other urban management sectors and institutions.

This fragmented perspective often results in unsustainable practices, as when certain technical choices have unintentional impacts on other parts of the urban system. For example, the construction of reservoirs for the Central District water supply has reduced the baseline ecological flow of the Choluteca River.

A more sustainable approach to water management should include, in addition to the integrated management of the various aspects of the urban water cycle, the coordination of actions with other sectors of urban management, which can help identify synergies and address conflicts. Within the context of climate change, effects are likely to be felt across a variety of sectors and urban services, which is why the integrated approach is particularly valuable for adaptation planning. Moreover, flexible options and technologies may also benefit other urban sectors.

Integrated management can also be achieved through the development of a continuous process, regularly evaluated with current options and designed to meet changing circumstances, through strategic planning.

6.3.5 Solutions designed to achieve better management in the basin where the city is located

Any solution designed to improve water resource management in the basin must be accompanied by the participation of the inhabitants, who may become active members, as supervisors and caretakers of the basin, in exchange for being allowed to undertake normal farming or livestock raising activities within programs to control and manage their activities.

A watershed management plan can and must be developed to include the best practices of resource management, seeking the mutual benefit of both the inhabitants of the basin and the cities that use it, mainly in the form of water to supply the population.

The best actions could be developed and implemented through the Forest Conservation Institute (ICF) through Honduras Forest Management and Sustainable Development, posited since July 2010.

Solutions that may be envisaged within a watershed management plan include the following:

a. Fire control. Burning within the watershed may be permitted, but farmers must be taught control techniques, such as practicing shifts, and the removal and disposal of waste and ash after burning.

b. Tree felling Trees are often felled for firewood, fencing and the construction of rural housing. Since tree felling satisfies some of farmers' needs, there should be a Municipal Government policy to choose the areas where this is allowed and to select the particular trees that may be cut down. In return, farmers must be shown the need to plant three trees for every one cut down. The reason for planting three trees is that at least one of them will germinate.

   This policy should be still valid for operating licenses for timber businessmen, since the refusal of permits forces them to engage in illegal logging, causing enormous damage to the watershed.

c. Family orchards. Families should be allowed to have family orchards, and be trained to prepare composts for making organic mulch.

d. Erosion control and sediment transport. Programs should be developed to lessen deforestation as mechanisms for reducing erosion within the watershed. These programs should include the implementation of public works for the control and management of sediment from erosion.

   Changes in the characteristics of vegetation and soil, due to rising temperatures and high evapotranspiration rates, may change mitigation and infiltration rates, affecting the soil's retention capacity.

6.4 Other variability issues

Cities have populations that require infrastructure to engage in economic activity and create wealth, and are therefore disproportionately affected by the local impacts of climate change. Cities located in coastal areas and/or on the banks of the rivers are particularly vulnerable to rising sea levels and flooding. Cities are also characterized by the predominance of impermeable surfaces, which are less able to absorb increased precipitation and thus, increase the intensity of rainfall runoff (International Water Association, 2011).

As overwhelming population growth occurs in cities, managers of agencies responsible for urban water management face the growing challenge of maintaining a safe, adequate water supply and wastewater services for urban residents. In the case of the Central District, the urban population has a high growth rate, as in other developing countries, exacerbating the problems associated with urban poverty, increasing the size of the sectors of vulnerable population, and exerting additional pressure due to the dwindling supply of resources such as water.

The vulnerability of the urban supply of water, wastewater and storm water systems is strongly affected by the various manifestations of climate change, impacts mainly related to their physical infrastructure and functionality.

6.4.1 Water supply

The water supply has been affected by most of the predicted expressions of climate change, both in terms of water quantity and quality. Flows into rivers, lakes and reservoirs, as well as groundwater, are affected by:

a. The modification of precipitation patterns and rising temperatures, which increase evapotranspiration.

b. Security of supply is directly affected by drought, in a negative sense, as it reduces the flow of rivers and the amount entering reservoirs, lakes and groundwater, and indirectly, for example, by increasing the occurrence of forest fires that destroy the topsoil, thereby significantly reducing the yields of the basin.

c. The seasonality of water supply levels may change in any region and affect the main source of water. The decrease in winter rainfall affects the period for recharging groundwater, lakes and reservoirs.

d. Water quality is a key component of water supply, and adverse changes in this quality affects users, as well as increasing the cost of services. Water quality is affected by flooding, erosion, which increases turbidity, rising nonpoint pollution, and faulty wastewater treatment plants, with the subsequent bacterial contamination of water. It is also affected by rising temperatures, which have an effect on the chemical and biological characteristics of water bodies, and decreased precipitation, which concentrates pollution. The consequences for certain sources of water have a knock-on effect on others. For example, decreased precipitation and its impact on surface water will result in increased extraction of groundwater and from sources with lower quality water (Bates, Kundzewicz, Wu and Palutikof, 2008).

e. The physical infrastructure of water supply is also adversely affected by floods, direct damage to pipelines and facilities, sedimentation of reservoirs and capacity overloading. Climate change may also reduce the functionality of water purification, for example, by reducing the effectiveness of treatment processes such as chlorination, or causing excess disinfection due to byproduct levels in distribution systems (Zwolsman et al., 2009).

f. Functionality is affected by rising temperatures that encourage the growth of algae that clog the equipment and result in higher spending on treatment to remove the taste and odor linked to the growth of bacterial and fungal growth. Moreover, certain management decisions made in response to climate change events may have consequences for water supply. For example, establishing the capacity of the reservoir as a buffer to absorb flooding may decrease the availability of drinking water.

g. Water supplies are also affected by climate change, altering water demand. Higher temperatures will increase water demand for all consumptive uses -restricting efficiency improvements- and may therefore lead to strong competition for water resources or require an alternative source of water supply. A related point is that in the context of reduced water availability, finding any minimum existing ecological flow requirement will become more challenging and could question the renewal of licenses for drinking water production (Zwolsman et al., 2009)

6.4.2 Wastewater Sewerage Systems

Like the water supply, the integrity and functionality of wastewater treatment infrastructure is affected by climate change. The physical infrastructure of the collection network and wastewater treatment plants, including drains, pipes and tanks, may be damaged by flooding caused by increased rainfall and overflowing rivers, as in the Central District.

Extreme events may challenge the functionality of wastewater treatment plants through the dilution or concentration of the inflow in the case of floods or droughts, respectively.

Functionality is also affected by higher temperatures, which may have positive or negative consequences for wastewater treatment (Bates, Kundzewicz, and Palutik and Wu, 2008). High temperatures with reduced precipitation may lead to more broken pipes due to the drying of the soil, as well as further deterioration of the pipes due to corrosion by hydrogen sulfide accumulation (Zwolsman et al., 2009; Howe, Jones, Maheepala and Rodas, 2005).

Wastewater management may also be indirectly influenced, for example, as happens when temperature increase affects oxygen levels in receiving water bodies, which in turn leads to stricter requirements wastewater treatment in order to stabilize these levels and not endanger ecosystems.

7. Conclusions

Honduras is a privileged country with abundance of water resources which means a good potential that can give relief to the growing demand for drinking water caused by the spread of urbanization.

The study case corresponding to the Capital of Honduras reflects the impact that the pressure of urban development exerts on the exploitation of natural resources, which is strong and relentless on the demand for water to meet this vital health need. The quality and quantity of water available is often exacerbated by the development of industrial and commercial activities that affect and degrade water resources in general, through deforestation, forest fires and wastewater discharges.

The lack of development of water infrastructure by the official provider of water supply in the capital of Honduras, oblige a rationed service with many interruptions by network failures and problems of pressure, being the most the severe the peri-urbans areas and the higher parts of the city where water does not reach due to insufficient of pressure. As a result, access to water service presents conventional solutions that are developing at a slow pace, and non conventional solutions that proliferate as relief measures to the despair of the population to meet their needs, among which are mentioned: tankers, bank public key, free sale "homemade tanks" capture or storage in improvised underground deposits denominated water harvesting, or on the surface of ground like water ponds

There is an enormous social debt to wastewater management, and the greater adverse impact of urbanization is the contamination of water sources due to the free discharge or improper disposal of urban and industrial wastewater, and lack of treatment thereof, contributing to the deterioration of water quality of the potential sources for drinking water

In relation to human health, as well as being a vital factor, water can also be a carrier of disease and death, and, in Honduras both extremes may occur, on one side there is shortage in water supply in urban and rural areas, and, on the other hand, there are floods caused by hurricanes and tropical storms. Both the scarcity and abundance affect the health of Hondurans. According to studies by the UNAH, the leading cause of childhood diarrhoea is the contamination of water and food washed with contaminated water. Due to the lack of potable water to meet the growing demand of the population, especially the lower-income people, water from polluted rivers is being used.

The effects of variability and climate change in Honduras can be observed at both extremes of the hydrological cycle: severe droughts and periods of heavy rain storms, and hurricanes that cause flooding. Its influence on the problems of water supply in the capital of Honduras is notorious, which added to the action of man with frequent burning of forest and deforestation has caused variability on natural resources as they are modified in rainfall patterns, extreme temperature changes, siltation of rivers due to effect of dragging erodible material, and frequent floods

8. Recommendations

In line with the conclusions, the main recommendations are given below:

1. The Honduran government must develop strategies and policies for sustainable development, maximizing its potential in its natural resources. It is necessary to establish policies and strategies oriented towards the rational and sustainable exploitation of its resources, taking into account three important characteristics: 1) It has a very young population (55% are under 25); 2) the population in rural areas is greater, and 3) the female population is larger.
2. The country's development strategy for the basins should be strengthened by allocating the necessary financial resources to promote progress by providing the required infrastructure.
3. SANAA, as the authority responsible for the water supply of the capital of Honduras, should undertake the necessary steps to harness the available supply of water resources, applying the well-known principle that the cheapest source is the nearest one.

4. The municipal authority must update the Land Use Plan of the capital to avoid urban sprawl to reserve areas and, as part of planning and governance, could typify urban developments, accompanying them with management plans for green environments. Thus, in the case of industrial development zones, the Taxation Plan must establish the need for wastewater treatment.
5. SANAA should expand water service coverage, particularly since the Honduran government is a signatory to the Millennium Development Goals, whose seventh goal is to: Guarantee the protection of the environment, by incorporating the principles of sustainable development into country policies and programs and reversing the loss of environmental resources; and halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015.
6. SANAA must develop a strategic plan to build the new dams proposed, based on the Master Drinking Water Plan, whose construction has been delayed, mainly due to financial aspects, which in turn, are related to the scale of the public works.
7. SANAA must develop a strategic plan to build the extension of water infrastructure, based on the Master Drinking Water Plan. Expanding the water supply will require the construction of new water storage tanks and new water lines and distribution networks.
8. Greater support must be given to the Water Boards through technical assistance in administrative and technical fields, since they have endured for over 30 years. The fact that they have continued to grow since then has shown that they are in fact an excellent alternative, particularly for periurban areas and developing neighborhoods in inhospitable, scattered settings where the water authority has failed to deliver regular service.
9. The Framework Law on Water and Sanitation and its Regulations must be updated and fully enforced. Water supply systems have yet to be decentralized, including the one in the capital of Honduras. Likewise, COMAS and LSCUs must be set up in all municipalities of the country, particularly in the capital of Honduras, so that the law achieves its main objectives.
10. Emphasis must be placed on setting up COMAS and USCL in each community, since it is through these instances that the Framework Law on Water and Sanitation proposes transparency mechanisms and citizen participation.
11. The three models permitted by the Framework Law on Water and Sanitation must be established in order to determine which model has the best fit, adaptability and flexibility for communities, according to the geographical area of the basin to which they belong and considering socio-cultural aspects.
12. It is essential for all the actors involved in water system management, including SANAA, the Water Boards and private providers, to develop solidarity programs to promote access to safe drinking water, especially for people who live in scattered areas and those living in areas where water is available. And for residents for whom access to water is quite distant, they must seek viable options, including low-cost solutions, such as: harvesting rainwater and storing it in underground deposits and extraction by manual pumping or buckets.
13. Greater control must be exercised, particularly of the quality of the water distributed through private tankers, free water sales, bottled water and generally any type of supplier, to prevent the population's desperation to have access to water for their use and consumption from leading to extreme cases of epidemics of waterborne diseases by consuming water of dubious quality. This desperation also exacerbates extreme poverty, since the population purchases water at high prices.
14. The water authorities must adjust water sales prices, setting higher prices for consumption ranges above the base quota of 20 m^3, so that consumers upstream of the basic fee pay the actual cost of production. This cost should be such that it discourages large users from use treated water for washing vehicles, watering gardens or walls and so on.
15. Wastewater treatment plants must be built to eliminate environmental pollution through direct discharges of wastewater into rivers.

16. In the particular case of the capital of Honduras, in order to eliminate multiple discharges into the streams and rivers that cross the city, a program of sanitary additions to the general collection system should be developed for the safe handling of this wastewater and the elimination of the odors that pollute the air in the capital.
17. The case of the city of San Pedro Sula should be analyzed and its model replicated in the capital of Honduras, since the public health level in Tegucigalpa has the highest rates of morbidity and mortality from waterborne diseases, proving that "water is health" and "health is well-being."
18. It is necessary to update the Master Sewer Plan for and the Project to Channel the Tegucigalpa and Comayagüela Rivers, since both projects provide solutions for developing sewer and storm drain systems until 2020. They should take advantage of the irregular geomorphology, which has created abundant micro-watersheds. A micro-drainage system integrated in a macro-system would be a viable and economical technical choice. This technical solution is fully compatible with the wastewater system and should be accompanied by wastewater treatment plants.
19. A supply of drinking water that is safe for human consumption must be ensured in order to maintain low morbidity rates from diarrhea, and if possible, reduce them further.
20. The recommendation for morbidity also applies to mortality rates from diarrhea, in other words, a drinking water supply that is completely safe for human consumption must be guaranteed.
21. It is essential to raise awareness of the variability and impact of climate change on water resources, by defining strategies and policies for the rational use of resources; adopting new technical criteria for adapting urban water systems, sewerage and storm sewers to climate change, and giving priority to water by declaring it a social good and an important factor in alleviating poverty.
22. The current water management infrastructure must be reviewed, since it requires immediate, practical solutions to address changing circumstances, since climate change projections show that variability may change capacity requirements by region or season. The choice of sustainable systems for water management in urban areas designed to address variable and unpredictable conditions would seem to be the best answer for planning new urban solutions and achieving the implementation of flexible, often decentralized options and technologies that take into account a range of future scenarios.

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10. Acronyms

AMDC:	Central District Mayor's Office
WB:	World Bank
COMAS:	Municipal Water Commission
CONASA:	National Water and Sanitation Council
BOD5:	Biological Oxygen Demand (after 5 days)
EPHPM:	Permanent Multi-Purpose Household Survey
EPS-APS:	Drinking Water and Sanitation Service Provider
ERSAPS:	Drinking Water and Sanitation Service Regulator
INE:	National Institute of Statistics
JAA:	Water Administration Board
Km:	Kilometer
KOICA:	Korea International Cooperation Agency
LPS:	Liters per second
WTP:	Wastewater Treatment Plant
SANAA:	National Autonomous Water and Sewerage Service
SEFIN:	Secretariat of Finance
LSCU:	Local Supervision and Control Unit

Mexico

View of Mexico City, which, centuries ago, was a beautiful lake. Photo credit: ©iStock.com/ isitsharp.

"In Mexico, water distribution is extremely uneven in quantity and quality, both for natural reasons and because of the historical evolution of our cities and productive activities. This condition makes us a country vulnerable to global climate change, since our ecological balances are very lean and much of the surface and groundwater resources that supply our cities are already overexploited. It is particularly worrying that over 70% of the surface bodies in the country show some degree of contamination; agricultural activities waste more than half the water used through improper practices; approximately 40% of the recorded species of fish are threatened, endangered or have become extinct due to the way their habitat has been affected, and that there are still 11 million Mexicans who do not have clean water" Mario Molina, Nobel Prize

Urban Water in Mexico

Coordinator
María Luisa Torregrosa

Contributing Authors
Ismael Aguilar Barajas, Blanca Jiménez Cisneros, Karina Kloster, Polioptro Martínez, Jacinta Palerm, Ricardo Sandoval, and Jordi Vera

Support
Amalia Salgado

Summary

Mexico's strong growth during the 20th century led to a significant concentration of the population in relatively small areas requiring large amounts of water, food and energy. Nearly eight out of every ten people live in urban areas throughout the country. Although there is good average water availability and supply service coverage has steadily increased, Mexican cities face growing problems with regard to water and sanitation services. This paper examines the current state of public water and sanitation services in the country and the main problems. It provides a general review of the population structure and the generation of cities, the types of water management and administration, sources of access, water quality, distribution, unequal access, water drainage in cities, sanitation, reuse, health risks, infrastructure and climate change. On the basis of this review, it proposes a number of recommendations for water policy in Mexico.

1. Introduction

During the 20th century, like other countries, Mexico experienced heavy urban development and the rapid growth of cities (Garza, 1990; Pineda et al., 2010), mainly due to the expansion of industrial activities and services and the increasing migration of the population that moved to cities, leading to their multiplication and rapid growth (Garza et al., 1995). This led to the concentration of the population in very small areas requiring large amounts of water, food and energy, which generated large volumes of waste and thereby an environmental imbalance. Worldwide, the spaces occupied by cities account for less than 1% of habitable space (Jiménez, 2013), while 73% of total gross output is produced in 56 metropolitan areas (UN HABITAT, 2011).

In Mexico, nearly eight out of ten people live in urban areas (INEGI, 2010). Although there is good water availability on the whole across the country, and supply service coverage has steadily increased, Mexican cities face growing problems in regard to municipal water and sanitation, particularly for the low-income population, in terms of service continuity and water quality.

Fifty-three per cent of all groundwater employed for all uses comes from overexploited aquifers (CNA, 2012a), while surface water sources such as Lake Chapala and the Cutzamala dam system, are threatened by pollution, competition with other users and climate variability. Likewise, the lack of water systems and high quality sustainable sanitation poses an enormous challenge to the country's economic wealth and social well- being.

Sewerage and sanitation services also face significant challenges. Although urban areas generally have high coverage, wastewater treatment coverage is extremely low.

The lack of high quality, sustainable water and sanitation systems poses an enormous challenge to the country's economic wealth and social well-being (Sandoval, 2012). Water availability per person has decreased due to population growth, but in the case of Mexico, the situation is serious because of the concentration of most of the population in urban, industrial and agricultural areas in central and northern Mexico, where there is less water available (Saltiel, 2008 in Sandoval, 2012). According to the General Census 2010, only 73% of households receive water every day.

The problem of achieving sustainable urban water service is more complex than having water or sanitary connections or importing water from other basins since urban areas require an extensive catchment area and space and financial resources for treating wastewater, which they discharge into a small area. Moreover, in cities, aquifer recharge areas are being paved and river banks invaded. On the other hand, climate variability and the effect of the heat island increase the risk of urban flooding.

2. Population growth and the structuring of cities

Mexico is a country of enormous contrasts. Its nearly two million square kilometers of biodiverse ecosystems are inhabited by over 112 million people with a broad variety of cultural backgrounds. Mexico is the eleventh largest global economy (considering the GDP for 2011) and a member of the Organization for Economic Cooperation and Development (OECD). It also has a high Human Development Index (HDI) (0.739 in 2010). However, these data conceal profound social contrasts and differences in access to water supply and sanitation among the inhabitants of the 31 states and the Federal District comprising the country (Map 1).

Map 1. Human Development Index for Mexican States

Source: http://www.fotosimagenes.org/estados-de-mexico-por-idh

Mexico has experienced different stages in regard to population growth. At the beginning of the 20th century, in 1900, there were only 33 towns with over 15,000 inhabitants, in which a total of 1.4 million people resided. From 1900 to 1940, a slow process of urbanization began that accelerated in the 1940s. By 1950, the number of towns with over 15,000 inhabitants rose to 84; by 1960 this number had risen to 119, covering virtually the whole country.

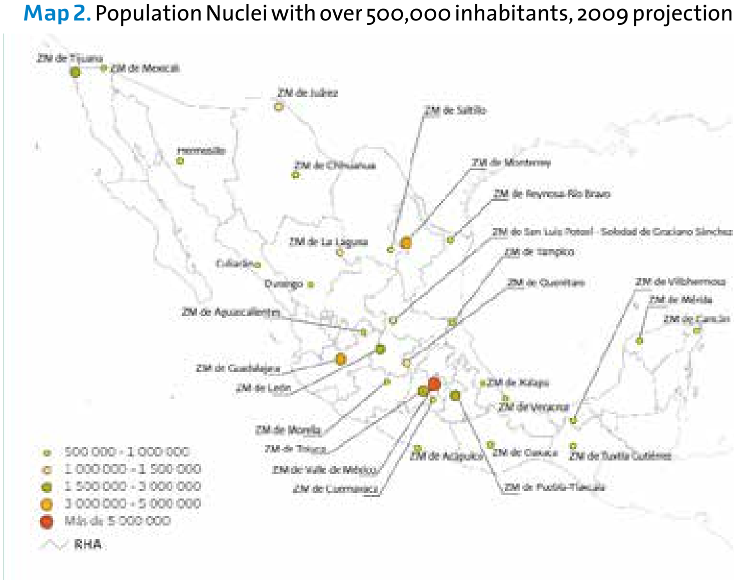
By 1990, Mexico had a total population of 81.2 million, 61% of which lived in 309 urban localities with over 15,000 inhabitants. Ninety-nine of these were cities with over 50,000 inhabitants, 15 had over 500,000 and four (Mexico City, Guadalajara, Monterrey and Puebla) had over one million inhabitants (Garza et al., 1995). In 2005, the country's population totaled 103.2 million, of which 62% were in towns with over 15,000 inhabitants, in other words, the urban proportion was maintained.

The City System or National Urban System is composed of 56 metropolitan regions and 327 cities with over 15,000 inhabitants, where 56% of the population live. Moreover, over the past 30 years, the territorial expansion of cities has grown four times more quickly than the total population and three times more quickly than the urban population.

In the last census (INEGI, 2010), the country's population totaled 112.4 million, of which 70.2 million live in towns with over 15,000 inhabitants (62.5%), and 53.6 million of live in 117 cities with over 100,000 inhabitants. Some of these cities are grouped into one of 56 metropolitan areas that currently exist in the country and concentrate a total population of 63.8 million inhabitants (57% of the country).

The urban population will continue to expand, exerting growing pressure on urban development and service delivery, particularly in areas of the country where natural resources (especially water) are already scarce, with patterns of over-exploitation and whose quality is generally threatened (Map 2).

Map 2. Population Nuclei with over 500,000 inhabitants, 2009 projection



Nota: incluye Zonas Metropolitanas (ZM) y municipios no conurbados. La población 2009 se ha calculado con base en las proyecciones de CONAPO.
Fuente: Conagua. Subdirección General de Programación. Elaborado a partir de:
CONAPO. *Proyecciones de la Población de México 2005-2050*. México, 2007.
SEDESOL, INEGI y CONAPO. *Delimitación de las zonas metropolitanas de México 2005*. México, 2007.
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Cities have experienced uneven, scattered growth and a low density spatial model, meaning that the introduction of services is not only more difficult but also more expensive (Sandoval, 2012). Medium-sized cities (with between 500,000 and 1 million inhabitants) are growing faster and there will be more than 20 large cities (with over 1 million people) in 2030 (UN HABITAT, 2011). The most difficult problem will be faced by "the Mexico City megalopolis" which will be formed of seven metropolitan regions: Valle de México, Toluca,

Cuernavaca, Cuautla, Puebla-Tlaxcala, Pachuca and Queretaro; all of which currently face water supply problems and have unsustainable supply conditions (Sandoval, 2012).

3. Water sources. Water availability and consumptive uses

Mexico is divided into 1,471 watersheds (Map 3), grouped or subdivided into 731 hydrologic basins for the purposes of publishing the availability of surface water.[1] The country also has 653 aquifers (*Diario Oficial de la Federación*, December 5, 2001). Most information on water resources is presented at the level of hydrological-administrative regions, basins, aquifers or in accordance with political-administrative criteria (states and municipalities). Therefore, much of the information in this section will be presented at that level rather than at the urban-metropolitan level as would be desirable. This is undoubtedly the first issue to be addressed: the need for information on water at the urban level for proper planning. This is perhaps a problem that should be solved by city mayors, who require this information to improve their decision-making process.

Approximately 37.5% of the total amount of water extracted in Mexico, comes from the subsoil while the remaining 62.3% is obtained from surface sources.

1. On December 31, 2010, the DOF published an average annual availability of 731 watersheds.

This ratio varies depending on usage. Domestic supply and industry are largely dependent on groundwater sources, whereas for irrigation and power generation, surface water sources are mainly used.

Map 4 shows the 2,457 municipalities in the country. Pink shows those that are predominantly dependent on groundwater, while blue shows those that rely mainly on surface water. Municipalities in the states of Baja California and Baja California Sur, the whole of the Yucatán Peninsula and many of the municipalities in the interior in the northern part of the country (Coahuila, part of Nuevo León, Zacatecas, San Luis Potosí, Guanajuato and much of Jalisco) employ mostly groundwater sources for their consumptive uses.

In 2012, approximately 82.7 cubic kilometers (km^3) of the total amount of water naturally available in Mexico were extracted. Of that amount, the water used to supply human settlements, which could be called urban water, was 12 km^3. To this figure, one should add 3.3 km^3 of water consumed by the self-supplied industry, usually located in urban areas. In other words,14.5% of the water utilized in Mexico is assigned for public urban use, 4% for industrial use and 5% for thermoelectric power generation, while the remaining 77% is employed for agricultural purposes (see Table 1). Water used for urban public supply and the urban self-supplied industry, 8.8 km^3 (60%), comes from groundwater while 40% is obtained from surface water.

The amount licensed for urban public use, employed by operating organizations to provide piped water services, rose from 9.57 km^3 in 2001 to 12 km^3 by 2012 (CONAGUA, 2013a), i.e. at a higher rate than the growth of the urban population. The three states with the highest amounts of public urban use concessions are the State of Mexico, Mexico City and Sonora, whereas those with the lowest volume for

Map 3. Watersheds into which the country is divided

Source: CONAGUA, 2012b.

Map 4. Predominant source (either surface or groundwater) for consumptive uses at the municipal level, 2009

Source: CONAGUA, 2011.

Table 1. Consumptive uses grouped by origin of type of extraction source, 2012

Use	Origin		Total volume (km^3)	Percentage of extraction
	Surface (km^3)	Ground (km^3)		
Agricultural*	41.2	22.2	63.3	76.6
Public supply*	4.7	7.3	12.0	14.5
Self-supplied industry **	1.4	1.9	3.3	4.0
Electricity excluding hydro electricity	3.6	0.4	4.1	4.9
Total	**51.0**	**31.8**	**82.7**	**100**

Note: 1km^3-1 000hm^3-billion m^3. The data correspond to volumes licensed to December 31, 2009. Numbers may not coincide due to the rounding of figures. * Includes agriculture, livestock, aquaculture, multiple and other sections from the REPDA classification. Also includes 1.30 km^3 of water corresponding to Irrigation Districts pending registration. Includes the public urban and domestic sections under the of REPDA classification. ** Includes the industrial, agro-industrial, services and trade sections of the REPDA classification.
Source: CONAGUA, 2013a.

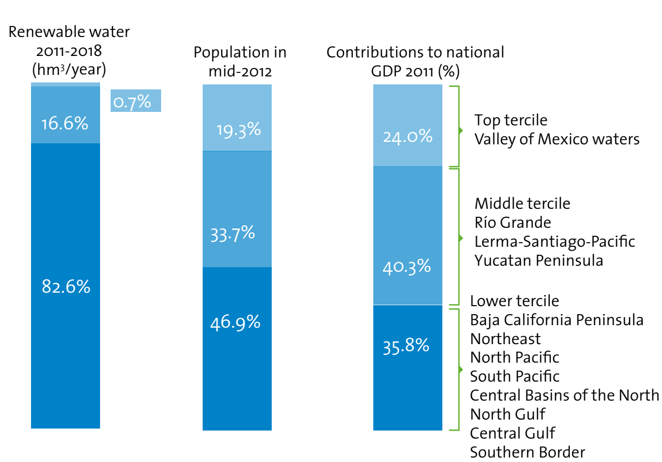
this use are Baja California Sur, Colima and Tlaxcala. Fifty-three per cent of this amount is obtained from groundwater sources. In 2001, the proportion of groundwater concessions for the provision of domestic piped water from underground sources was 65.4%, suggesting that there has been a reduction in the reliance on groundwater sources.

Map 5 shows the municipalities whose predominant consumptive use (over 50% of the total volume) is public urban use (marked in blue). In these municipalities, there is less agricultural irrigation, meaning that that the water consumed is predominantly for domestic uses.

Map 5. Predominant Consumptive Use at the Municipal Level, 2009

Source: CONAGUA, 2011.

Graph 1. Regional contrast between development and renewable water, 2011



Source: CONAGUA, 2013a.

3.1 Water Distribution in Relation to Population Distribution and Wealth Creation

As discussed above, Mexico displays broad regional diversity when the population distribution of renewable water and the generation of the Gross Domestic Product (GDP) is analyzed. On the basis of Administrative Hydrological Regions (AHR), they can be classified into large groups according to their contribution to national GDP. For example, the 13th Water Region of the Valle de México alone, with 24% of GDP, accounts for almost a fifth of the national population, while having low amounts of renewable water. Conversely, the following group of hydrological-administrative regions, I (Baja California), II (Northwest), III (North Pacific), IV (Balsas, V (South Pacific), VII (Central Basins of the North), IX (North Gulf), X (Central Gulf) and XI (South Border) with a low contribution to GDP, have the highest amount of renewable water in the country, as can be seen from Graph 1.

These regional contrasts are also observed when analyzing the amounts of water licensed and therefore consumed for different purposes. The states with the largest volumes of water licensed for different uses are Sinaloa, Sonora, Michoacán and Chihuahua, main due to the large agricultural volumes they consume. Conversely, the states of Aguascalientes, Tabasco, Baja California Sur and Tlaxcala have smaller volumes of water under concession. The State of Mexico, Mexico City and Sonora are the states with the largest amounts of water concessions for urban use. In terms of per capita consumption, calculated on the basis of the amount of urban water concession, however, the top two states are Chihuahua and Sonora.

As regards consumption in Mexican cities, a recent study of 142 cities with over 50,000 inhabitants, comprising 51.5 million urban dwellers, showed that the flow rate provided is 171 m³/s (CNA, 2012b), in other words, that the mean amount of water supplied per capita in the country's largest cities is 288 liters per capita per day. This value fluctuates between cities with a high daily demand (over 575 l/inh. in cities such as San José del Cabo, Guaymas and San Juan de los Lagos, Jalisco) and those with a supply of less than 125 liters per inhabitant per day (Zinacantepec, Toluca Metropolitan Area; Acayucan, Veracruz and El Pueblito, Querétaro Metropolitan

Area). It is necessary to conduct a more detailed study to determine the reasons for these differences as well as the possibilities for improving the efficiency of urban water use.

3.2 Overexploitation of surface and groundwater in urban areas

The degree of exploitation of surface water in the country's 731 watersheds is calculated on the basis of their annual mean availability. The basins that currently have surface water available for concessions are shown on the map in green, while those with deficits are presented in red (Map 6).

Since the 1970s, groundwater resources and their exploitation have increased significantly. There were 32 overexploited aquifers in 1975, 80 in 1985 and 101 in 2011. A total of 53.6% of the groundwater for all uses is extracted from over-exploited aquifers. Map 7 shows the availability of groundwater by administrative hydrological region.

The Río Grande and Lerma Santiago hydrological-administrative region contains the largest number of overexploited aquifers in the country. In the North Central Basins, Aguas del Valle de México and Lerma Santiago regions, at least 25% of aquifers are overexploited. Conversely, none of the aquifers in the regions of the South Pacific, Northern Gulf and Southern Border and the Yucatán Peninsula are overexploited .

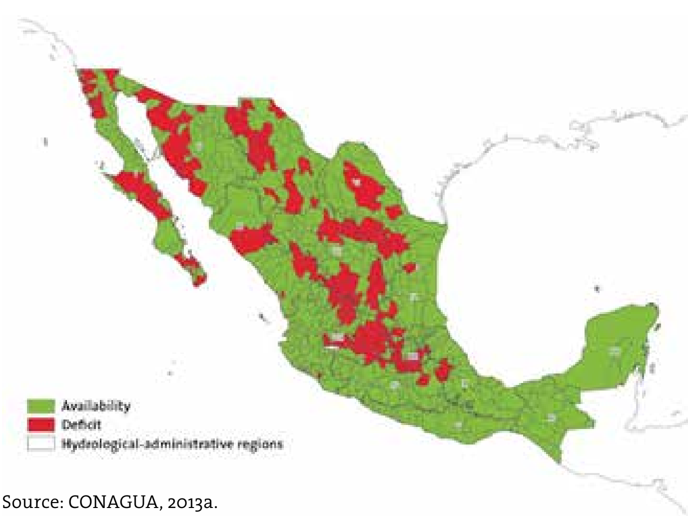
Recently, a study by the Mexican Institute for Competitiveness (IMCO, 2013) published several indicators to assess the urban competitiveness of the 77 major Mexican cities. The environmental indicators included data on the overexploitation of aquifers, more specifically the percentage of area that is over-exploited. Cities with more severe problems of aquifer overexploitation include Aguascalientes, Mexicali, La Paz, Ensenada, Tijuana, Los Cabos, Campeche, Ciudad del Carmen, Saltillo, Monclova-Frontera, La Laguna, Piedras Negras and Tecomán. As shown in Table 2, several of the country's cities lie on aquifers that do not experience a degree of exploitation of over 25%.

The Mexican government has several instruments, including closed areas, to deal with the exploitation of water resources, whether surface or underground. A closed area is a specific area of a

Map 6. Availability of surface water

Source: CONAGUA, 2013a.

Map 7. Availability of groundwater by administrative hydrological region



Source: CONAGUA, 2013a.

hydrologic region, watershed or aquifer, which the state regulates by setting the volume of extraction, use and discharge that may be authorized. Closed areas can be decreed due to the deterioration of the water as regards either quantity or quality, effects on hydrological sustainability or damage to surface or groundwater. In the case of groundwater, by December 2009, 145 closed areas had been announced between 1948 and 2007.

3.3. Water in Mexico's Peri-urban Areas

Urbanization in Mexico has followed a similar pattern to other countries in Latin America and much of the rest of the world. When the recurring crisis of world capitalism revealed the limits of the import substitution development model, Latin American countries and Mexico in particular, undertook industrialization in their own territories, thereby accelerating urbanization. Like so many others, Mexico City expanded exponentially, superimposing different areas and cultures. This gradually shaped a growth model towards the periphery, which, although driven by industrial development, did not always meet with appropriate government regulations for territorial occupation. In many places, population growth came up against (and indeed continues to do so) the ways in which governments produce territorial zoning and discourage the progress of housing towards areas classified as conservation areas. At other times, the communities of origin themselves are the ones that refuse to address the issue of population growth in their territories. This is how informal, irregular and even illegal urban spaces begin to emerge in periurban zones. The growth restraining mechanism used in almost all cases is the denial of services to the population, including water, as an essential element for building dwellings.

Peri-urban areas are thus characterized as transitional spaces between rural and urban settings, where specific relations and cultures from the two areas coexist, enabling the creation of new forms of water supply. Some of these options are more or less autonomous, independent of the government option based on formal mechanisms establishing network access as the only alternative. Among the different forms of water supply found in various studies are commercialization through water trucks, where people buy water or community arrangements for the construction, maintenance and operation of the local system, usually based on high investment by the residents themselves (by working on tasks and serving in honorary positions to administer the system, payment of regular and special quotas, etc.). In addition to infrastructure aspects, these mechanisms also include self-management regulations that include the control and monitoring of systems and the implementation of sanctions. In this respect, the ways in which the territory is built create a complex mosaic of water supply alternatives, many of which produce original, independent forms that even contradict government arrangements (Palerm, 2013; Torregrosa et al, 2006).

Therefore, it can be said that in response to the state's withdrawal from the capacity to ensure the supply of universal quality water, viable alternatives emerge such as more or less autonomous, informal, irregular and illegal community arrangements, which, together with a broad spectrum of the water market, whether formal, informal or illegal, provide solutions to what the state is unable or unwilling to resolve. In these territories, the regulations and mechanisms of access and operation of the water supply system are built on a day to day basis and are part of the daily struggle for a better quality of life.

Table 2. Overexploitation of Aquifers in Major Mexican Cities, 2012

% Aquifer surface Overexploited	Cities
> 90%	Aguascalientes, Campeche, Ciudad del Carmen, Ensenada, La Paz, Los Cabos, Mexicali, Monclova-Frontera, La Laguna, Piedras Negras, Tecomán, Tijuana and Saltillo.
Between 75% and 90%	Colima-Villa de Álvarez, Chihuahua, Manzanillo, Tapachula and Tuxtla Gutiérrez
Between 50% and 75%	Celaya, Durango, Juárez and Valle de México.
Between 25% and 50%	Guanajuato, Irapuato and León
< 25%	Acapulco, Cancún, Cárdenas, Ciudad Obregón, Ciudad Victoria, Coatzacoalcos, Córdoba, Cuautla, Cuernavaca, Culiacán, Chetumal, Chilpancingo, Guadalajara, Guadalupe, Guaymas, Hermosillo, La Piedad-Pénjamo, Los Mochis, Matamoros, Mazatlán, Mérida, Minatitlán, Monterrey, Morelia, Nuevo Laredo, Oaxaca, Ocotlán, Orizaba, Pachuca, Pánuco, Poza Rica, Puebla-Tlaxcala, Puerto Vallarta, Querétaro, Reynosa-Río Bravo, Ríoverde- Ciudad Fernández, Salamanca, San Francisco del Rincón, San Juan del Río, San Luis Potosí, Soledad, Tampico Tehuacán, Tehuantepec-Salina Cruz, Tepic, Tlaxcala-Apizaco, Toluca, Tula, Tulancingo, Uruapan, Veracruz, Villa Hermosa, Xalapa, Zacatecas and Zamora-Jacona.

Source: Prepared by Jordi Vera, using information from IMCO, 2013.

Table 3. Main cities in Mexico with their population, flow produced and average

State	Locality	Population	Population with service		Flow produced	Supply average
			(Inhabitants)	(%)	(l/s)	(l/inhab./day)
Federal District	Mexico City	8,609,001	8,367,691	97	31,418	315
Jalisco	Guadalajara	3,952,185	3,873,141	98	9,586	210
Nuevo León	Monterrey	3,702,161	3,686,612	100	11,076	258
Puebla	Puebla de Zaragoza	1,830,376	1,767,777	97	3,615	171
Baja California	Tijuana	1,619,270	1,586,885	98	3,589	191
Chihuahua	Juárez	1,360,865	1,320,039	97	5,437	345
Mexico	Ciudad Nezahualcóyotl (conurbat-ed municipality of Mexico City)	1,096,911	1,085,942	99	2,472	195
Yucatán	Mérida	878,059	834,156	95	3,000	295
Mexico	Naucalpan de Juárez (conurbated municipality of Mexico City)	834,525	817,835	98	1,300	135
Chihuahua	Chihuahua	831,211	764,714	92	3,992	415

Source: CONAGUA, 2012c.

Table 4. Evolution of drinking water coverage in urban areas, 1990-2012

Year	Total population in private dwellings	Inhabitants (millions)			Percent Coverage
		With service	Without service	Beneficiaries	(l/inhab./day)
1990	57.3	51.2	6.1		89.4
1995	66.7	62	4.7	10.8	92.9
2000	71.1	67.3	3.8	5.3	94.6
2005	76.1	72.3	3.8	5	95.0
2010	84.4	81	3.7	8.7	95.6
2010*	85.4	81.5	3.9	0.5	95.4
2012*	87.9	84.0	3.9	1.3	95.5

Adapted from: INEGI, 2010.

4. Drinking water supply in urban areas

4.1. Current status of drinking water coverage and access in the country

Table 3 shows some of the most densely populated cities in the country, including Mexico City, Guadalajara, Monterrey and Puebla. In these cities, coverage is above average, fluctuating between 97% and 100% of the population (CONAGUA, 2012c). Mexico City and Monterrey consume the largest volume of water. In both cases, the urban water supplied travels long distances through complex hydraulic systems. The case of Mexico City and the Cutzamala system are the best known example of this.

As regards the mean provision of the ten main Mexican cities, Juárez and Mexico City are the two cities with average supplies exceeding 315 liters per inhabitant per day, while cities such as Puebla and Naucalpan have the lowest water supply (under 172 liters / inhabitant/day).

In December 31, 2012, 92.0% national drinking water coverage was recorded, when 1.7 million inhabitants were incorporated into the service for the first time (CONAGUA, 2013b). At the state level, 25 Mexican states recorded coverage of over the national average, with Yucatán and Colima leading with over 98%. By contrast, Chiapas, Oaxaca and Guerrero have less than 80% coverage. In urban areas, the evolution of piped water coverage (1990-2011) is shown in the Table 4.

4.1.1 Coverage in relation to income groups

Nationwide data of this nature is unavailable. However, there are several studies that address the problem at the level of localities, *delegaciones* (boroughs) and municipalities. These studies reveal the fragility of official figures, since, even in cities with good network coverage such as the Federal District, the issue of receiving supplies water in shifts, irregular grid connections and the supply of significant sectors of the population by water trucks is significant and qualifies the coverage figures mentioned in the official data. With regard to official information, there are studies at the neighborhood level in urban areas of the country (Urban Marginalization Index 2010, CONAPO), where the degree of marginalization of the inhabitants is known and may be linked to piped water coverage.

An indirect indicator of water vulnerability is the availability or otherwise of water tanks, cisterns and underground cisterns known as *aljibes* (water tanks containing between 500 and 10,000 liters). This indicator was available for the first time as part of the expanded questionnaire of the INEGI Population and Housing Census 2010. Given that the piped water service in the Mexican cities is provided in shifts, this indicator reflects the water vulnerability of residents who lack these water supply systems. As can be seen in Table 5, inhabitants of major urban areas are less vulnerable than those of rural areas.

4.2 Characterization of services by continuity, water quality and water leaks in the system

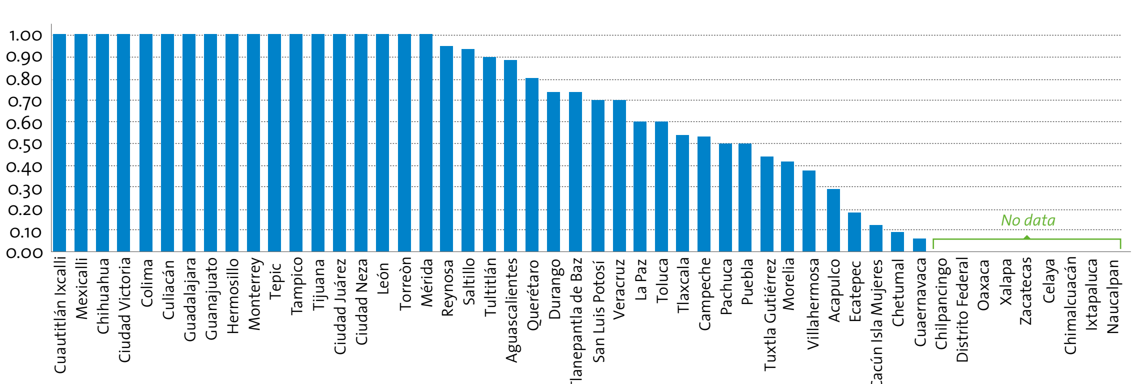
Data on continuity of service nationwide were collected for the first time in the INEGI Census 2010. However, these data are not available for urban areas in the country, but only for the national mean and the 31 states and the Federal District. The data show that the states of Baja California, Chihuahua, Quintana Roo, Nuevo León and Tamaulipas have the best water service, since more than 95% of dwellings are supplied with water on a daily basis. By contrast,

Table 5. Availability of water storage systems by size of locality

Size of locality	Equipment	Inhabited private dwellings	Availability		
			Available	Unavailable	Unspecified
Mexico	Water tank	28,643,491	55.1	43.6	1.3
Mexico	Cistern or underground cistern	28,643,491	25.8	72.8	1.4
Under 2500 inhabitants	Water tank	6,282,646	36.2	63.0	0.8
Under 2500 inhabitants	Cistern or underground cistern	6,282,646	11.3	87.9	0.8
100,000 or more inhabitants	Water tank	14,317,340	63.3	35.0	1.9
100,000 or more inhabitants	Cistern or underground cistern	14,317,340	34.6	63.5	1.9

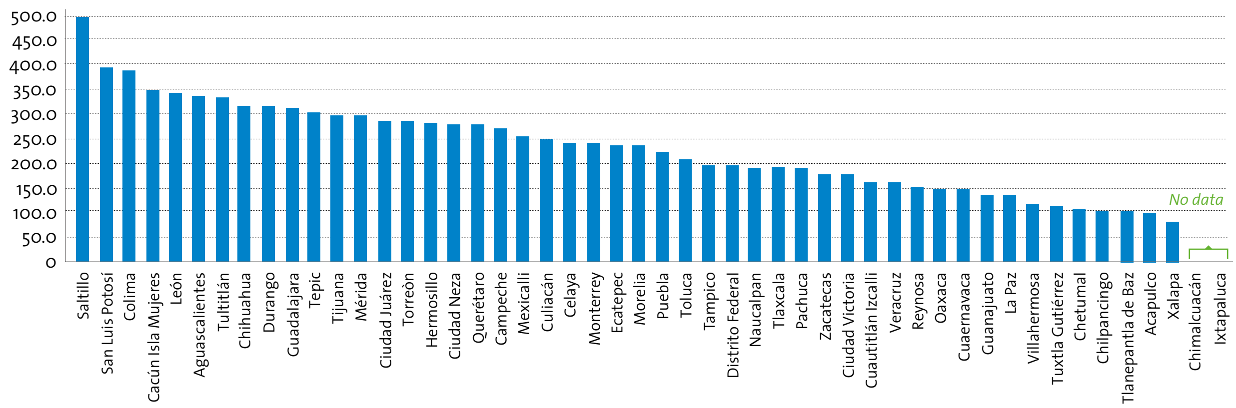
Adapted from: INEGI, 2010.

Graph 2. Distribution of continuity factor in 50 Mexican cities



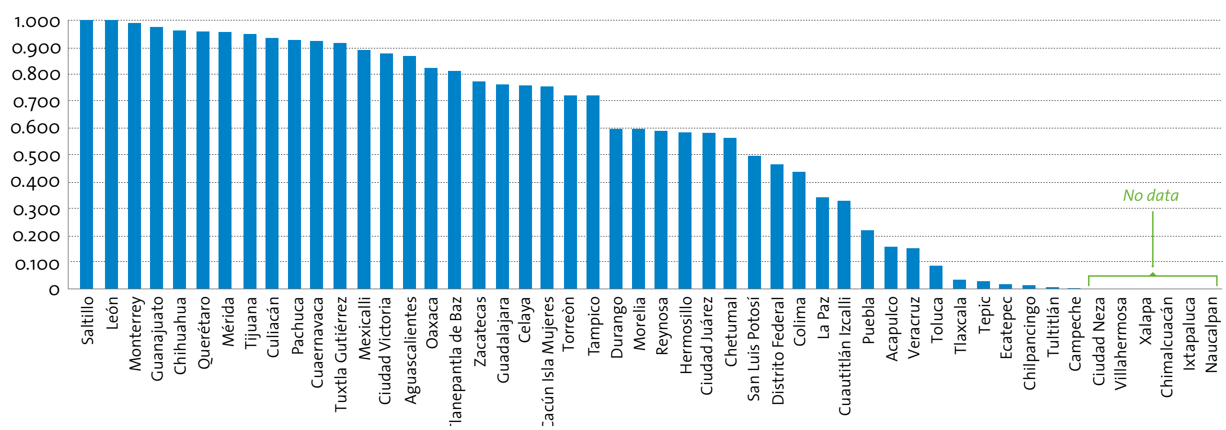
Source: CCA, 2011.

Graph 3. Distribution of productivity factor among 50 Mexican cities



Source: CCA, 2011.

Graph 4. Distribution of percentage of connections with household meters in 50 Mexican cities



Source: CCA, 2011.

the states of Chiapas, Guerrero, Oaxaca and Puebla have the worst service, with several dwellings having sporadic water service provided once or twice a week, despite being the states with the greatest water availability in the country.

Graph 2 shows the distribution of a continuity factor (Sandoval, 2012), in other words, the percentage of connections that receive water 24 hours a day, 7 days a week, according to information from the utility companies.

Graph 3 shows the distribution of a "productivity factor" that takes into account the number of connections per operator of the piped water system. Nearly half the sample falls below acceptable levels. In this case, although the topographical context of each city and the complexity of the networks may play a role, this indicator is mainly due to the existence of powerful unions in certain regions of the country that prevent the optimization of the workforce (Sandoval, 2012).

In Graph 4 shows the percentage of metered connections. Nearly two-thirds of cities have under 80 percent of metered connections. On the basis of the above information, Sandoval (2012) notes that:

- National service coverage statistics, measured in terms of household connections that enable the supply of drinking water and wastewater discharge, indicate high coverage, but when continuity of service is analyzed, numbers vary widely.
- There are significant differences in labor

productivity and commercial efficiency. Cities in the north of the country have the best indicators.

4.3 Water source management and administration

4.3.1 The water service structure

In recent years, Mexico has undergone profound changes in its water policy. These changes begin in the 1980s, when the Mexican state expressed its determination to decentralize public drinking water provision. The first step occurred in 1980, when the federal government ceded the operation of water and sewerage systems to state governments, which in some cases was in turn transferred by the states to municipalities (Castro et al., 2004).

Drinking water service was subsequently municipalized in 1983 through the passage on February 3 of a constitutional amendment to Article 115, stipulating that drinking water services were the responsibility of municipalities. This resulted in the devolution and decentralization of drinking water administration, infrastructure and investment, from the federal government to state and municipal governments.

On January 16, 1989, President Salinas created the National Water Commission (CNA) as a decentralized agency. Towards the end of that year, he proposed the decentralization, autonomy and promotion of private participation in the operation of water services, with citizen participation. In 1992 a new National Water Law was passed, designed, among other things, to strengthen the concession of rights of use and encourage private water management. Two new agencies were created: the Watershed Councils, understood as a new field of water management involving the various sectors and local authorities, and the Public Water Rights Register, designed to stimulate a commodity circulation of the water rights licensed by CONAGUA. The Law also explicitly stated the authorities' interest in having society participate in various fields: by paying more for services, creating a new water culture or investing in capitals (Aboites, 2004).

The 1992 legal reforms reinforced the decentralization and private participation policies in the sector, radically reorienting the role of public institutions in resource administration and management. Likewise, irrigation districts were transferred to the users thereof. Districts were divided into irrigation modules according to the secondary network, networks and roads, and an Association of Users was created in each of them, to which the CNA granted a Water Concession and Infrastructure Use Title (Castro et al., 2004).

State programs generally reflect federal policies marked by frequent statewide negligence as regards assuming a larger role in regulating water and sanitation, and a lack of capacity. However, some states have established investment programs with support from the federal government to contribute to the expansion of service coverage on the one hand, and encourage the streamlining of water and energy use and business development on the other (Sandoval, 2012).

4.3.2 Organizational mechanisms and/or innovative technologies for providing services for urban areas

CONAGUA allocates federal funds through a set of investment programs, each with individual operating rules that tend to vary slightly from year to year and in addition have to conform to the rules also set by state authorities. In recent years, the main programs have been:

a. APAZU (Drinking Water, Sewerage and Sanitation in Urban Areas Program), created in 1990 to support state and municipal projects for the expansion and improvement of water services.
b. PAL (Clean Water Program), implemented since 1991, designed to increase and maintain, through chlorination, disinfection levels of the water supplied to the population, in order for it to meet the criteria for human use and consumption.
c. Prossapys (Program of Sustainability of Drinking Water and Sanitation Services in Rural Areas), implemented in 1999, designed to expand coverage of services in localities with under 2,000,500 inhabitants.
d. PROMAGUA (Program for the Modernization of Water Operating Organizations), implemented in 2001 to support public services in cities with more than 50,000 inhabitants, where private participation schemes are promoted.
e. PRODDER (Devolution of Rights Program), which seeks to contribute to the implementation of measures to improve the efficiency and

infrastructure of drinking water, sewerage and wastewater treatment in municipalities, by assigning federal income obtained from the collection of dues for the exploitation, use or exploitation of national waters to drinking water and sewerage providers.

f. Support program for the Valley of Mexico for water and sanitation projects, recently named "Water Sustainability Program for the Valley of Mexico." This program is assigned federal funds, in addition to the funds obtained from the public services that receive water supplied by the CONAGUA infrastructure (Cutzamala, Lerma and wells operated by the federal organization). Funds are managed by a trust originally established for the implementation of an international credit.

g. PROTAR (Wastewater Treatment Program), the forerunner of which was created to support public utility companies' investment programs in construction, improvement and expansion.

h. PROSANEAR (Federal Wastewater Treatment Program), in which a tax incentive is created through the cancellation or exemption from payment of water discharge rights by municipal authorities. Funds have been allocated to offset the operating costs of sewerage treatment for public services demonstrating full compliance with discharge standards.

i. PROME (Program for Streamlining Public Water Services) under a technical assistance program signed with the World Bank (called "PATME"), with the aim of reinforcing the technical development and financial self-sufficiency of a

Table 6. Strategic Urban Infrastructure Projects for Water, Sewerage and Cleaning

Category	Projet	Metropolitan area or city	Investment (approx. figure in million USD).	Status Nov. 2012
Valle de México	New sources	Mexico	353	Studies
	Cutzamala System	Mexico	547	Under construction
	Atononilco Wastewater Treatment Plant	Mexico	794	Under construction
	El Caracol Wastewater Treatment Plant	Mexico	61	Under construction
	East (TEO)	Mexico	1574	Under construction
	Sewerage works	Mexico	246	Under construction
	River Company Tunnel	Mexico	150	Completed
	Rio de los Remedios Tunnel	Mexico	62	Completed
	Main Canal Pipeline	Mexico	38	Completed
Dams and aqueducts	El Zapotillo Dam	León - Guadalajara	349	Under construction
	El Zapotillo Aqueduct	León	666	Under construction
	El Purgatorio	Guadalajara	449	In bidding process
	El Realito Dam	San Luis Potosí–Celaya	82	Completed
	El Realito Aqueduct	San Luis Potosí	191	Under construction
	Improvement of integral water management	San Luis Potosí	71	Under construction
	Paso Ancho Reservoir	Oaxaca	73	Under preparation
	Paso Ancho Aqueduct	Oaxaca	132	Under preparation
Wastewater treatment	Sewerage works	Guadalajara	286	Under construction
	Agua Prieta Wastewater Treatment Plant	Guadalajara	202	Under construction
	El Ahogado Wastewater Treatment Plant	Guadalajara	67	Completed
	Cleaning up of Atoyac River	Puebla and Tlaxcala	66	Under construction
	Cleaning Apatlaco up of Río	Morelos (Cuernavaca)	130	Under construction
	Total Acapulco Sanitation	Acapulco	57	Under construction
Desalination projects	Ensenada	Ensenada	40	Under construction
	Other projects	Seven cities	251	Under preparation
Total			**9112**	

Source: (CONAGUA, 2012e) – In millions of pesos, November 2012.

selected group of public services. It has a component to enhance CONAGUA's capacity to collect information, assess the development of the sector and "modernize" public utility companies' services, by providing assistance and technical evaluation as well as a "classic" investment program based on assessment and diagnosis, with certain actions implemented within the framework of a results-based spending plan.

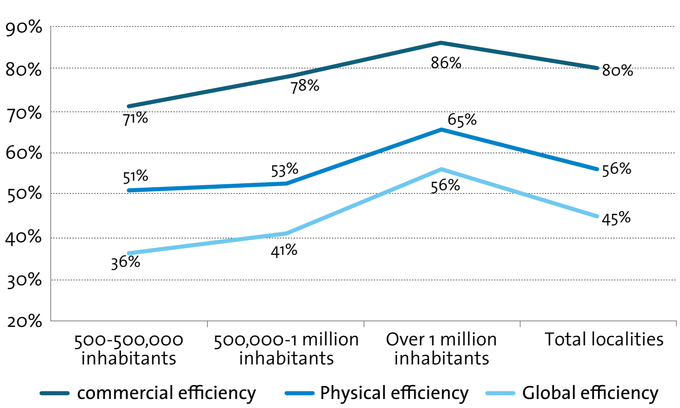
Most of the funds are allocated by transferring resources to the state or municipal authorities, under a coordination agreement whereby the executors agree to follow federal rules.

Increases in water demand in metropolitan areas pose an enormous challenge for local and federal authorities, as a result of which strategic projects have been developed. Table 6 shows the most important ones, where the amount of investment exceeds $9 million USD. Most projects have been implemented in conjunction with capacity building programs to improve the performance of public services and to make projects financially viable.

4.3.3 Efficiency indicators of operating companies

Graph 5 shows the physical and commercial efficiency of the operating companies by size of the locality. As one can see, the larger the urban population, the greater the commercial and physical efficiencies. The highest efficiencies are found in cities with over one million inhabitants.

Graph 5. Physical and commercial efficiencies by size of locality



Source: CONAGUA, 2012c.

Investments for 2011 totaled $2,911,300 USD (37,474.9 million pesos), of which 83.1% were assigned for urban areas and the remainder for rural areas (CONAGUA, 2012b).

In urban areas, resources were spent on drinking water (19.3%), sewerage (37.5%), sanitation (22.3%), improving efficiency (14.7%) and other items (6.2%). The State of Mexico, Mexico City and its metropolitan area alone absorbed 9.7 billion pesos. Of these 37.47 billion pesos, 31 billion were spent on the construction and rehabilitation of drinking water works, sewerage and sanitation; 15,688.4 million were provided by the federal government; 5907.2 million by state governments; 3,456.7 by municipal governments and 6,076.7 million by other entities. These areas are home to approximately 30% of the country's total population.

4.3.4 Water financing and management in Mexico

In Mexico, water infrastructure is funded by the following:

- Tariffs, with a limited ability to generate resources for capital investment.
- Taxes, transferred from chapters to municipal spending and federal or state transfers, since local taxes such as property taxes are rarely applied to capital investments for water in cities, partly as a result of the existence of the aforementioned transfers.
- Transfers, directly as specific chapters in federal taxes, are assigned on a regular basis, as well as in the form of state and federal programs, usually associated with a set of operating rules stipulating the technical, administrative and financial commitments expected from the utility company or municipality.
- Credit, which is only directly available to the few utility companies operating with sound financial structures and reasonable stability. Recently, however, there have significant efforts to support certain private participation schemes, together with venture capital and subsidies where the federal or state government usually assumes financial commitments, rather than the municipality or utility company.
- Direct private investment, which, with the exception of "Aguas de Saltillo" is unusual (Sandoval, 2012).

The rates charged for drinking water collection for domestic use are shown in Table 7, for major cities of the country in the years 2011 and 2012. The table shows that in eight cities, rates remained unchanged for the water collection service, while the remaining 24 increased. Within this group of 24 cities, the most striking cases involve Aguascalientes, León, Xalapa and municipalities in the Mexico City Metropolitan Zone such as Naucalpan and Atizapán, where increases of between 7% and 15% were recorded, even though their rates per cubic meter were already among the highest in the group of cities presented.

4.4 Water saving in cities, efficient water use and new designs for low water consumption

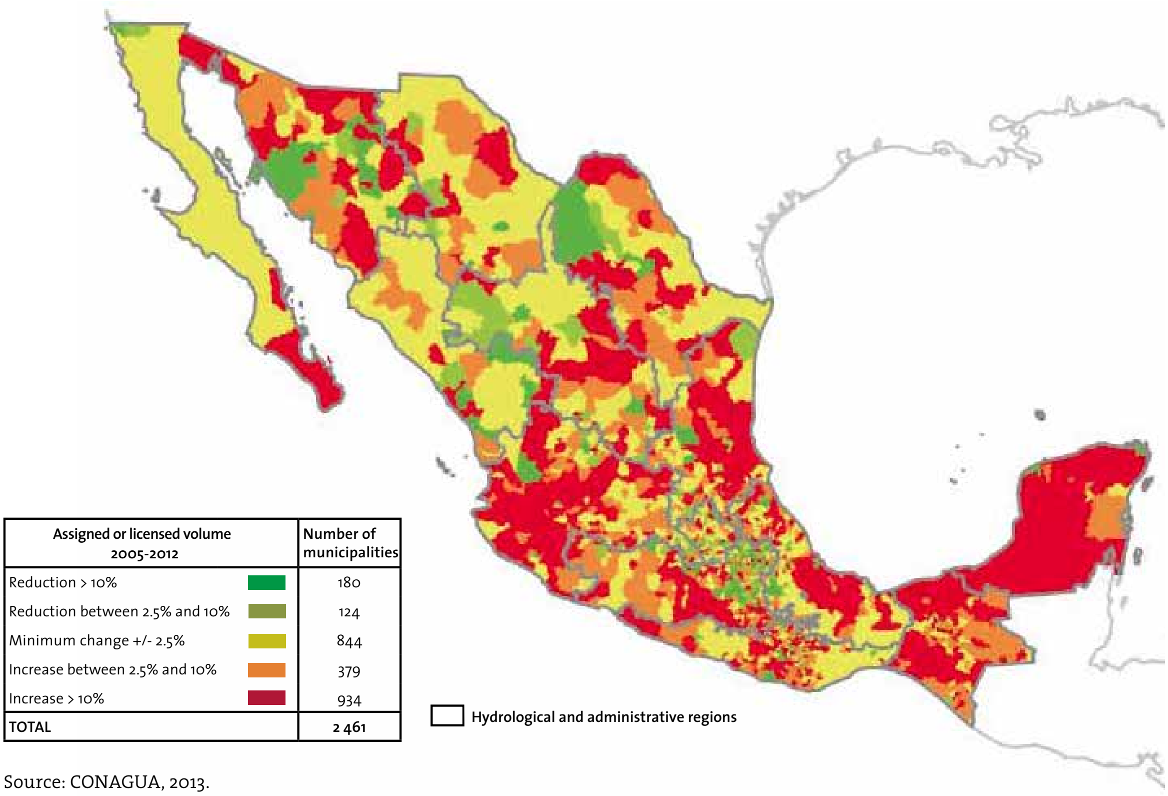
Map 8 shows that very few municipalities experienced a reduction in consumptive uses of water between 2005 and 2009. Conversely, several municipalities saw increases of over 10%. Unfortunately, this data includes all consumptive uses not just urban public use, which would be more helpful for determining trends in cities.

Table 7. Percentage change in water rates for domestic consumption in the main cities in Mexico (2011-2012)

City	2011	2012	Variation in rates ($)	% to/
Acapulco	9.3	10.4	1.1	12
Aguascalientes	17.8	19.2	1.4	7.7
Atizapán	13.5	15.2	1.7	12.9
Campeche	1.8	1.8	0	0
Cancún	9.9	9.9	0	0
Chetumal	9.9	9.9	0	0
Colima	4.2	4.3	0.2	4.1
Culiacán	4.5	4.9	0.4	9.1
Delicias	5.4	5.4	0	0
Mexico City	15.6	16.2	0.6	3.6
Ensenada	13.8	14.2	0.5	3.5
Gómez Palacio	7.1	7.4	0.3	4.1
Guadalajara	5.6	5.8	0.2	4
Hermosillo	4.7	4.7	0	0
Juárez	5.8	5.8	0	0
La Paz	7.6	8.3	0.7	9.3
León	15.5	16.8	1.4	8.7
Mérida	3.9	3.9	0	0
Mexicali	4.5	4.6	0.1	2.9
Monterrey	8.2	10.2	2	23.8
Morelia	18.3	18.3	0	0
Naucalpan	13.5	15.4	2	14.6
Oaxaca b/	1.6	4.4	2.8	172.8
Puebla	10.1	10.5	0.3	3.5
San Juan del Río	5.3	5.5	0.2	4.2
San Luis Potosí	7	7.7	0.8	10.8
Tijuana	17.3	18	0.6	3.5
Tlaxcala	4.9	5.1	0.2	4.3
Toluca	8.7	9.5	0.7	8.4
Torreón	7.7	8	0.4	4.7
Tula de Allende	3.8	4.6	0.9	22.8
Xalapa	9.4	10.1	0.7	7

This information is based on monthly consumption of 30 m³, a volume regarded as sufficient for a family to cover its basic needs.
Source: CONAGUA, 2013b.

Map 8. Evolution of Consumptive Use by Municipality in the Period from 2005 to 2012



Source: CONAGUA, 2013.

5. Wastewater treatment

Up to December 31, 2012, national drinking water coverage of 90.5% was recorded, when 1.5 million inhabitants were incorporated into the service for the first time (CONAGUA, 2013b). However, the population without this service still stands at 10.9 million, 200,000 less than in 2011 (Table 8). At the state level, 17 states in Mexico recorded coverage above the national average, such as the Federal District and Colima, with coverage of over 98% while Yucatan, Guerrero and Oaxaca registered coverage of below 80%.

Mexico has 2,342 municipal wastewater treatment plants formally operating with a total installed capacity of 140.1 m³/s and a treated flow of 99.7 m³/s. It is estimated that treatment coverage of 47.5% of all the wastewater collected has been achieved. Between 2000 and 2011, wastewater treatment coverage doubled. At the top end, Aguascalientes, Baja California, Nuevo León, Tamaulipas and Guerrero have treatment coverage of over 75% of treated water, while Yucatán, Hidalgo, Campeche, Tabasco and Chiapas have the lowest wastewater treatment rates. Table 9 lists the ten urban areas with the highest installed capacity and treated flow, led by Monterrey, Mexico City, Chihuahua and Juárez.

States that experienced a significant increase in coverage in the period from 2003 to 2011 include Baja California, Chiapas, Chihuahua, Querétaro, San Luis Potosí, Tamaulipas and Veracruz (CONAGUA, 2012c).

5.1 Treatment Systems

The most commonly used method in terms of the number of plants in the country is stabilization ponds, utilized in 732 plants, equivalent to 31.2% of the total number. This is followed by activated sludge, employed in 698 plants, 29.8% of the total, and in third place by the URA (Up-flow Anaerobic Reactor) process, utilized in 188 plants equivalent to 8% of the total. These figures contrast when the treated flow is analyzed. In this case, the most important systems are activated sludge, which treats 46% of the wastewater collected, ponds, which account for 16% and advanced primary treatment, which processes 11% (CNA, 2012c).

5.2 Reuse and recycling

The Mexican government has a program to promote wastewater reuse through CONAGUA. Known as the CONAGUA Wastewater Reuse and Exchange Program, it is designed to "achieve integrated, sustainable water management, stipulated in the National Development Plan 2007-2012, regarding the management and preservation of water to achieve social well-being, economic development and the preservation of the ecological wealth of our country."

The government is currently in the process of consolidating actions to promote treated wastewater reuse in the country and its exchange for first-use water in those activities in which this option is viable and feasible. The government has also encouraged the participation of both the public and the private sectors in the treatment and reuse of wastewater from various productive activities for agricultural uses, watering green areas, industrial cooling proceses, cleaning and secondary municipal services. As regards the exchange of treated wastewater for first-use water, it would be used in agriculture and industry, among other uses, to stop exploiting ground and/or surface water. The surface water saved would be used to serve growing cities and industries.

Another incentive measure implemented by CONAGUA has been to persuade the operators of water systems for domestic use which decide to

Table 8. Evolution of Sewerage Coverage in Urban Zones, 1990 to 2012

Year	Total population in private dwellings	Inhabitants (millions)			Percent Coverage
		With service	Without service	Beneficiaries	
1990	57.3	45.3	12		79
1995	66	58.5	8.1	13.3	87.8
2000	71.1	63.8	7.4	5.2	89.6
2005	76.1	71.9	4.2	8.1	94.5
2010	84.7	81.6	3.2	9.7	96.3
2010*	85.4	82.2	3.2	0.7	96.3
2011*	86.8	83.6	3.1	1.4	96.4
2012*	87.9	84.8	3.1	1.3	96.5

Note: Percentages and sums may not coincide due to the rounding of figures. * Information up to December determined by CONAGUA. Source: CONAGUA, 2013b on the basis of information from the Censos de Población y Vivienda 1990, 2000 and 2020; Conteos y Vivienda 1995 and 2005.

Table 9. Treated flow in the main localities of over 50,000 inhabitants

State	Locality	Population	Number of treatment plants	Installed Capacity (l/s)	Treated flow (l/s)
Nuevo León	Monterrey	3,702,161	13	10,030	8,728
Federal District	Mexico City	8,609,001	25	6,685	3,148
Chihuahua	Chihuahua	831,211	3	3,705	2,222
Chihuahua	Juárez	1,360,865	4	3,551	2,551
Baja California	Tijuana	1,619,270	14	3,095	2,796
Veracruz	Veracruz	576,437	28	2,986	1,620
Baja California	Mexicali	777,404	5	2,797	1,946
Puebla	Puebla de Zaragoza	1,830,376	5	2,620	2,060
Guerrero	Acapulco de Juárez	685,336	15	2,240	1,937
Coahuila	Torreón	621,541	5	2,125	1,561

Source: CONAGUA, 2012c.

obtain the benefit of federal programs, to include in their construction, expansion, rehabilitation, projects and studies actions the reuse and exchange of treated wastewater, as typified in the Operating Rules for Hydro-Agricultural Infrastructure and Drinking Water, Drainage and Sanitation Programs, applicable as of 2012.

As for water reuse, since 2007, achievements have exceeded the goals set, particularly in 2011 when 2,700 m^3/s more were reused than the amount set (Table 10).

During the first two years of the program, the goal for exchanging treated wastewater was slightly exceeded. This did not happen in 2009 or 2010, but in 2011 the target was once again exceeded by 600 l/s, due to the increase in the use of treated water in industrial activities, with first-use water no longer being employed in activities other than domestic consumption.

While gray or rainwater is rarely treated in Mexico, water from stormwater collectors is normally mixed with that from sanitary collectors and treated together in treatment plants as sewage.

5.2.1 Examples of the reintegration of water into ecosystems. Reuse and Recycling in Mexico City

A study by Jiménez (2013) reports that in order to cope with the challenge of meeting the growing demand for water in Mexico City, local water services that also manage wastewater have implemented various projects for utilizing reuse water for municipal and industrial purposes, some of which have been in operation since 1956. Moreover, the federal government has been responsible for a water reuse program in Mexico City and a second basin for agricultural irrigation since 1920.

At present, at least 260 l/s of water is reused to supply various industries in Mexico City. The main constraint on increasing reuse is cost, since treated wastewater is more expensive than first-use water and there are no regulations requiring companies to use reclaimed water. It is estimated that a proper legal framework for industrial reuse could increase the volume treated by an additional 1,000 l/s.

In addition, 1,300 l/s of reuse water are supplied to prosuction power plants for cooling. Nearly 2,000 l/s are used for the irrigation of green areas and recharging recreational lakes and agriculture. Within the city, 1,200 l/s are used for recharging groundwater and 175 l/s for car washing.

New car wash centers are obliged to use reclaimed water. In addition, a treatment plant produces 600 l/s for ecological purposes, consisting of recharging what was formerly Lake Texcoco, which was drained by the Spaniards during the colonial era.

The last major public projects for planned reuse began operating in late 1980. The amount of reused water from public plants accounts for 10% of the total supply. Moreover, even though they are not officially registered, several dozen private treatment plants reuse water in sports clubs, golf courses and schools for watering the lawn or flushing toilets. Private reuse is not controlled by the government.

The rest of the wastewater produced in Mexico City, approximately 60,000 l/s, is used in its entirety, without any treatment to irrigate 90,000 hectares in the Valley of Tula, located 100 km north of Mexico City. This form of irrigation has been conducted for more than 110 years and, as a result of its use, over 25,000 l/s of wastewater filters into the aquifer. This aquifer provides water from various springs that are

Table 10. Goals 2007-2012 regarding the reuse of treated wastewater (l/s)

Year	Goals	
	Set:	Actual
2007	20,000	20,100
2008	21,000	21,500
2009	21,500	21,700
2010	22,000	22,400
2011	22,500	25,200
2012	23,000	25,200

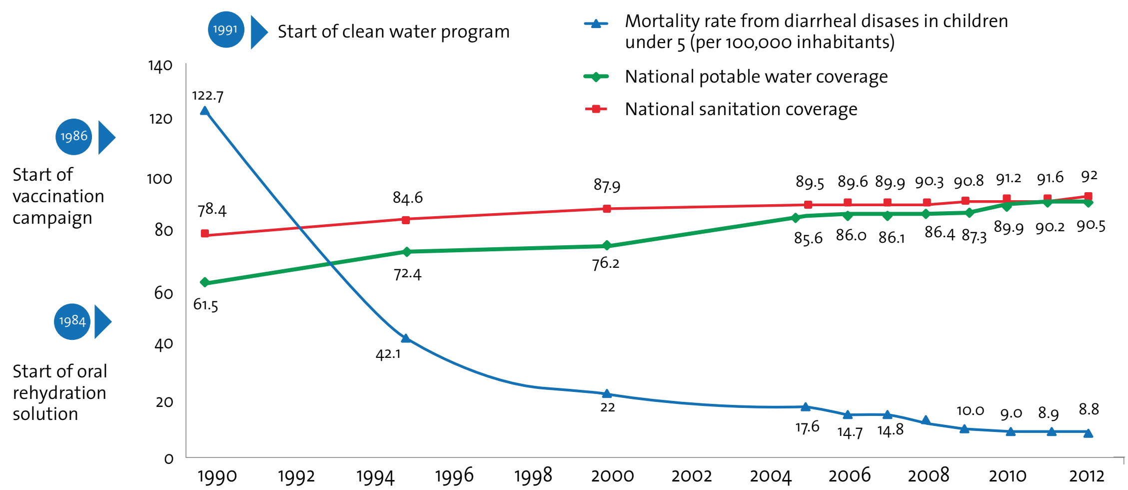
Source: CONAGUA, 2013b.

Table 11. Goals for 2007 to 2012: exchange of treated wastewater (m^3/s)

Year	Goals	
	Set:	Actual
2007	5	5.3
2008	5.5	5.7
2009	6	5.7
2010	6.5	6.2
2011	7	7.6
2012	7.5	7.8

Source: CONAGUA, 2013b.

Graph 6. Drinking water and sewerage coverage and mortality from diarrheal diseases in children under five, 1990-2012



Source: CONAGUA, 2013a.

used to supply the 500,000 people living in the valley of Tula. Despite its origin, the water has proved to be of acceptable quality (Jiménez and Chávez, 2004) due to various treatment mechanisms of natural origin that occur during its transport, storage and infiltration into the soil. In fact, it has been shown that some pollutants such as heavy metals and emerging contaminants remain in agricultural soils for several years or even decades (Siebe, 1995, Gibson, 2007 and Durán, 2009 in Jiménez, 2013).

5.2.1.1 "*WQ*" Standards and Treatment Technology

With regard to standards, Jiménez (2013) explains that wastewater reuse for agriculture has been regulated since the 1980s. These standards were amended in 1986 (NOM-001- SEMARNAT 1986) to adjust the characteristics of the quality of treated wastewater discharged into the atmosphere. In the case of use for agricultural irrigation, in order to control health risks, fecal coliform content was limited to 10^3 MPN/100 ml and helminth egg content to 1/l for all types of irrigation and 5 helminth eggs/l for the irrigation of crops that are not consumed raw or processed. Moreover, a higher BOD was allowed in order to improve the quality of agricultural soils, whereas the use of the amount of heavy metals was limited to the values established by the 2004 Standards of the US EPA for reuse water. As in most countries around the world, in Mexico, there is no government standard for water reuse for industrial purposes. For water reuse in public uses, the NOM-003- SEMARNAT-1997 water standard is employed, which only covers restrictions for biological contaminants. In order to regulate the infiltration of reuse water into groundwater, the NOM-014-CNA-2003 standard has been adopted.

Planned wastewater reuse for industrial and municipal purposes has always been carried out after at least one secondary treatment together with filtration. The effluent produced has proved adequate for most uses, except for recharging recreational lakes, particularly Lake Xochimilco, which currently suffers from eutrophication and therefore require advanced treatment.

All investments in public projects have been through public funding. Plants are also operated by the government in general.

Public reuse projects are managed by Mexico City and municipal water services, while water reuse in agricultural fields outside the Mexico City basin is operated by the federal government.

6. Water and health in cities

The provision of safe water and sanitation is a key factor in the population's health, especially that of children. These services contribute to the control of the incidence of waterborne diseases such as viral hepatitis, typhoid fever, cholera, dysentery and other causes of diarrhea as well as possible effects resulting from consumption of water with toxic chemicals, such such as arsenic or fluoride.

In Mexico, infant mortality from diarrheic diseases was reduced to 8.8 per 100,000 by 2012 (Graph 6), as a result of various public health actions and interventions, among which the distribution of oral serum (as of 1984), vaccination campaigns (as of 1986), the Clean Water Program (since 1991) and increased drinking water and wastewater, sewerage and sanitation coverage. Despite these results, there are states such as Chiapas, Oaxaca and Guerrero with high mortality rates in the order of 41.6, 29.2 and 21.1 respectively (CONAGUA, 2011).

Graph 6 shows the incremental behavior of drinking water and sewerage coverage shown in comparison with the reduction in mortality rates from diarrheal diseases in children under five.

In 2012, more than 6 million cases of intestinal infectious diseases were reported, equivalent to a rate of 5,275 cases per 100,000 inhabitants (considering the INEGI Census 2010 and applying the CONAPO projection for December of that year), indicating a growth rate in relation to 2010 due to the increase in the population and number of cases (CONAGUA, 2013b) (Table 12).

5.1 Certain issues related to health problems and water in Mexico

To understand more about the problems of water-related diseases, it is important to explore the purification and disinfection processes undergone by drinking water. There are 699 water purification plants in operation nationwide (with an installed capacity of 135.1 m^3/s, CNA 2013b). Of the 329.8 m^3/s of water supplied nationwide, it is estimated that 205 m^3/s, equivalent to 62%, comes from groundwater sources, the remaining 124.5 m^3/s being obtained from surface sources, of which 88.8 m^3/s (71%) are processed for potabilization. Conventional clarification is the most commonly used process in terms of the number of plants, since it is employed by 206, followed by reverse osmosis treatment, utilized in 193 plants and, thirdly, the clarification patent used at 158 facilities.

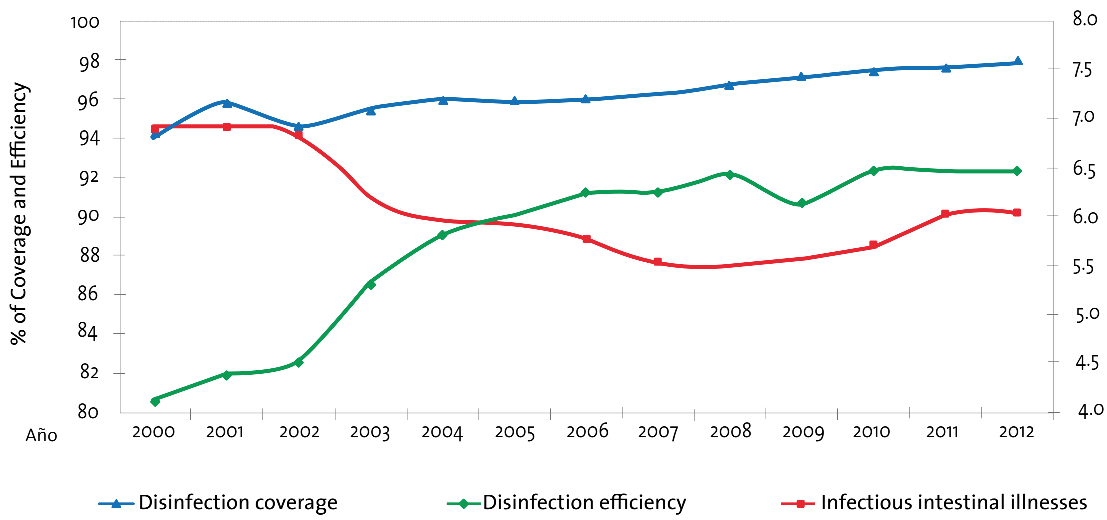
The service provider, usually the municipality and occasionally the state, is responsible for performing chlorination. The effectiveness of the procedure for disinfecting the water supplied to the population through formal supply systems is evaluated through the determination of residual free chlorine, a key indicator, whose presence in the domestic outlet indicates the efficiency of disinfection. The latest available data (CNA, 2013b)

Table 12. Registered cases of infectious diseases of the digestive tract, 2002-2012

Disease	Number of cases per year										
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011a/-	2012
Intestinal infectious diseases	6,831,630	6,191,011	5,351,869	5,912,952	5,765,081	5,533,670	5,500,546	5,564,841	5,705,412	6,025,664	6,045,506
Shigellosis	31,473	27,704	22,321	19,441	16,483	14,799	12,885	13,136	11,378	9,975	8,181
Cholera								0	0	1	2
Typhoid Fever	7,889	20,020	25,952	31,790	37,012	44,076	44,199	46,174	44,757	48,055	54,147
Paratyphoid fever and salmonellosis	80,494	102,754	109,444	109,536	115,014	122,956	120,986	139,143	120,414	122,345	128,434
Intestinal virus infection, other agencies and ill-defined	5,374,980	4,823,611	4,778,135	4,765,567	4,716,011	4,616,080	4,645,091	4,715,783	4,923,459	5,283,896	5,345,173
Bacterial food poisoning	21,659	36,057	39,947	40,559	37,987	36,121	35,887	38,555	40,903	44,467	47,165

a / The number of cases by type of illness does NOT coincide with those reported in the CONAGUA 2012c edition, because the Secretariat of Health adjusted its information. SOURCE: Secretariat of Health, *Boletín Epidemiológico*, Published by the Single Information System for Epidemiological Surveillance of the Secretariat of Health (week 52, 2012, Preliminary Information).
Source: CONAGUA, 2013b.

Graph 7. Disinfection coverage and efficiency vs. Incidence of intestinal infectious diseases, 2000 to 2012



Source: CONAGUA, 2013.

show that in 2012, disinfected water coverage of 97.9% was achieved (Graph 7).

Since supply sources receive increasing amounts of contamination, they have deteriorated and when they are subjected to a conventional disinfection process such as the addition of chlorine, they produce disinfection by-products known generically as organochlorinates (Aboites et al., 2008), there being a relationship between these compounds and various forms of cancer.

7. Climate Change and Variability and the Resulting Impact on Water Resources in Cities

Although Mexico produces about 1.5% of greenhouse gases, it is one of the countries most at risk of climate change. In urban areas, the effects of climate change will be increased and intensified by other processes that will make them more dangerous, meaning that a prospective view of the vulnerability of cities in Mexico must be integral.

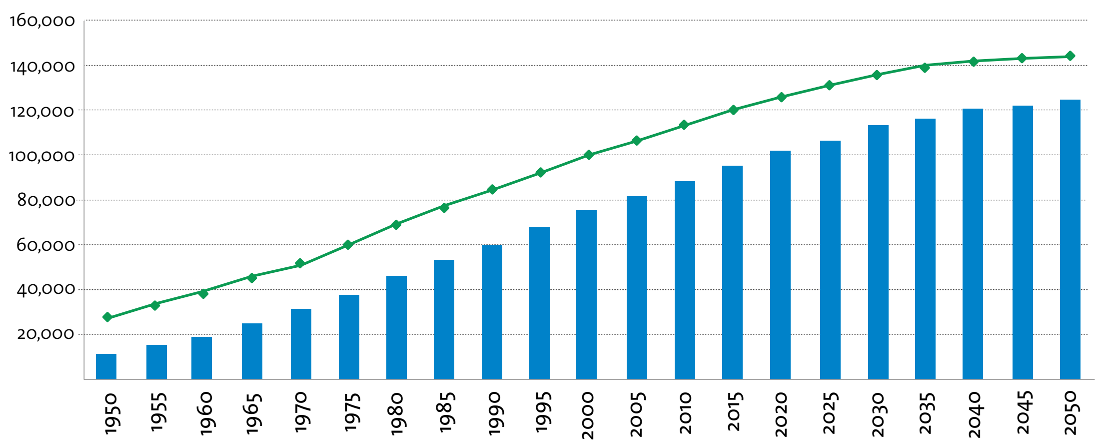
One might assume that the most vulnerable areas are rural areas, due to their historical conditions of poverty and marginalization. However, some of the most vulnerable regions are in fact certain major cities, mainly due to factors that increase their vulnerability, such as population growth, urban concentration and the location of cities in areas with scant or overexploited water resources, or which increase settlements in high risk areas due to climate change impacts, which increase their degree of exposure. Climate and hydrometeorological disasters include the following: droughts, food insecurity due to lack of irrigation water or drought, extreme temperatures, floods, forest fires, insect infestations, earth movements associated with situations of a hydrological origin and windstorms. These events account for a significant portion of the estimated damage caused by disasters, which in 2009 caused $35,409 billion USD in damages, 85% of the total caused by all types of disasters.

The urbanization process, which has stabilized in developed countries, will continue in the following decades in developing countries, as foreseen by the United Nations Population Division (UN, 2012). Thus, the urban population will increase by 72% between 2011 and 2050, from 3.6 billion to 6.3 billion, respectively. Virtually all of the new urban population will be concentrated in cities in less developed countries. These urbanization processes will pose enormous regional challenges to water management, since with very few exceptions, nature does not provide the water necessary to supply human concentrations of this magnitude locally, not to mention the difficulties of of the resulting wastewater treatment and disposal, as well as the by-products of processing, particularly sewage sludge.

As noted earlier, in Mexico this urbanization process began rapidly in the 1950s and will continue into 2050, as shown in Graph 8. According to these estimates, in 2030, the country will achieve an urban population of nearly 112 million (82.6% of the total) and of nearly 124 million by 2050 (86% of the total). Mexico's urban population will increase by 35.7 million in 2050 compared to the 2010 data, which is greater than the sum of the current metropolitan areas of Mexico City, Guadalajara, Monterrey and Puebla population, the four largest in the country. The challenges associated with supply and sanitation will be enormous and require extremely efficient urban water management, together with wastewater treatment and environmental conservation measures, required to preserve supply sources.

Urban concentration in mega-cities poses special problems. According to United Nations estimates (UN, 2012) , the population in cities with

Graph 8. Total (line) and urban (bars) population in Mexico for the period from 1950 to 2050



Source: Prepared by Polioptro Martinez using data from the United Nations Population Division.

Table 13. Observed effects and possible impacts on water services as an effect of climate change

Observed effect	Observed or potential impacts
Increase in ambient temperature	Reduced availability in basins fed by shrinking glaciers, as observed in certain cities in the Andes in South America.
Increased water temperature	Reduction of dissolved oxygen, mixed patterns and capacity for self-purification. Increased eutrophication
Rising Sea Level	Salinization of coastal aquifers.
Changes in rainfall patterns	Changes in availability due to changes in rainfall and other related phenomena (i.e. aquifer recharge, evapotranspiration)
Increased variability of annual precipitation	Greater difficulty in controlling avenues and using storage in rainy season.
Increased evapotranspiration	Reduced availability Salinization of water resources Lower groundwater levels
More frequent and intense extreme events	Avenues affecting water quality and the integrity of the hydraulic infrastructure, further erosion of channels that introduce different types of pollutants into water resources. Drought affecting water availability and quality.

Source: Bates et al., 2008.

over 10 million people will reach more than 10 million, compared with the 148 million residing in cities that size in 1970. In Mexico, in approximately 2030, about 50% of the population will live in just 31 cities with over 500,000 inhabitants, with high concentrations in the mega-cities of Mexico City, Guadalajara, Monterrey and Puebla (Box 1 shows a case related to climate change and its effects on cities). Many of these Mexican cities, as mentioned earlier, are located in regions where almost all the water resources have been used up or are being overexploited.

Without even considering the effects of global climate change, by 2030 some of Mexico's major basins will record high water stress conditions. In approximately 2030, in the Valle de Mexico, the absolute shortage it already suffers will be exacerbated. The Rio Grande and Baja California Peninsula regions will experience extreme scarcity while the Lerma-Chapala basin will be under conditions of water scarcity (less than 1,700). The Balsas and North Central Basin hydrological-administrative regions will encounter conditions of virtual scarcity, which they will probably experience if the effects of climate change are added.

The above mentioned scenario, which basically takes changes in water demand into account, will be compounded by the effects of changes in water supply and hydro-meteorological risks, caused by alterations in the water cycle due to climate change.

According to the International Panel on Climate Change (IPCC) (Bates et al., 2008) certain effects of changes in temperature and precipitation on water services can already be observed. Some of the major changes observed or expected are shown in Table 13. With regard to annual average water availability, recent studies on Mexico (Martínez Austria and Patiño Gómez, editors, 2011) estimate that by the end of this century, precipitation will be reduced by about 15.2%, as shown in Table 14.

This reduction in rainfall will produce even greater decreases in runoff and groundwater recharge, which ultimately determine availability. This is because, with drier soil and increased evapotranspiration of natural vegetation, caused by higher temperatures, more rainfall will be retained and evaporated in soil and vegetation, without reaching rivers or other surface or ground water bodies. Examples of this ratio include estimates for the Río Conchos basin, a sub-basin of the Río Grande, which shows that while rainfall will decrease by an average of 20% by the end of the century, runoff will be reduced by 27% (Rivas et al., 2010).

As for the reduction of dissolved oxygen in water bodies as a result of a higher temperatures, this seems to be the cause, combined with lower available volumes, of cyanophytes algae blooms in the Valle de Bravo dam, which feeds the Cutzamala sys-

Table 14. Percentage decrease of precipitation due to climate change

State	Projected decline in the period from 2060 to 2090 as a percentage		
	Winter	Summer	Annual
Aguascalientes	22.20	6.53	13.00
Baja California	28.70	13.80	21.28
Baja California Sur	28.73	18.10	18.01
Campeche	13.83	28.09	17.61
Coahuila	12.64	19.90	12.92
Colima	24.68	7.07	14.43
Chiapas	16.40	7.91	12.45
Chihuahua	20.48	15.25	14.24
Federal District	20.14	12.82	12.86
Durango	28.06	8.69	15.59
Guanajuato	21.12	7.04	12.30
Guerrero	18.54	12.65	11.86
Hidalgo	18.22	13.05	13.25
Jalisco	22.73	12.48	14.45
Mexico	21.49	12.68	13.05
Michoacán	20.70	11.68	12.84
Morelos	20.69	13.76	12.84
Nayarit	28.37	10.82	16.28
Nuevo León	13.28	11.02	12.72
Oaxaca	17.57	19.01	13.67
Puebla	15.96	16.38	13.18
Querétaro	19.40	10.04	12.45
Quintana Roo	13.11	29.26	17.65
San Luis Potosí	16.81	6.80	11.30
Sinaloa	31.58	9.55	17.05
Sonora	28.47	20.15	21.26
Tabasco	10.95	27.04	16.18
Tamaulipas	14.06	18.05	14.88
Tlaxcala	16.78	15.62	12.37
Veracruz	12.82	19.96	13.93
Yucatán	16.65	26.81	18.87
Zacatecas	23.07	6.33	13.13
National	**20.00**	**15.76**	**15.15**

Source: Montero et al., 2010.

tem available, which requires additional treatment through large amounts of activated carbon before sending the water to the metropolitan area of Mexico City (CONAGUA, 2012D).

The increased risk associated with climate change for Mexican cities, from the point of view of water, is the occurrence of extreme hydrometeorological events, especially droughts and floods.

With respect to flooding, in 2010, the cost of damage caused by extreme weather phenomena alone amounted to $6,412,270,000 USD. Damage caused by the tropical storms of 2013 has yet to be quantified, but considering previous data from the Secretariat of Finance and Public Credit and insurance companies, it could easily reach a similar figure.

In Table 15 shows the damage caused by these phenomena between 1999 and 2010 in terms of loss of life and property damage. As can be seen, the cost of damage due to hydrometeorological disasters tends to increase. The period from 2005 to 2010 saw the five most costly disasters of the eleven analyzed during this period.

The value of this damage is mainly associated with its impact on cities. Thus, for example, the record figure for 2010 is largely due to the amount of damages in the metropolitan area of Monterrey, Nuevo León. That year, in that state, damage from Hurricane Alex accounted for 2.45% of the state's GDP (CENAPRED, 2012).

Table 15. Damage caused by hydrometeorological disasters in Mexico

Year	Deaths	Damage Millions USD*
1999	480	901
2000	100	157
2001	163	188
2002	120	836
2003	138	331
2004	104	55
2005	203	3,503
2006	220	340
2007	187	3,839
2008	148	1,079
2009	100	1,090
2010	199	6,412

Source: CENAPRED. * Rate exchange 12.87 pesos by dollar.

Drought is one of the natural phenomena that produce the greatest loss of life, economic damage, delays in the process of social development and environmental damage. However, as noted in the UN risk report in 2011, one of the main problems of drought management is that their impacts are not registered or properly measured. To estimate the effects of drought, sufficient information is only available in a few cases in developed countries. According to the FAO (2013), "since 1900, over 11 million people have died as a result of drought, and more than 2,000 million have been affected, more than by any other physical risk." Moreover, according to many researchers, the duration and intensity of droughts has increased, particularly since 1940. In Mexico, studies on droughts reconstructed for the past 600 years show that the country, in addition to short regional droughts, has recorded mega-droughts at intervals of approximately 50 to 100 years (Cerano Paredes et al., 2011), as shown in Graph 9.

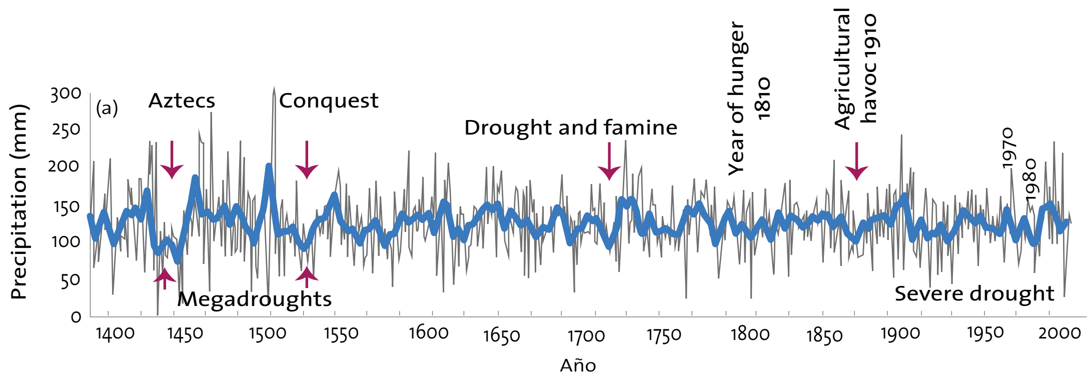
The most recent droughts that have affected Mexico –the first between 2003 and 2006 and the second between 2010 and 2013– have been particularly intense. Graph 10 shows the percentage of national territory under drought conditions from 2003 to August 2013, the month when this phenomenon was interrupted by heavy rains, the other weather extreme, which has produced unprecedented damage throughout the country.

As one can see, 2011 saw a rain deficit in 90% of the country, with over 40% under severe drought. Throughout the decade, an average of over 30% of the country has been under rainfall deficit conditions.

Since many of the effects of climate change are present in the water problems affecting cities, many of the recommended adaptation measures will be useful in any case. The emphasis on adaptation focuses on building resilience, understood as the ability of a city to anticipate, cope with and recover from catastrophic events. In cities, however, risk is not distributed evenly, and mostly affects the poor, who have less capacity for risk prevention and disaster recovery; settle in high-risk areas and under conditions of high demographic concentration. The urban poor should therefore be in the front line of efforts to increase urban resilience (Baker, 2012).

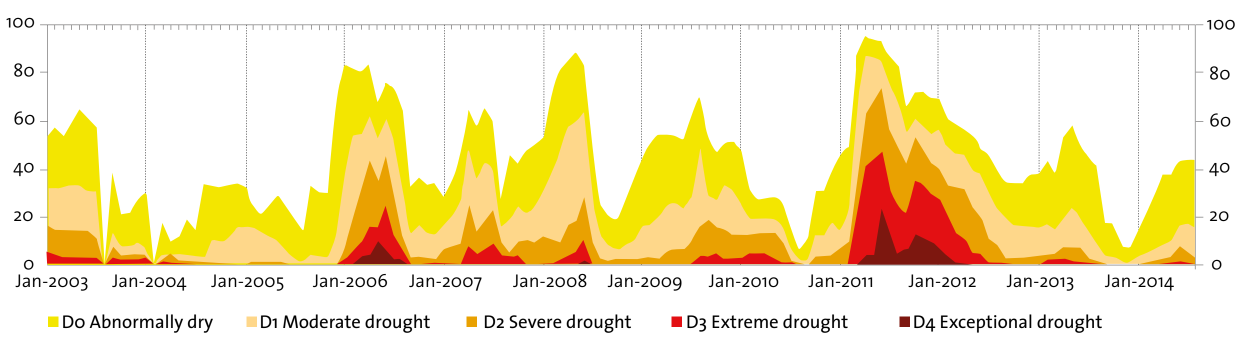
There are numerous technical measures to increase resilience (see, for example, Martínez Austria and Patiño Gómez, 2012). However, the

Graph 9. Variability of precipitation in northwest Mexico in the past 600 years



Source: Cerano Paredes et al., 2011.

Graph 10. Percentage of Mexican territory affected by droughts between January 2003 and August 2013



Source: SMN, 2013.

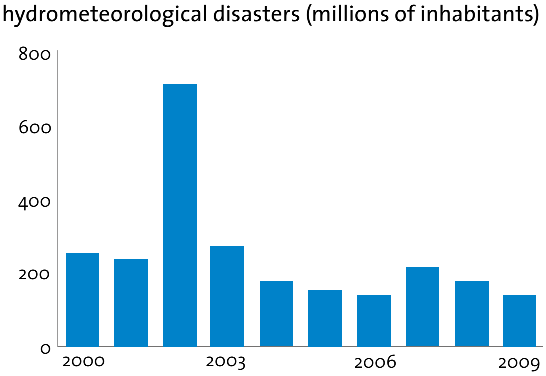
crucial actions are those designed to increase the social resilience of urban communities. During the latest congress on "Resilient Cities" (Balbo et al., 2013), the following key messages for achieving the desired result were reported:

- The participatory approach facilitates the exchange of knowledge and the most successful interventions.
- Resilience requires community construction.
- Actions based on community action create opportunities for innovative, cost-effective solutions.
- The urban poor are active, resourceful agents, yet still the most vulnerable.
- Development planning should be integrated with adaptation.

Adaptation is a process. There are no single, universal or eternal measures. Most cities are unaware of the effects and expected magnitude of events in a changing climate. However, the construction of urban resilience cannot afford to wait.

Regarding the number of people affected by climatic and hydrometeorological disasters during the period from 1999 to 2009, Graph 11 shows that annual variability in the occurrence of major disasters is exacerbated by hydrometeorological phenomena.

Graph 11. Number of those affected by climatic and hydrometeorological disasters (millions of inhabitants)



Source: CONAGUA, 2011.

Box 7

Resilience and Adaptation to Extreme Weather Events: The case of the floods (Hurricane Alex) in the Metropolitan Area of Monterrey

Located in northeastern Mexico, the Metropolitan Area of Monterrey (MAM) is one of the main urban centers in Latin America. With a population of approximately four million inhabitants and a dynamic, diversified economy, Monterrey has become one of the principal industrial regions in Mexico and a leading destination for foreign direct investment, particularly in the manufacturing sector.

The city's water supply and extreme weather phenomena are closely related. Hurricanes Alex (July, 2010) and Ingrid (September, 2013) caused significant damage to the metropolis. For example, Hurricane Alex harmed pipelines and collectors, adversely affecting water service delivery. Fifty-four kilometers of water pipes and 45 kilometers of collectors were destroyed, which required the reconstruction and rehabilitation of seven pumping stations and approximately 10,000 household connections. Treatment plants were also affected. The event left large sectors of the population without a water supply. Although most services were restored within 72 hours, there were areas where the damage due to this natural phenomenon could not be repaired as quickly. In the MAM alone 50,000 people were left without drinking water for days and in some neighborhoods, service was interrupted for several weeks. Four years after the hurricane, the devastation it caused to the city's road structure is still visible yet water services were fully restored shortly after the hurricane.

The same month that hurricane Alex occurred, the state government established the State Board for the Reconstruction of Nuevo León (CERNL). Although a full evaluation of the latter is still pending, the scheme itself warrants examining. It should be stressed that estimates of the damage were not without difficulties or friction between the different spheres. The Council was formed of representatives of all three levels of government and civil society actors, predominantly from the business community. The Council was divided into ten committees. Each committee liaised with federal and state agencies. It is not difficult to imagine the complex operation of a Council with so many committees. This was exacerbated by the rotation of those responsible for federal and state agencies due to changes in administration, with adverse effects on the development of the corresponding work. Three years after Alex, the CERNL formally concluded its work. Regarding financial aspects, contributions to the reconstruction process were estimated at over 17 billion pesos. However, almost all the resources were allocated to road, urban mobility and water infrastructure, ignoring the social agenda of reconstruction. It is also fair to say that while the CERNL contributed to the city's reconstruction after the occurrence of Alex, it lacked the structure to address underlying issues and structural matters associated with urbanization and the presence of climatic events. The complexity of these issues and their understanding go beyond actions designed in times of emergency.

The lessons and experiences drawn from the case of Monterrey may also be of interest to other Latin American cities. The greatest challenges are associated with rapid population and economic growth, which complicate the design of coherent policy responses, rather than with natural phenomena resulting from climate change. Alex and Ingrid, and the storms and hurricanes that preceded them, revealed the existence of a dysfunctional, fractured institutional architecture, unable to fully addressing this phenomenon. In fact, there was a double dysfunction: One relates to the water sector framework in which institutions, programs and laws from different levels of government came together, not always in the direction of sound resource management but often running in opposite directions. This is crudely exemplified by the operation of the National Fund for Natural Disasters. The other concerns the dysfunctionality of the metropolitan area itself, which is reflected in a pattern of urbanization that magnified the damage. Thus, what has proved to be natural has been the unsatisfactory response to the flash floods that from time to time impact the Metropolitan Area of Monterrey.

8. Conclusions

Mexico is a country with unequal access to water and sanitation, as shown by some of the facts that have been presented. The outlook may worsen, especially because it is estimated that the urban population will continue to grow, placing increasing pressure on urban development and water service delivery, particularly in parts of the country where water is already scarce.

A key finding for achieving better decision-making about urban water management is the need to have appropriate information for this use. This requires a change in the way databases are constructed, rather than new or different ways of obtaining data.

In Mexico, efforts should be made to ensure that the human right to water is fulfilled as regards access, coverage, quality and affordability. However, in certain areas where access is precarious, it has been observed that this is only possible through the creation of new forms of water supply, such as commercialization through water trucks or community arrangements for the construction, maintenance and operation of the local system, usually based on high investment by the settlers themselves and self-management regulations that include monitoring, surveillance of the system and the implementation of sanctions.

Given the above scenario, water governance becomes important in achieving an equitable distribution of water based on access to water as a human right. And despite the fact that in recent years, water policy has undergone profound changes through the decentralization of the provision of public drinking water, the growth of water demand in metropolitan areas and the incorporation of the population's participation into problem solving poses an enormous challenge to local and federal authorities. Therefore, efforts to sort out the governance framework of urban water services and implement demand management mechanisms should be at least as great as those still devoted to major projects for transporting the water flow between basins.

As mentioned earlier, although Mexico produces about 1.5% of greenhouse gases, it is one of the countries most at risk of climate change. In urban areas, the effects of climate change will be increased and exacerbated by other processes that will make them more dangerous, meaning that a prospective view of the vulnerability of cities in Mexico must be integral. One might assume that the most vulnerable areas are rural areas, due to their historical conditions of poverty and marginalization. However, some of the most vulnerable regions are in fact some of the major cities, which is mainly due to constant population growth, urban concentration and the location of cities in areas with scant or overexploited water resources, which increase settlements in high risk areas due to climate change impacts and in turn increases their degree of exposure. The three levels of government should therefore improve their coordinated action to optimize and manage land use practices, and implement new urban planning models that incorporate the impacts of climate variability and enable stormwater runoff to be more effectively management.

In regard to water and health, although progress has been observed in the declining rates of intestinal infectious diseases, much remains to be done since other diseases such as typhoid or salmonella cases have increased. Certain programs such as the Clean Water Program should be reinforced while new programs that promote increased drinking water coverage should be implemented.

On the other hand, as we have seen, not all cities can bear the financial burden of large pressure aqueducts. These also create social and environmental damage in the basins of origin and during the route of the aqueducts, in many cases increasing the use of energy for pumping and treating water. The design of such projects on the grounds of "substituting sources" must not be interpreted as abandoning the mandate to control groundwater extraction and discharges into surface bodies.

The financial area must be reformed to help give operators stability and incentives for increasing their efficiency. Nowadays, a system that has been damaged due to poor decisions in the past, can always aspire to be rescued through federal funds, if the city has the political and financial negotiating capacity to do so. Subsidy programs should gradually be implemented in conjunction with performance enhancements that promote the professionalization of municipalities and agencies in the administration of the systems. Likewise, although the Mexican government has made enormous efforts to increase coverage and improve the performance of municipal systems, huge challenges remain to ensuring sustainable, quality services. There is an urgent need to implement an effective system for the custody, restoration and preservation of national waters that will reverse the imbalance of numerous hydrological basins and aquifers. It will be of little benefit to seek greater energy efficiency in extraction if groundwater levels continue to decline and quality, reliable sources are increasingly distant and vulnerable. There will be never be enough water if we lose clean water sources.

Likewise, a radical institutional reform should be promoted in municipalities and states to clarify the responsibilities of each organ or order of government for citizens. Operating organizations should have operational clarity and independence, sufficient resources and budgetary support tied to their performance, while municipal and state authorities should focus on regulating rates and the performance itself, but without continually interfering with operational decisions and the administration of systems. Users should be entitled to learn about and understand the situation of their water and sanitation systems, participate in decisions and demand that they provide quality services at a fair price, and that they also undertake to comply with the payment and proper use of services.

A view from Villahermosa, Tabasco. Image courtesy of Jordi Vera

A key point is agency boards of directors, which should be integrated into medium-sized cities with citizens who can really professionally support the proper running of systems, using good corporate governance practices and establishing mechanisms to ensure that councils are fully held to account, particularly if they are citizens. Local political authorities should be fully responsible for the state of the assets and flows of operating organizations, and accountable for the delivery thereof to the following municipal administration. Better communication mechanisms, such as citizens' water observatories, can help construct a mature, informed dialogue between authorities, operators and citizens.

Among the challenges derived from the physical aspects of water is the lack of criteria for determining appropriate volumes for efficient use, and utilizing them to establish programs in cities to ensure efficient water use. This would not only save water but also the energy used for transporting, purifying and treating it. On the other hand, and as yet barely acknowledged nationwide, there is the importance of water reuse in Mexican cities. In comparison with many other countries (Jiménez and Asano, 1998), Mexican cities, particularly the largest ones, are characterized by much higher reuse levels than many cities in various countries including those in the developed world. This advantage is one that Mexico should not only preserve but further increase, making it a country that exports knowledge and technology in this field.

As one can see, the current situation and prospects for water supply in Mexican cities is undoubtedly critical. It will require an enormous effort of organization and coordination to stop the dramatic decline in the quality and availability of water, land use and the lack of accountability mechanisms that would lead to professional management of the systems involved. The lack of reliable information in certain areas such as the number of illegal connections or the amount of water supplied through water trucks qualifies the coverage figures mentioned in the official data. Access to information, its analysis and communication to decision makers and citizens can be an important lever in this change and is a task in which the academic community must play a central role.

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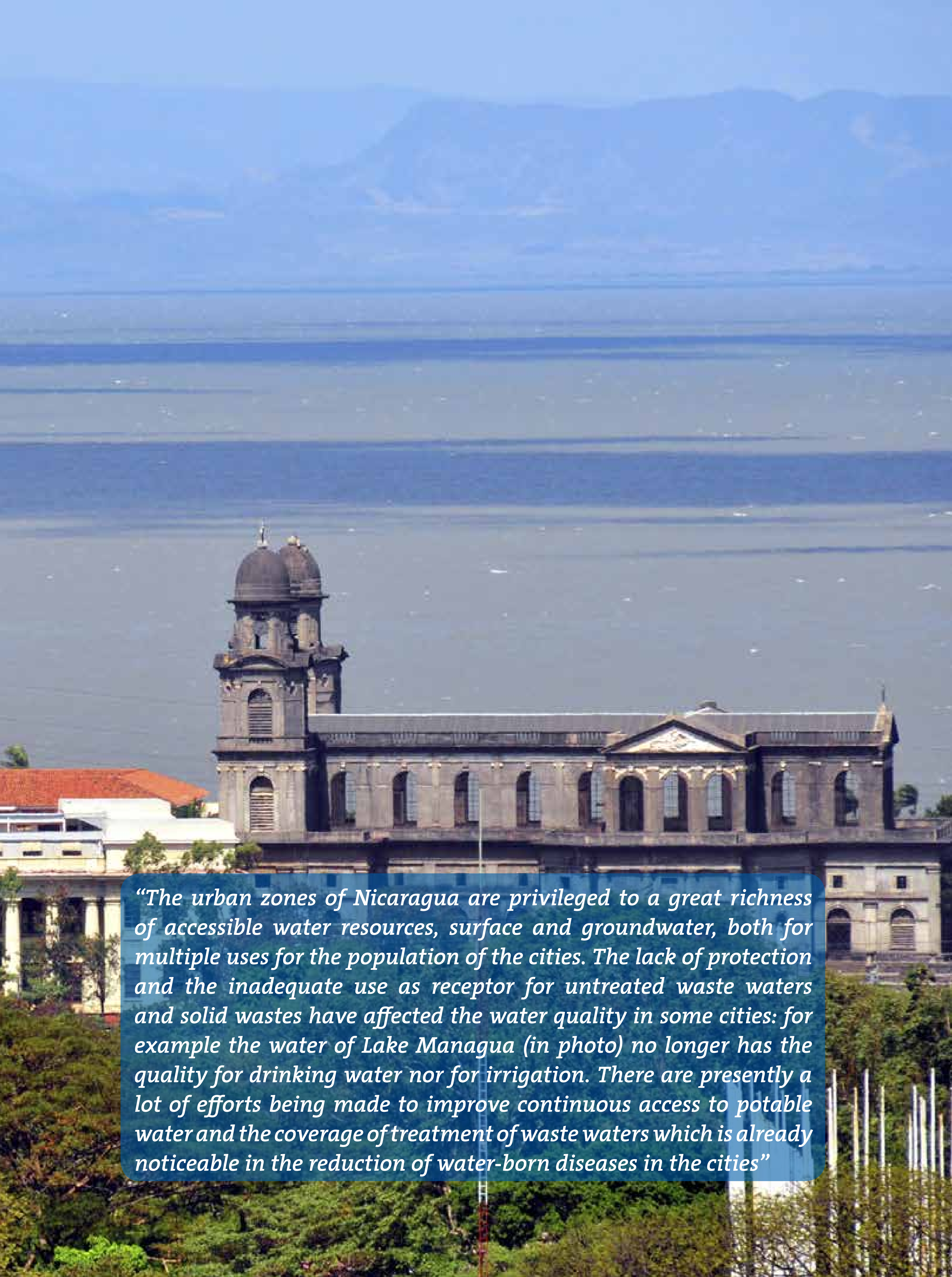
Nicaragua

Managua, Nicaragua. Plaza de la Revolución. Lake Managua and mountains in the background, seen from Loma de Tiscapa. Photo credit: ©iStock.com/M.Torres.



"The urban zones of Nicaragua are privileged to a great richness of accessible water resources, surface and groundwater, both for multiple uses for the population of the cities. The lack of protection and the inadequate use as receptor for untreated waste waters and solid wastes have affected the water quality in some cities: for example the water of Lake Managua (in photo) no longer has the quality for drinking water nor for irrigation. There are presently a lot of efforts being made to improve continuous access to potable water and the coverage of treatment of waste waters which is already noticeable in the reduction of water-born diseases in the cities"

Urban Water in Nicaragua

Katherine Vammen, Selvia Flores,
Francisco Picado, Iris Hurtado,
Mario Jiménez, Gustavo Sequeira,
and Yelba Flores

Summary

The urban population in Nicaragua has reached 58% of the country's population. The capital is the most extensive urban area, reporting a concentration of 24% of the country's total population. Nicaragua has been able to meet the Millennium Development Goals (MDG) in relation to access to water, with a 98% coverage in the urban zones. However, that is not true in relation to the urban population's use for improved treatment, which still remains at 63%. Currently, plans exist and projects are being executed to increase the sewage system coverage by reforming or building treatment plants in most cities. A great impact on the quality of water has been observed in the cities due to factors associated with the urbanization process, such as mismanagement of solid and liquid waste, the lack of drainage systems to handle rainwater, the lack of protection for **watersheds** located around the cities, which affects the groundwater used as drinking water source by the population, and cases of contamination due to the lack of an appropriate infrastructure. Substantial improvement has been seen in the health of the population in Managua due to water transmitted diseases such as malaria and dengue, although problems exist that could be improved, especially with the increase in treating wastewater and overseeing health. The cities in Nicaragua are vulnerable to extreme events of climate change, due to uncontrolled growth, the lack of modernization in the water and sanitation networks, and infrastructure in general to deal with extreme events.

1. Introduction

The population of Nicaragua has been reported to be 6,071,000 inhabitants for 2012, according to the National Development Information Institute (INIDE in Spanish). The average growth rate for the population is 1.2% per year. Different sources estimate the urban population to be from 58% to 60% (INIDE, 2012; WHO, and UNICEF, 2014; Ortuste, 2014). Twenty-four percent (24%) of the Nicaraguan population lives in the capital city, Managua. This is the largest urban area with a population of 1,042,012 people (INIDE, projection applying the 2005 census). There are 25 cities with a population above 20,000 inhabitants in the country. Some 215 cities and districts are considered to be urban areas. Due to the population concentration in the urban areas, the cities have a high demand for water. Consequently, they have the largest volumes of wastewater generated by domestic, industrial, and agricultural activities that need treatment systems.

An increase in the coverage of access to potable water has been observed, reaching 98% for 2012. This is due to investment programs by the Nicaraguan Aqueducts and Sanitary Sewer Company (ENACAL in Spanish), which is responsible for providing services at the urban level. It is important to mention that Nicaragua has fulfilled the Millennium Development Goals (MDG) of the United Nations (ONU)in relation to access to potable water, achieving an increase in coverage of up to 98% for 2011. Like most Latin American countries, Nicaragua has not reached the MDG for sanitation. However, in the urban areas, Nicaragua has been able to improve sanitation coverage to 63% for 2012 (WHO and UNICEF, 2014). Currently, many efforts are underway to improve the sewage system coverage with treatment plants in most of the country's cities. Although Nicaragua has a high level of water availability per inhabitant (38,668 m^3 per capita), the water quality has been affected throughout the country and especially in the urban areas, which is the focus of Section 2 of this chapter. The current status and the efforts underway to improve the access and sanitation coverage situation in the cities is the core subject of sections 3 and 4. Priority has been given to the water situation and the prevalent diseases in the population that are transmitted by water in the subchapter on water and health (Section 5) in the urban centers, examining the capital city, Managua, in more detail. Nicaragua has been heavily impacted by climate change and Section 6 shows the problems and recommendations to deal with it in the country's cities.

2. Water Sources in Urban Zones and the Types of Impact Caused by Urbanization

2.1 Water Sources to Supply the Main Cities in Nicaragua

The water supply system in the main urban areas in Nicaragua is sustained by exploiting, first of all, groundwater sources, and second of all, surface water. Thus, in addition to the demand for water for human consumption, the supply for public, industrial, commercial, and other sectors is covered in this way.

For domestic use, the potable water supply through groundwater sources represents 70% of the total; the remaining 30% comes from surface or sub-surface water. This is due to the fact that more than 86% of the population is located on the Pacific watershed (20% of the territory) where only 6% of the surface water is located (Montenegro, 2009). Particularly in Managua, this water supply is achieved by using a distribution grid and distribution points which exploit water from 129 wells and the Asososca Lagoon (ENACAL-PNUD-OPS, 2006).

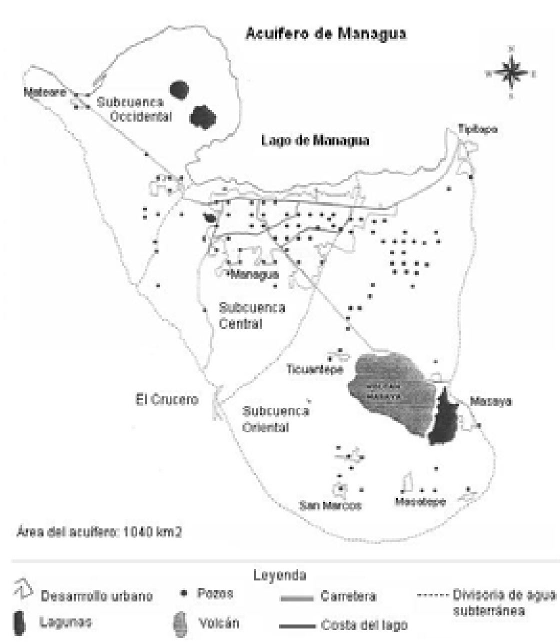
As well as the domestic sector, the supply for industry is covered by using groundwater as the main supply source due to its availability in the regions where most of the industries are located (the Pacific and North-Central regions of the country). In addition, the good quality of the aquifers makes investment in supplying water low. Most of the country's large industries have their own water supply sources, which are from groundwater and have not been registered. They are not invoiced so there is no data about volumes of water extraction. Nevertheless, water consumption for industry has been estimated to be 14% of the total annual water extraction (Vammen & Hurtado, Climate Change and Water Resources in Nicaragua, 2010).

In Managua, a high number of industries belonging to the industrial park have been established on the Lake Xolotlán coastal strip. The purpose is to take advantage of the availability of groundwater on the one hand, and due to how easy it is to dump the effluents into the lake, on the other hand. Economically and administratively, industries show low levels of industrial water productivity, which is a reflection of the low value assigned to this resource and to its inappropriate use. (Vammen & Hurtado, Climate Change and Water Resources in Nicaragua, 2010).

The information presented in this document addresses characteristic aspects of urban zones that represent a permanent hazard, such as sources of pollution for water resources (ground and surface), placing special emphasis on the capital city, Managua. This set of problems is also specifically linked to the fact that sources are exploited to supply the population in both urban and peri-urban areas in Managua, considering the fragility of the sources in relation to human activity. Protecting and conserving these resources is fundamental to guarantee the future supply, based on the extraction-supply-availability balance (quantity and quality).

Figure 2.1 The Asososca Lagoon

Figure 2.2 The Managua Aquifer



Source: Proyecto Uno Sostenible de los Recursos Hidricos (SUWaR)

A fact that stands out is that the uncontrolled growth of Managua has increased the sources of pollution as a result of spontaneous human settlements in areas that have no sanitary sewer coverage, as well as the intensification of agriculture in the aquifer recharge zone. This has caused greater demand for the use of agrochemicals. All of this is linked to the lack of awareness in the general population in relation to using surface water resources.

2.2 Water Resources in Managua

Within the national territory, particularly in Managua, there is high potential for both surface and groundwater resources. They include the Asososca Lagoon (Figure 2.1) and the Managua aquifer (Figure 2.2), which currently serve as supply sources.

Another body of surface water is Lake Xolotlán, the second largest lake in the country, which is embedded, for the most part, in a formation of volcanic materials and occupies part of the Nicaraguan graben (rift valley) (ENACAL, INETER, CIRA/UNAN, 2008). Although the capital is built on the shores of Lake Managua and could, as it did prior to 1930, have an abundant water supply from Lake Xolotlán, its contamination makes it unsuitable to directly benefit the populations living along its shores. The lagoons of Nejapa, Tiscapa, and Acahualinca, which occupy the bottoms of old volcanic craters formed by explosion and sinking approximately 5,000 years ago, are also located in the urban zone.

Of the two **watersheds** for the municipality of Managua, the north and south **watersheds**, the south watershed (825 km^2) drains its waters into Lake Managua or Lake Xolotlán. It is divided into four sub-**watersheds** with three pertaining to Managua that occupy approximately 70% of the municipality (INIFOM, 2013).

The southern watershed of Lake Xolotlán, due to geo-morphological, environmental and particular urban development characteristics, is vulnerable to natural phenomena related to climate, volcanoes, and earthquakes. This part of the watershed does not have significant watercourses; there are only seasonal ephemeral and some permanent streams with a short course and low volume (the Santa Elena, Borbollón, and Lodoso Rivers). The topography of the southern watershed and replacement of the original vegetation by dispersed annual crops have made it possible for erosion to form gullies and ravines, especially in the piedmont areas (200-450 meters above sea level) (INIFOM, 2013).

2.2.1 Surface Water Resources in Managua South Watershed for Lake Xolotlán

Of the 4 sub-**watersheds** into which the southern watershed of Lake Xolotlán is divided, the sub-watershed III covers a territory of 178 km^2 and extends from the coasts of Lake Managua (40 meters above sea level) to the El Crucero Plateau (940 meters above sea level).

Sub-watershed III is the most important recharge area for the aquifer that supplies potable water to Managua. It contains three fields of wells that produce 60% of the water supply for the city of Managua. Sub-watershed III is also an invaluable area for biodiversity and rich soil quality for production. However, it is a highly vulnerable zone due to the uncontrolled growth of the city and the inadequate management of agriculture, solid waste, sewage and rainwater, which causes environmental and socioeconomic devastation. In the high part, agriculture has contributed to rapid deforestation (Figure 2.3), especially in areas with steep to moderate slopes (the Mayor's Office of Managua, 2008).

Figure 2.3 Agriculture (Pineapple Crops) in Ticuantepe, Aquifer Mantle

In the last several years, the medium and low part of sub-watershed III has gained importance as a residential area. This is especially due to the development of the highway to Masaya and the neighboring areas. The growth of urban developments and changes in land use imply an increase in surface runoff, more erosion, and more demand for infrastructure in the drainage and basic service network (the Mayor's Office of Managua, 2008).

The more outstanding surface water resources are the waterbodies in craters:

The Lagoon of Asososca

from Nahuatl for Blue Waters, is a natural water reservoir and the only waterbody that the city has with quality suitable for human consumption. The fact that it supplies between 14% and 20% of the demand for the population makes it a major source. It began to be exploited for potable water in 1914 and has been part of the water supply system since the wells that were dug around Lake Managua were abandoned (ENACAL-PNUD-OPS, 2006).

Current Condition. Progressive deforestation of the southern watershed for Lake Managua has decreased infiltration and caused a drop in the water table on the subjacent plains with the consequent drop in the level of the lagoon, which reached critical limits at the beginning of the 90s. This body of water is well preserved due to the fact that it is protected as a water supply source for the city of Managua.

The activities around the protected area include commerce, oil refining, sand extraction, and residential deliveries.

Main Threat. The study titled "Industrial Contamination of a Municipal Water Supply Lake by Induced Reversal of Ground-Water Flow, Managua, Nicaragua," carried out in 1991-1992, found that a possibility exists that when more water is extracted than the recovery capacity for the Lagoon of Asososca, an inversion of the gradient may occur causing contamination from the waters of Lake Managua. Likewise, evidence was found of

Figure 2.4 The Refinery on the North Bank of the Asososca Lagoon

Source: El Nuevo Diario. 2011.

Figure 2.5 Lagoon of Tiscapa, Receptor Waterbody for Rainwater and Domestic Waste Water since 1980

Figure 2.6 Lagoon of Tiscapa

the relative mobility of synthetic organic chemical compounds coming from the industrial area (Figure 2.4) (Bethune, Farvolden, Ryan & López, 1996).

The possibility also exists of contamination of the underground currents that cross the city and supply water to the lagoon due to the presence of fuel service stations (Figure 2.8).

The Lagoon of Tiscapa

From Nahuatl Uticapa Techcath, the sacrificial stone, the smallest of the crater lagoons (Figure 2.5, Table 2.2), was declared to be a Natural Reserve in 1991 by Decree 4291 (The Mayor's Office of the Municipality of Managua, 2004).

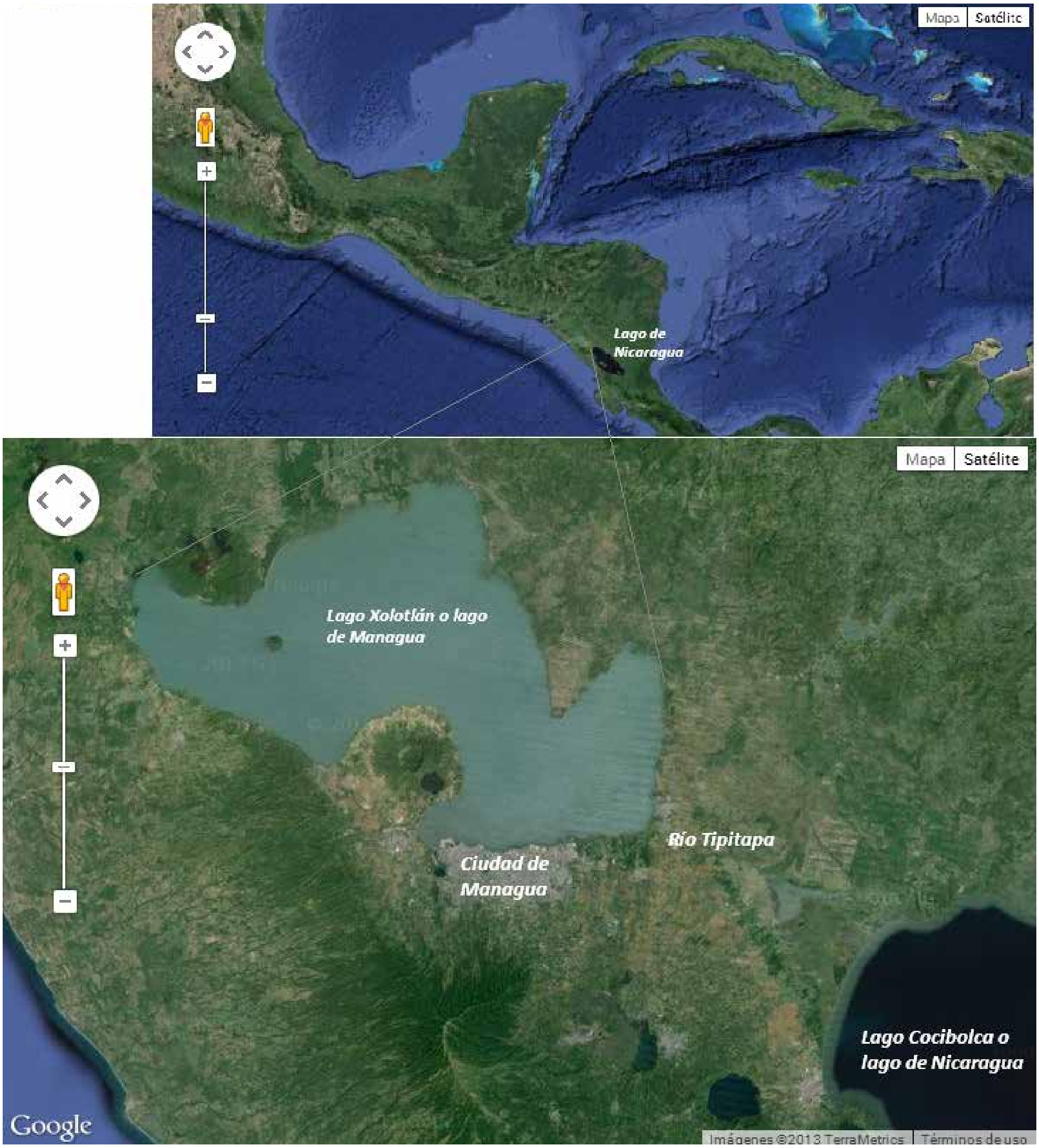
Current condition. Until several decades ago, this waterbody was recommended as a potential source for human consumption for Managua (the United Nations, 1976; Sawyer H. A., 1973). Studies carried out from 1989 by the Nicaraguan Research Center for Water Resources of the National Autonomous University of Nicaragua (CIRA/UNAN) to date have revealed a progressive, generalized deterioration in the environmental status and the quality of its waters. Evidenc for these conditions are provided by the drastic decline in dissolved oxygen beginning at 2 meters, a high concentration of nutrients and phytoplankton biomass dominated by cyanophytes that is associated with its hypereutrophic status, as well as a high content of microbiological contamination indicators (thermal tolerant Coliforms, *Escherichia coli* and fecal streptococci). Currently its waters are severely restricted for any type of use (CIRA/UNAN, 2008).

The inappropriate management of its micro-watershed (Micro-watershed D) and the erroneous institutional decisions led to the contamination with an accumulation of solid waste in its waters and on its shores (Figure 2.6), as well as the excess of nutrients and large quantities of sediments around the discharge canal, all damaging the terrestrial and aquatic ecological diversity (The Mayor's Office of the Municipality of Managua, 2004). Information supplied in June 2000 by the cleaning coordinator of the Municipality (David Castillo) indicates that the lagoon receives two metric tons of organic wastes per week (La Prensa, 2013).

Lake Xolotlán or Lake Managua

Is the second largest lake in Nicaragua based on its dimensions (Table 2.1); the volume of stored water is around 1010m³. In 1910, the connection of this waterbody through the Tipitapa River to Lake Cocibolca or Lake Nicaragua (Figure 2.7), which has the largest dimensions and is located some 9 meters lower (Plata, Araguás, Avilés & Peña, 2001), was interrupted. Since then, the connection has been reestablished sporadically in the years of the large hurricanes and extraordinary water discharge events, when the level of its waters exceeds 39.22 msnm (Paso Panaloya) (INETER, 2014). This occurred during the last century in 1993, 1954, 1982, and 1998. But recently the two lakes have been connected constantly since October of 2010.

Figure 2.7 Lake Xolotlán or Lake Managua



Current condition. Lake Xolotlán is a body of water that has been contaminated naturally by the volcanic activity from the immediate surrounding areas (hot springs enriched by boron and other metals) and externally by the increase in human activity in the surrounding watershed (Meulemans, 1991).

Managua, which is located on the southern bank of the lake (Figure 2.7), has used this waterbody as a recipient of its waste waters (industrial, domestic, and rainwater) without any sort of treatment from 1927 (Vammen & Hurtado, Climate Change and Water Resources in Nicaragua, 2010) to 2009, when a water treatment plant began operations. In addition to wastewater, leachates also have contributed to contamination of its waters since 1972 from solid wastes from La Chureca municipal dump (47 hectares in area) located directly on the banks of the lake (CIRA/UNAN, 2010). There was no environmental management applied to the wastes until it was sealed in 2010. Currently, the site has the most modern treatment plant in Latin America which is part of the Integral Development Project for the Acahualinca-La Chureca neighborhood in Managua. It was installed six years ago by the Spanish Cooperation in Nicaragua and now recycles at least 1,000 tons of waste daily. A breakwater wall was also built there to protect Lake Xolotlán which has an extension of 1,745 meters.

One of the worst source of contamination for the lake was the Hercasa-Elpes complex (Pennwalt) which produced sodium hypochlorite and chlorine gas. Their wastewater had a high mercury content which was released to the lake from 1967 until 1992., This factory set up operations, like many other industries, in the southern coastal strip of the lake in order to easily dump its wastes into the ecosystem. It is estimated that it released 40 tons of elemental mercury into Lake Xolotlán. Very high levels of mercury were found in the different ecosystem compartments, according to the study done by CIRA/UNAN en 1991 (Lacayo, Cruz, Lacayo & Fomsgaard, 1991). Some results of the project titled "Environmental Contamination by Mercury in Lake Xolotlán, Nicaragua: An Evaluation of the Risk to Human Health," currently being executed by the Nicaraguan Research Center for Water Resources in cooperation with the National Institute of Minamata Disease from Japan, have confirmed that the area surrounding the old factory facilities (soil and groundwater) is contaminated. It constitutes a potential source of mercury for Lake Xolotlán (Peña, Montenegro, Pitty, Matsuyama & Yasuda, 2007).

Both the northern and southern sectors of the watershed have undergone deforestation and this is a major source of nutrients and suspended solids in the lake due to erosion as well as other human activities that have been improperly managed (ENACAL, INETER, CIRA/UNAN, 2008; CIRA/UNAN-CARE-MARENA/PIMCHAS, 2012). In general, the waters of Lake Xololtán are not suitable for human consumption. There are also heavy restrictions on irrigation due to the high concentrations of sodium, chlorides, and boron, as well as the danger of salinization and alkalinization of the soils (ENACAL, INETER, CIRA/UNAN, 2008).

2.2.2 Groundwater Resources in Managua

The Managua aquifer, located south of Lake Xolotlán, oscillates between 6 and 150 meters in depth (ENACAL, 2008) and has an approximate area of 600 km². Numerous activities are carried out in its area that are potential sources of contamination such as industry, agriculture, municipalities, and fuel service stations, etc.

Table 2.1 Characteristics of the Main Surface Water Resources in the City of Managua

Body of Water	Form and Surface	Depth
Lagoon of Asososca[1] 37.69 meters above sea level	Circular form Area: 0.8 km² Diameter: 1.2 km	Maximum: 95 m
Lagoon of Tiscapa[2,3] 51.79 meters above sea level	Approximately circular Area: 0.16 km² Diameter: 500 m Practically vertical coastline	Maximum: 33 m Median: 20 m
Lake Xolotlán[4,5] 37.84 meters above sea level	Area: 1,052.9 km² Maximum Length: 58.4 km Maximum Width: 32.7 km	Maximum: 26 m Median: 7.8 m

Source: Ministry of Finance, 2014
1. MARENA - PROTIERRA - CBA; 2. The Mayor's Office of the Municipality of Managua, 2004; 3. CIRA/UNAN, 2008; 4. ENACAL, INETER, CIRA/UNAN, 2008, 5. INETER-OIEA, 2001

Knowing the aquifer's water potential has been the object of much concern and, therefore was the objective of several studies carried out in the last several decades. In 1993, the Nicaraguan Water and Sewer Institute (INAA in Spanish) and the Japanese International Aid Agency (JICA), using a modeling program for groundwater, found indications of overexploitation and the threat of contamination in the central sector. Therefore, they recommended reducing the pumping rate and developing new sources based on the increase in the demand that was determined for 2000 (553,000 m^3/day). Later, (Cruz, 1997) determined that, with the level of extraction in 1996 from the aquifer, it was not overexploited and that it did have the capacity to cover the demand for 2010.

The groundwater produced by this watershed is the main means of supply for a large part of the capital city. There are five major fields of wells whose extraction volume represents more than 50% of the well production of the Nicaraguan Water and Sewage Company for all of the Managua aquifer (SUWaR-Nicaragua, 2000). In general, the water quality is suitable for human consumption; it has been classified geochemically as mostly carbonated-bicarbonated with a pH between 7.2 and 8.2.

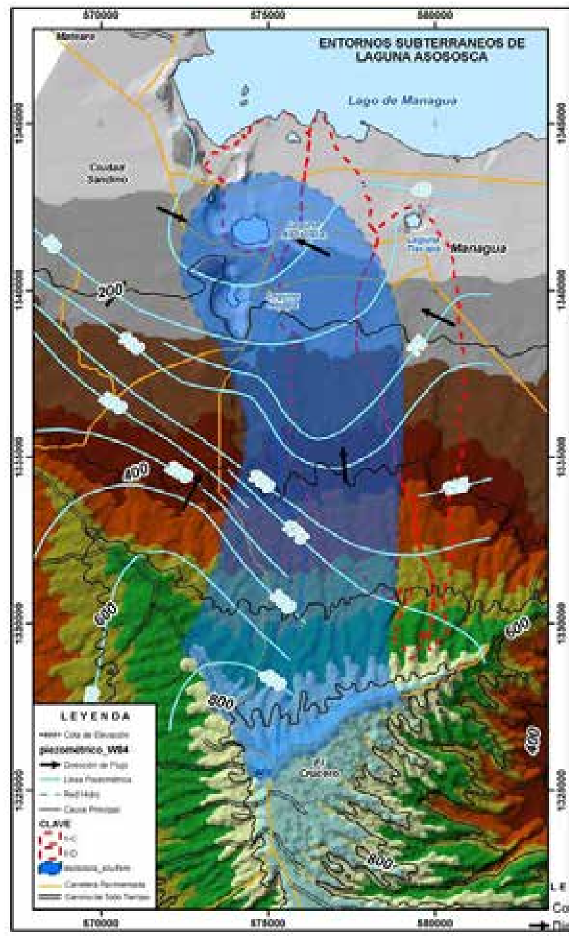


Figure 2.8 Underground Environs for the Asososca Lagoon

2.3 Factors that Contribute to Contamination of the Surface Water

2.3.1 Water Overexploitation

The Lagoon of Asososca, considered to be a huge open-air natural well, i.e., part of the aquifer, was the main source of water for Managua until the beginning of the 90s. The increase in population caused rapid exploitation of the lagoon. Beginning in the 80s, its overexploitation became evident when the levels dropped so much that the underground intrusion of water from Lake Managua made the lagoon susceptible to the danger of contamination. This is a water resource that is basically fed by the inflow of groundwater (Figure 2.8). The contribution by surface water is minimal; however, the lagoon is an endoreic surface waterbody. Therein lies the importance of identifying and regulating the sources of contamination. With a water volume of 44.4 MMC, it has been a source for the potable water supply for the city of Managua since 1914. It currently supplies 50% of the population of Managua with an average extraction of 17 million gallons per day. The water is of very good quality and fulfills all the potability parameters based on international standards. Different external factors represent a risk to the water quality of the Asososca Lagoon if they are not controlled: 1) The growth in spontaneous settlements that do not have adequate sanitation; 2) Extraction of sand and other materials in the surrounding areas without regulating or measuring the impact on the quality of the water resource and its environmental vulnerability; 3) Spontaneous dump sites around the lagoon and the bad habits of the visitors to the nearby Las Piedrecitas Park, who throw rubbish into the lagoon; and 4) The lack of land zoning for the lagoon's underground watershed (and in general in the city of Managua) that affects the recharge areas, both as to quantity and quality of the water infiltrating into the zone.

2.3.2 Solid Urban Waste

Solid urban waste is generated by the population and disposed of without any sort of control in open areas that are not allocated for that purpose. The wastes come from residential sectors that are not connected to the municipal collection service; areas that are outside the reach of the public sanitation service. This is of course also due to bad hygienic habits of the citizens. The lack of solid waste control is another source of contamination for water resources.

The primary rainwater drainage system in the city of Managua is made up of nine main channels (the Mayor's Office of Managua, 2010). In the high part of the watershed, they run parallel in their natural state, from south to north and are backed up by a protection system in the middle part (small dams made of earth and concrete curtains) to regulate the waters that descend and act as a barrier for collecting sediments. In the middle and lower parts, the channels are covered in concrete, stones and other stable materials; however, due to the change in land use, many of them have hydraulic deficiencies (The Mayor's Office of the Municipality of Managua, 2004).

The situation related to solid waste is serious in the city of Managua because the channelss are used as illegal dumping sites and liquid wastes converge with all sorts of waste (domestic and industrial) in large quantities (Figure 2.9a). This is due to the fact that the population does not use the garbage dumps and some sectors with small businesses and companies (workshops, eateries, etc.) do not hook up to the municipal collection system. According to

Figure 2.9a Solid and Liquid Waste in the drainage canals in the City of Managua that are Carried to Lake Xolotlán

Figure 2.9b Sediment in the drainage canals in the City of Managua that is Carried to Lake Xolotlán

Figure 2.10a Tiscapa Lagoon, waterbody that Receives Liquid and Solid Wastes

Figure 2.10b Clean-up Work in the drainage canals Carried Out by the Mayor's Office of Managua

official data from the Municipality, Managua creates daily some 1,500 tons of waste, of which, 1,200 tons are collected daily. There is a collection deficit of some 300 tons that are thrown without control into the drainage systems, streets, and channels in the city (*El Nuevo Diario,* 2012).

The problem with solid waste as a source of contamination is that the garbage is carried directly, via the drainage channels, to the surface waterbodies. The most affected are the Tiscapa Lagoon and Lake Xolotlán and the load of sediments of course increases during the rainy season (Figure 2.9b). Despite positive steps taken by the Municipality of Managua (Figure 2.10b), this problem needs broad participation by the civil society with campaigns to raise awareness through hygienic education and training.

2.4 Water Contamination

2.4.1 Waste Water

One of the aggravating factors related to insufficient coverage by the sanitary sewer grid is the risk of contamination of the groundwater reserves for the city of Managua. This is due to the rapid growth in the population, where construction is not regulated and sectors are inhabited spontaneously without investing in the appropriate system to manage wastewater. Residential developments have also proliferated in the areas of Ticuantepe, Veracruz, and Sabana Grande where most of the water wells are located that are used to supply the population in the city of Managua (ENACAL, 2008).

2.4.2 Hydrocarbons

The high density of service stations, currently 75 (*El Nuevo Diario,* 2013) spread out over the urban and peri-urban area (Figure 2.12) represents a high risk and inherent danger of contamination by hydrocarbons for the groundwater supply sources for the city of Managua.

According to an evaluation about environmental matters in 2007 that was presented by the Humboldt Center (an environmental NGO), gas stations were located on sites in Managua that were not approved by the safety authorities and they were built without the pertinent permits in the city of Managua. A very emblematic case occurred in May

Figure 2.11 Clean-up Work in the River Beds Carried Out by the Mayor's Office of Managua

2003 involving a spill of 25,000 gallons of gasoline in a service station located in the northeastern part of the city of Managua. The spill encompassed 3.2 km^2 in a residential, commercial and industrial area of high vulnerability.

Currently, the Ministry of the Environment and Natural Resources (MARENA) and the Nicaraguan Energy Institute (INE) are directing actions to protect the environment by carrying out inspections at the national level to detect problems in the gas stations. During the period between December 2010 and November 2011, 13 faults were detected based on 99 tests of impermeability that were carried out at fuel distribution and storage facilities. In all cases, actions were recommended to overcome the situations, to issue warnings, or to apply sanctions based on the contents of the legal framework (Law Number 742, the Law on Reforms and Additions to Law Number 277, the Hydrocarbon Supply Law and its Bylaws) (INE, 2012).

2.4.3 The Effects of Urbanization on the Water Resources for the Future Supply in the City of Managua

In the last five years, the increase in new urban developments in the Sub-watershed III has exceeded 10,000 houses (the Mayor's Office of Managua, 2008). This Sub-watershed is the most important water recharge area for the aquifer where three fields of wells are located that produce 60% of the supply of potable water for the capital city. With the disappearance of the forest and the impermeabilization of the soils, the water runoff increases and the infiltration rate decreases. This has an impact on the aquifer, affecting the availability of water resources for the population for each square kilometer in the urban development. For each square kilometer that is compacted or impermeabilized by buildings, the Managua aquifer stops receiving 240,000 m³ of water annually. This is the estimation considering soil absorption under natural conditions. If these 240,000 m³ are divided by 80 cubic meters, which is what each citizen of the capital consumes per year, it would mean that 3,000 people would not be supplied (El Nuevo Diario, 2013).

3. Potable Water Service in the Urban Zones

The water and sanitation policy for Nicaragua projects an increase in the coverage, an improvement in the quality of the service, securing service, maintenance of the existing systems and networks, and the promotion of the rational use and protection of water sources.

In the country's urban zones, the water supply for 2.5 million inhabitants is the responsibility of ENACAL. It directly manages 74% of the potable water systems throughout the country (ENACAL, ENACAL Institutional Development Plan 2008-2012; Water Sector Strategy, 2008). This company manages 28 sanitary waste systems and 147 water supply systems or networks (Argüello, 2008). The water supply covers 88% of the urban areas and a much lower percentage (18%) in the rural areas, for which there are 5,276 local water supply systems. In the capital city, this coverage is 92% (ENACAL, ENACAL Institutional Development Plan 2008-2012; Water Sector Strategy, 2008) corresponding to a population of approximately 1,075,847 people which is equivalent to some 222,847 residential connections, according to data from 2006.

3.1 Coverage in Urban Zones in Nicaragua

The figures for coverage and access to sources of portable water are an indication of compliance with the Millennium Development Goals, at least in the country's urban areas. In 2011, the improved service coverage for potable water in Nicaragua was 98% in the urban area and 68% in the rural area.

The national water supply rate includes a large number of subsidized users and covers subsidies for consumption rates above 30 cubic meters per month, although the average consumption for users is practically that same quantity.

For Managua, the quality related to continuity of the water supply has been characterized by interruptions as shown in Figure 3.1, based on data from 2008. Interruption in the water supply in the capital (made up of 7 districts) has been a product of the deficiency in the supply caused by the lack of rehabilitation and poor maintenance for the existing wells during the 10 years prior to 2008 as well as the use of old equipment that have not been replaced.There are large volumes of water lost due to commercial activities (~50%) that still possess obsolete distribution systems. There are also loss of water due to clandestine, informal connections and extensions of the supply rates that cause an imbalance in the supply systems.

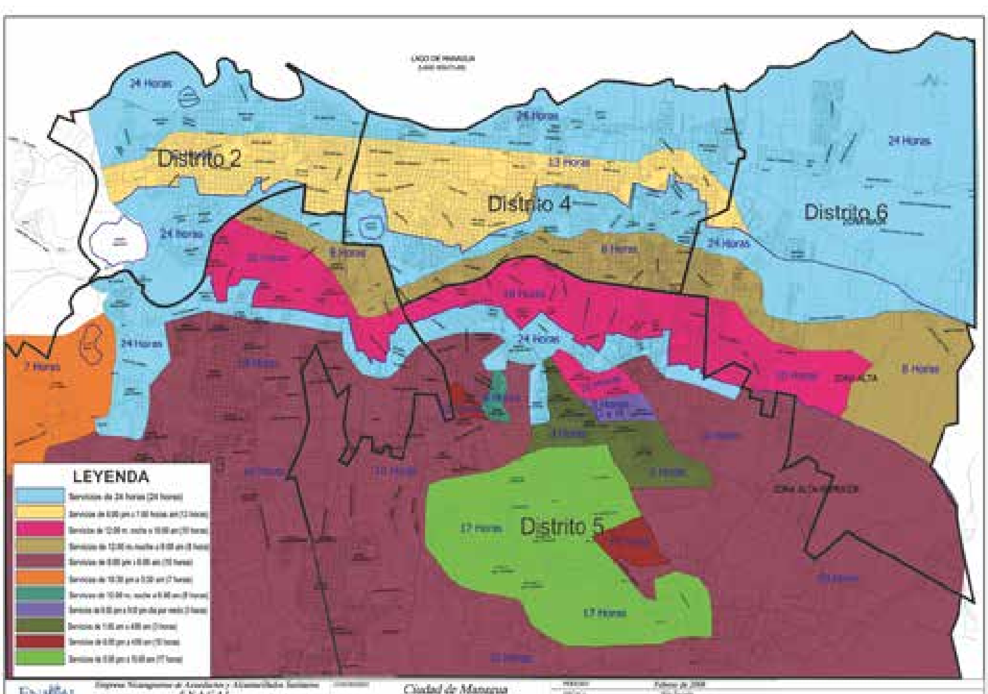
In 2007, a little more than 53% of the available water in the systems was lost due to leaks (ENACAL, ENACAL Institutional Development Plan 2008-2012; Water Sector Strategy, 2008). These losses have been caused by factors such as the appearance of 350 informal settlements (BM/WSP, 2008) that had grown haphazardly with a lack of urbanization standards. Two hundred of the settlements are located in Managua and pertain to 73,000 users who are supplied by ENACAL. At the world level, losses due to leaks in urban distribution systems are 50% (UN, 2010); this percentage is similar to the losses that have been observed in the urban areas in Nicaragua.

Other factors that attribute to the interruption of the supply of potable water in urban areas are the absence or poor quality of electricity supplied to the pumping systems (ENACAL, 2009) and also, but to a lesser degree, to the inefficiency of the electrical systems in the pumping stations and treatment plants.

From 2007 to 2011, coverage in the urban area increased from 65% to 85% (Figure 3.2) for a new number of consumers of between 87,239 and 145,233 in those years, respectively. Other sources have disclosed that, as of 2010, the potable water coverage in urban zones in the country reached 89% and the number of recipients of the coverage between the period from 2006 to 2010 was some 530,000 people (IMF, 2011).

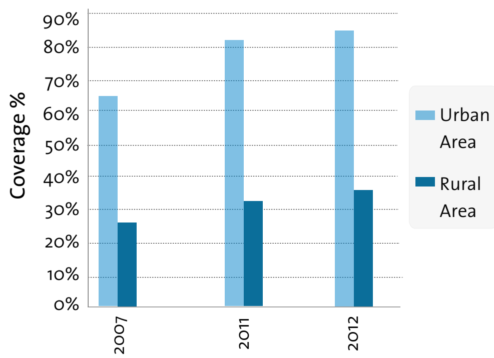
Achievements reached from 2007 to 2010 in relation to potable water coverage in the urban zone include the construction of more than 80 water distribution systems and 50 wells; this means a total of 68,120 connections (IMF, 2011). In Managua alone, 90 kilometers of pipes were replaced for potable water distribution to reduce losses. According to new projections, between 2012 and 2016, 118 wells with 59,903 new connections will be constructed and rehabilitated in the urban zones in the country and a smaller number (12,434) of connections for rural zones (GRUN, 2012).

Figure 3.1 Districts in Managua with Potable Water Services in Relation to Supply Continuity (ENACAL, 2008).



Source: ENACAL, 2008

Figure 3.2 Potable Water Percentage (%) in Urban and Rural Areas in Nicaragua



Between 2012 and 2016, the government has proposed increasing the potable water coverage in the urban and rural areas to reach a coverage index of 91.0% and 50.7% for the respective areas (GRUN, 2012). This would mean 845,277 new people with potable water service and a total of 1,524,717 people with access to improved sources of potable water. With the drilling and rehabilitation of 118 wells, the urban zones in the country would have a total of 59,903 potable water connections.

3.2 Coverage at the *Economic Level*

According to the International Monetary Report (IMF, 2011), the government of Nicaragua has made a total investment for water, sewage, and sanitary systems between 2007 and 2010 of some US $195,800,000. Of that amount, approximately 80.6% of the investment pertains just to water and sanitation. This investment will be carried out for the construction of new water and sanitation systems in the urban and marginal rural zones as well as the construction of mini-pipelines for electrical pumping.

Currently, ENACAL is executing, with a loan from the Inter-American Development Bank, the Potable Water Project for Managua (PRASMA). It has benefited 27 neighborhoods in Managua and provides continuity to improving the lives of people of Managua by increasing the efficiency and sustainability of the water supply. In 2008, investments made for rehabilitating, expanding, and modernizing these water and sewage systems was around US $38.8 million. This represented approximately 61% of the total investments made (ENACAL, ENACAL Institutional Development Plan, 2008-2012; Water Sector Strategy, 2008). In that same year, ENACAL projected an investment of US $492.04 million (with funds from the World Bank, the Inter-American Development Bank, German financial aid, and Korea, Japan, Spain and other cooperating countries) for water and sanitation throughout the country for the 2008-2012 period. For the cities in Nicaragua that benefit from this investment, ENACAL has projected a per capita cost for the investment of US $100 (ENACAL, ENACAL Institutional Development Plan, 2008-2012; Water Sector Strategy, 2008). This represents 22% of all the cities and a population to be benefited of 55,678 inhabitants.

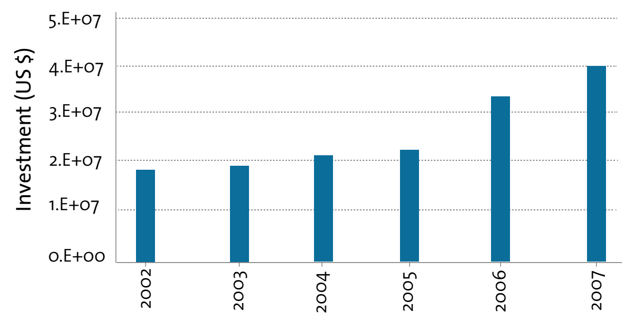
For the period from 2002 to 2006, the investment in potable water coverage in the urban area is presented in Figure 3.3. This investment went from US $17,337,030 in 2002 to US $39,730,504 in 2006 (ENACAL, ENACAL Institutional Development Plan, 2008-2012; Water Sector Strategy, 2008). As may be observed, unlike the first two years, there was a substantial investment in the last two years of this period. Between 2007 and 2009, the ENACAL investment in building 70 new systems (an average of about 23 wells per year) was some US $10 million (ENACAL, 2009). In that same period, legalization of new users made it possible for the company to increase its revenue up to 43% (ENACAL, 2009). This is despite the fact that, in 2008, 53% of the water was still not registered throughout the country (BCN, 2009). Beginning with this year, with a vision toward protecting the poorer residential customers who consume less, the government has projected a differentiated rate adjustment in potable water consumption, which will make an increase in the ENACAL revenue possible (GRUN, 2012).

After 2007, the coverage was impacted by settlements around the urban areas. They not only affected the distribution networks and increased the water losses, but also increased the number of users that were not paying for the service. For example, of the 30,000 new users in Managua, only 30% paid the fees. Between 2002 and 2006, the annual water production for consumption by people living in Managua went from 240,400,600 cubic meters to 273,130,000 cubic meters. However, the water that was not billed in that same period went from 56% to 61% of the total water produced. According to other sources of information, the annual potable water production in 2006 for Managua was some 160,495,432 cubic meters distributed through 28 pipelines. The sources were 130 groundwater pumping wells and the Lagoon of Asososca. According to data from the Central Bank of Nicaragua (2011), the national consumption of potable water that was billed for 2009, 2010, and 2011 was 151,551,100 cubic meters, 146,799,900 cubic meters, and 146,373,500 cubic meters, respectively. The highest percentage (~86%) went to the residential sector.

According to ENACAL, the projections for scheduled investments in the urban sector in the 2008-2011 period was in the amount of US $425,580,000.

In 2012, ENACAL installed an additional 76.5 kilometers to the potable water supply network in 31 neighborhoods in the Municipality of Managua as well as the supply sources. This consisted of building 12 new wells, most located southeast of the center of the city. This work increased the supply schedule for some sectors of the capital since, as of 2008, the hours without potable water service vary from 0 to 24 (Figure 3.1) for 189,461 users.

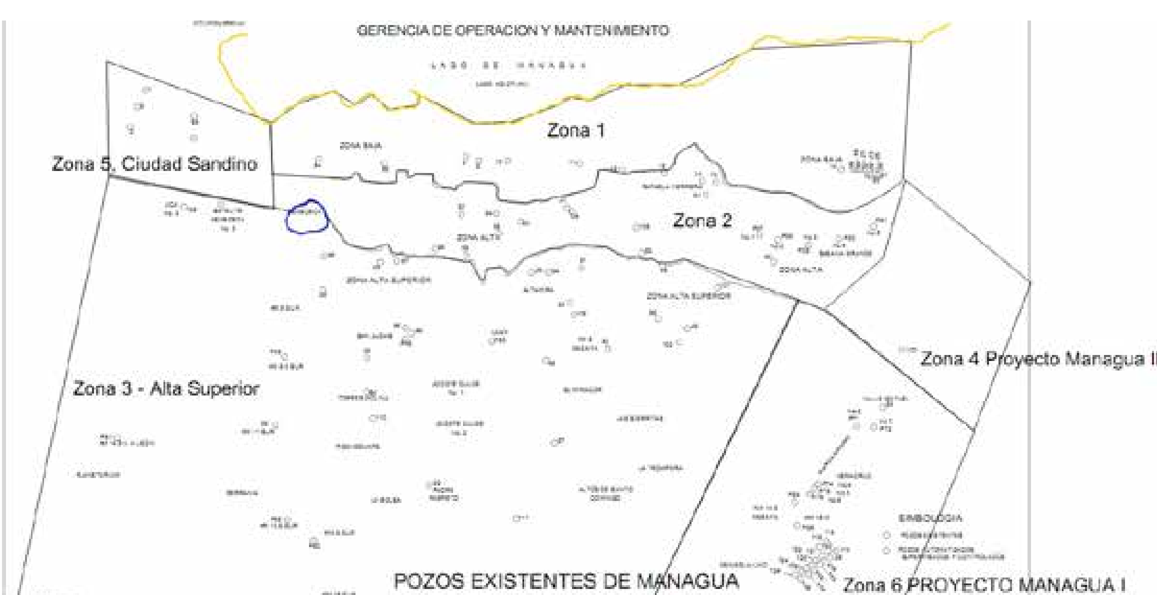
Figure 3.3 Investment (US $) in Potable Water Coverage in the Urban Areas in Nicaragua



3.3 Management of Potable Water Supply Sources

Some 32% of the sources of water used to secure the water supply for human consumption in the urban zones in Nicaragua is from surface water and requires complex treatment systems, while 68% is from groundwater. For example, of the 200 potable water supply systems existing in 2007, 136 are from groundwater (ENACAL, ENACAL Institutional Development Plan, 2008-2012; Water Sector Strategy, 2008). In Managua's case, the sources of the water

Figure 3.4 Location of Wells for the Potable Waters Supply in the City of Managua



Source: Padilla, 2002

supplied to the population are the Asososca Lagoon (average daily usage of 59,900 cubic meters) and groundwater (average daily use of 445,820 cubic meters). This water is extracted through some 130 wells (Figure 3.4). The groundwater comes from the watershed south of Lake Managua (Lake Xolotlán) and is extracted via wells located in specific areas known as: Managua I Well Field, Managua II Well Field and Las Mercedes Well Field, as well as wells drilled throughout the city.

The percentage of the population that uses improved sources of water in the country has gone from 92% in 1990 to 98% in 2011 in the urban areas and from 54% to 68% in the rural areas. (WHO/UNICEF, 2013). According to projections by the government, between 2012 and 2017 some US $56,600,000 will be invested in water and sanitation on the Pacific and central area of the country, which will mean some 60,830 new residential potable water connections (BCIE, 2012). Nevertheless, other projections reflect a higher investment in potable water for the urban area during the 2012-2015 period of some US $201,599,300 (Argüello, 2008). This year (2014), ENACAL will continue improving the water supply to the Nicaraguan population. To do so, it will allocate $34.5 million to be financed through international aid and funds from the Reconciliation Government and National Unity (ENACAL, 2009).

4. Water Treatment in the Cities in Nicaragua

Due to the concentration of the population in urban areas, which has reached 58% of the total population in Nicaragua, there is a high demand for water for human consumption and consequently, considerable volumes of wastewater is discharged as a product of daily activities.

4.1 Waste Water Treatment Coverage in Nicaragua's Urban Zones

According to the report presented by ENACAL for 2010, the potable water coverage increased from 72% to 84%, but the sanitary sewer coverage still is lagging behind. However, an increase from 33% to 39% was achieved from 2007 to 2010. Likewise, wastewater treatment increased by 200% in 2010 in relation to the existing coverage in 2007 (ENACAL, 2010). It is important to point out that ENACAL provides its services mainly to the country's urban centers. This implies that the figures that were presented are for urban areas.

Currently, there is no official data about wastewater treatment coverage but the country has new treatment units that include the Waste Water Treatment Plant (PTAS in Spanish) for the city of Managua. This is the largest work in the water and sanitation sector in the Central American region and was installed in 2009. The plant has a treatment capacity of 180 cubic meters per second; however official data indicates that the plant is currently treating 66.6 million cubic meters per year. Parallel to the installation of the plant, 121,000 sewage system users were connected in the city of Managua (ENACAL, 2010). The project is part of the Lake Xolotlán sanitation program, where wastewater has been discharged since 1927. It intends to recover this resource for recreation without contact and to promote sanitation in the city of Managua (Figure 4.1).

The government has made efforts to rehabilitate the wastewater treatment plants in the cities of León, Chinandega, Rivas, Nagarote, Granada, and El Viejo. Likewise, repairs are planned for another 25 treatment plants throughout the country (ENACAL, 2010).

4.2 Treatment Coverage According to Economic Level

Speaking of wastewater treatment coverage in Nicaragua is difficult since the belief is that the wastewater that receives treatment comes from the sanitary sewage drainage system whose coverage in the urban areas is just 39% (ENACAL, 2010). In addition to this scenario, it is important to note that not all the sewage systems discharge their wastewater into a treatment plant and not all the wastewater treatment plants treat 100% of the water that they receive.

In Managua, the whole urban center of the old downtown (prior to the 1972 earthquake) and the new downtown Managua, including populated neighborhoods located in the peri-urban zones whose existence dates back to prior to the 80s, has a sanitary sewer system. This is not true for the spontaneous settlements that peaked in the decades of 80s and 90s. The settlements were a product of internal migration within the country where the rural population migrated to urban areas as a result of the war in the 80s, famines, and extreme events such as droughts and flooding and the presence of hurricanes. The proliferation of these human settlements without any urban utilities has meant that many so far do not have any sanitary sewer systems.

The government, through ENACAL, has made efforts to solve this problem. The construction project for the wastewater treatment plant in Managua increased the sanitary sewer system coverage in some of the human settlements in the capital. Also, in the Condominium Sanitary Sewer Implementation Project, an innovative system will be installed. The system consists of a network of connections as horizontal property within each block that are connected with collective pipelines through an inspection box (ENACAL, 2009). The system consists of public collectors, treatment units. The benefits of this system include the low cost and easy construction of residential connections, a greater number of connections, the use of smaller diameter pipes, and participation by the population in the project. The settlements that have this type of system are: Arnoldo Alemán, Lomas de Guadalupe, Maria Dolores Alemán, Israel Galeano, Comandante Aureliano, Nueva Sabana, Villa Reconciliación Norte, Carlos Núñez, Georgiano Andrade, Laureles Norte, Parrales Vallejos, and Pedro Aráuz Palacios. The project will serve more than 120,000 inhabitants in 27 neighborhoods in the capital with an investment of 320 million cordobas financed with funds from the World Bank and the Reconciliation Government and National Unity (ENACAL, 2009).

But these new middle and upper class urban developments in the capital, which are mostly located outside the perimeter of the Managua urban area, are unable to connect their sanitary drains to the city's sanitary sewer system. Consequently, they have their own wastewater treatment systems in the form of individual septic tanks or collective sanitary sewer and wastewater treatment systems of their own. They consist of compact plants or packages pertaining to systems with activated sludge, Imhoff Tanks, etc.

Figure 4.1 Modern Wastewater Treatment Plant for the City of Managua

4.3 Treatment of *Gray Water*

Currently, the installed capacity to treat municipal wastewater consists of 32 plants throughout the country including: Lagoon systems, Imhoff tanks followed by Upflow Anaerobic Biological Filter, Imhoff tanks followed by bio-filtering, septic tanks followed by Upflow Anaerobic filters an Upflow Anaerobic Sludge Blanket (UASB) system and a modern system (the Managua Treatment Plant) made up of physical and biological removal processes, which consists of primary settling tanks, drip filtering, and secondary settling tanks. It is important to point out that more than 55% of the treatment plants existing in Nicaragua are lagoon systems; however this policy has changed due to budget restrictions and availability of suitable areas for building lagoon systems (ENACAL, 2009).

In Nicaragua, municipal wastewater that flows through sanitary sewers is made up of gray water, black water, and in the rainy season, rainwater from some domains that have connected their rainwater drainage to the system illegally. This situation brings consequences for the composition of the domestic wastewater and means a higher organic load, a high concentration of nutrients such as nitrates and phosphorus, abundant presence of pathogenic groups, sediments, and detritus (IANAS, 2012).

Most of the treatment systems implemented in the country under optimal operating conditions turn out to be efficient in removing the organic load and suspended solids but this is not the case for the removal of nutrients and pathogens. However, most of the domestic wastewater treatment systems in the country are in a state of advanced deterioration due to lack of maintenance (Figures 4.2 a and b), poor operations, and not adecuate dimensioning of capacity for necessary load and treatment.(IANAS, 2012).

4.4 *Reuse* (Successes and Problems)

Currently, no data is available about the volume or portion of treated water that is reused. This portion may be minimal due to the fact that generally final disposal of treated effluents is into surface waters such as lakes and rivers.

Using treated water in the country is not a common practice. This might be due to the fact that wastewater treatment systems in the country have turned out to be not very efficient in removing pathogens, which does not facilitate their reuse (ENACAL, 2009).

4.5 Returning Water to the Environment or Ecosystems

The effluents from the treated water from wastewater treatment plants in the country are mostly returned to surface waterbodies. For example, the effluent wastewater from the wastewater treatment plant in Managua is released into Lake Xolotlán through a submerged emitter located at a distance of 1½km from the coast. The effluents from the treatment plants in Granada and San Juan del Sur are discharged through runoff into Lake Cocibolca. The effluents from the treatment plant in Masaya are discharged directly into Lake Masaya, etc. (ENACAL, 2010). For example, returning the treated water to Lake Masaya (Figures 4.2a and b) has resulted in the deterioration of the lake's water, causing anoxia in 80% of the water column (CIRA/UNAN, ENACAL, 2013).

The effluents from residential developments are disposed of through infiltration wells. This becomes a latent risk of contamination for the groundwater resources and many of them are located in the recharge area in the watershed south of Managua (Section 2.4.3).

Figure 4.2 State of Maintenance of the Oxidation Lagoon in the City of Masaya

Returning the treated water to the environment, to aquatic ecosystems, is very feasible if the water were not a threat and an environmental tensor for the receiving waterbodies. However, in practice, this is not the case, due to the high deficiency of treatment, to the point that the treated water from these plants mostly holds large quantities of groups of pathogens, high concentrations of nitrogen, phosphorus, and detergent, and a considerable organic load, etc. This becomes a threat from the limnological and sanitary point of view.

Table 5.1 Classification of Diseases Originating in Water

Classification	Mechanism	Disease Type
Transmission by water	Human or animal contamination	Cholera, typhoid fever, shigellosis, polio, meningitis, hepatitis, diarrhea.
Originating in waterbodies	Living creatures who live part of their life cycle in aquatic hosts	Schistosomiasis, diseases caused by nematodes, trematodes, and cestodes.
Vector-born diseases related to water	Related to vectors that develop in water	Malaria, dengue, yellow fever, filariasis
Related to a shortage of water	Shortage of fresh water and deterioration of sanitary condition of the water	Trachoma, ring worm, lice, and scabies

5. Urban Water and Health

5.1 Concept, Definition and Classification of Water Transmitted Diseases

Diseases that are transmitted by water are related to consumption, use, and the availability of water. Some authors make a classification based on the agents or substances that may cause harm to human health, including viral and parasite related diseases. Other authors group them into diseases transmitted by water, diseases that originate in water, vector-born diseases related to water, and diseases that are produced from a shortage of water (Deutsche Gesellschaft für Technische Zusamenarbeit, 2009)

The diseases transmitted by water that are found with high frequency in urban sectors in Latin America may be summarized as: dengue, malaria, leptospirosis, viral and bacterial dysentery, acute diarrhea related disease, etc.

5.2 Urban Development and its Effect on Human Health

An urban development is a residential center made up of dwellings that have similar characteristics and that are provided with electrical services, potable water, sewage systems, public transportation, access to education, employment, and services.

Despite all the good things that an urban development may have, there are negative aspects that should be mentioned. The urban development companies in Nicaragua mostly build in areas where potable water and sewage systems are not always accessible. Therefore, they have to dig wells to obtain potable water and build oxidation lagoons in areas that are very close to the wells. If sanitary zoning is not done properly, it may affect human health. An example of this is that some urban development companies introduce systems that only partially treat the wastewater. For economic reasons, they often infiltrate the wastewater into the sub-soil again. This leads to a high degree of contamination of the aquifer. In a short period of time, this could convert the water into a quality not suitable for human consumption. Another issue is the topography where the new urban developments are built and in many cases are built on the banks of drainage channels without the proper protection and convert into flood zones when there is heavy rainfall and become focal points for vector diseases.

5.3 Health Indicators

The health situation will be addressed, specifically for Managua. Based on the information available, mortality indicators are shown such as general mortality, mortality in infants less than five years of age and mortality due to acute diarrhea related diseases.

General Mortality in the City of Managua

This indicator includes the total deaths due to all causes that occur in people living in Managua. Beginning in 2006, a sustained increase is seen in the general mortality rate. The same trend is observed in the different districts (Figure 2.1, map with districts indicated) in the city of Managua.

Figure 5.1 shows that the highest general mortality rate is found in District IV for the 2006-2011 period. This area is the old urban center in the city of Managua that was destroyed by the earthquake in 1972. The population density for this district is estimated to be 16,248 inhabitants per square kilometer. This district contains the Oriental Market which generates the most solid waste (annual average of 41,300 cubic meters of trash) in the city of Managua.. Another issue related to District IV that may contribute to its higher mortality index is its proximity to Lake Xolotlán, which is a breeding ground for insects that have a high presence in standing water (Collections NiKa CyberMunicipio, 2013).

Mortality in infants less than 5 years of age

The mortality rate for infants less than five years old is a sensitive indicator because it reflects all of the deaths due to the different causes in this age group including minors one year old. At the level of the city of Managua, an increase is also observed in the years that were studied. District VI has the highest increase in the 2007-2011 period (Figure 5.2). This district has 167 neighborhoods. Of them, four are residential developments, 31 are working-class neighborhoods, 47 are progressive urban developments, 85 are informal urbanizations (shantytowns), and four are rural districts(Collections NiKa CyberMunicipio, 2013).

This district is characterized by having the largest number of linear kilometers that border on Lake Xolotlán. They are also characterized by having figures of 53.3% of inhabitants that are categorized as being poor or extremely poor, despite the fact that most of the existing industrial zone in the capital is located in this district (the Mayor's Office of Managua, 2011).

Acute diarrhea

Mortality due to acute diarrhea is relatively low if all of the deaths reported in the city of Managua are taken into account; since in 2010, 21 deaths due to acute diarrhea were reported out of a total of 4,296 deaths due to all causes. For 2011, seven deaths were recorded for this same cause out of a total of 4,493 deaths. In 2010, 42.8% of deaths due to diarrhea were in infants less than one year old. In 2011, 85.7% of the deaths due to acute diarrhea occurred in the same age group. This evidences the high susceptibility that minors one year old have in relation to acute diarrhea related diseases. In the two years that were reviewed for mortality due to acute diarrhea related diseases, the districts with the highest mortality rate reported were District VI and District II, with 12 and eight deaths, respectively. The reduction in the recent years of cases of deaths due to acute diarrhea related diseases is believed to be associated in part with an improvement in the quality of the sanitary sewer services. In addition, the reduction is related to introducing a vaccination program for children against rotavirus, which is the cause of a large part of the acute diarrhea related diseases. The level of medical care and sanitation education for the general population has also contributed to effectively prevent and treat this major health problem on time.

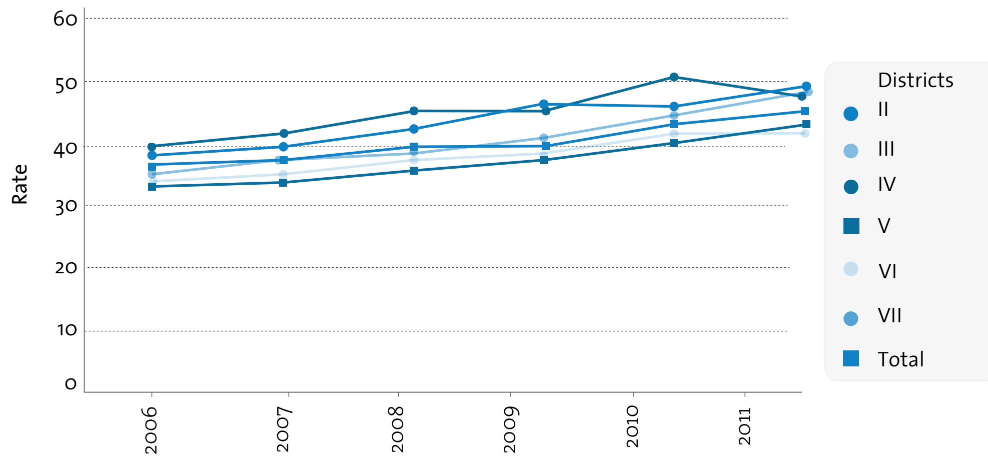
5.4 Water and Vector-Born Diseases: Dengue and Malaria

Dengue is an infectious disease caused by the flavivirus that is transmitted by the *Aedes aegypti* and *A. albopictus* mosquitos. People who have the disease may infect mosquitoes that bite them and drink their blood and continue promoting the virus transmission cycle. There are four dengue virus serotypes (DEN1, DEN2, DEN3, and DEN4); any of them may cause the disease. The most frequent for classic dengue is Serotype 1. The clinical manifestation is characterized by acute fever, an intense general discomfort, accompanied by skin eruptions. Hemorrhages from moderate to intense severity may appear, with gingival and nasal bleeding, causing shock and death. The *A. aegypti* is a diurnal species and most frequently bites two hours before sunset and several hours before sunrise. It lives and lays its eggs around and inside houses, in containers used to store water for domestic needs and tubs, old tires, and other objects that are used to store water.

Dengue at the country level has had a cyclical behavior. According to research by the CIRA/UNAN water and health unit, it is not necessarily related to the amount of precipitation that the country experiences (Figure 5.4).

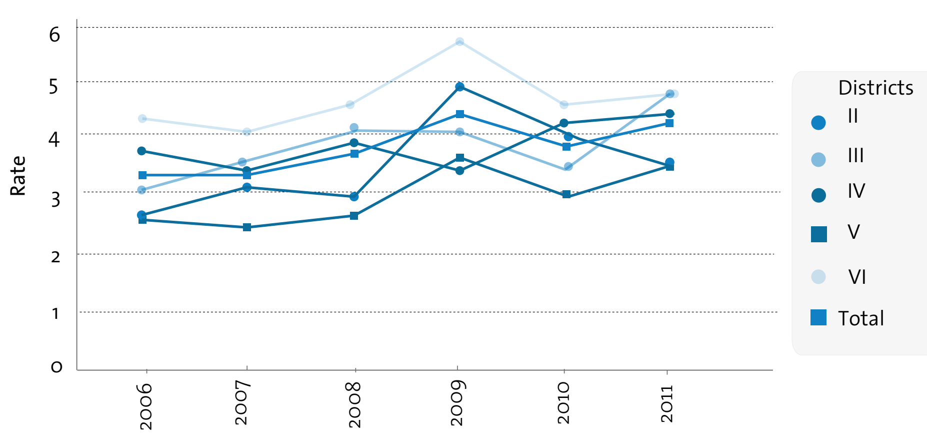
According to the Panamerican Health Organization (PHO), the epidemic cycles for the disease are due to the fact that the "eradication program proposed in the past years did not fail;

Figure 5.1 General Mortality Rate by District in the City of Managua, 2006-2011



Source: General Planning and Information Systems Division, MINSA.

Figure 5.2 Mortality in Children under Five Years Old by District in the City of Managua, 2006–2011



Source: General Planning and Information Systems Division, MINSA.

instead, after the participating countries successfully eradicated the vector, oversight was relaxed and this resulted in re-infestation and, followed by that, the introduction of diverse virus serotypes. This ended up aggravating the dengue situation in the region (Dr. Jorge R. Arias, regional PHO consultant for transmittable diseases) (AP agendapropia.com, 2012).

Two large epidemics have occurred during the last ten years that were mentioned: one in 2009-2010 and one in 2012-2013.

Table 5.2 compares the national incidence rates per 10,000 inhabitants in the 10 years being studied. It shows the highest rate of incidence for severe dengue (hemorrhagic), without taking into consideration the epidemic in 2003, was 2005 (0.32 cases per 10,000 inhabitants).

The year with the highest incidence of classic dengue in the series being studied was 2013. For that period, the situation in relation to dengue was aggravated by the circulation of different virus strains.

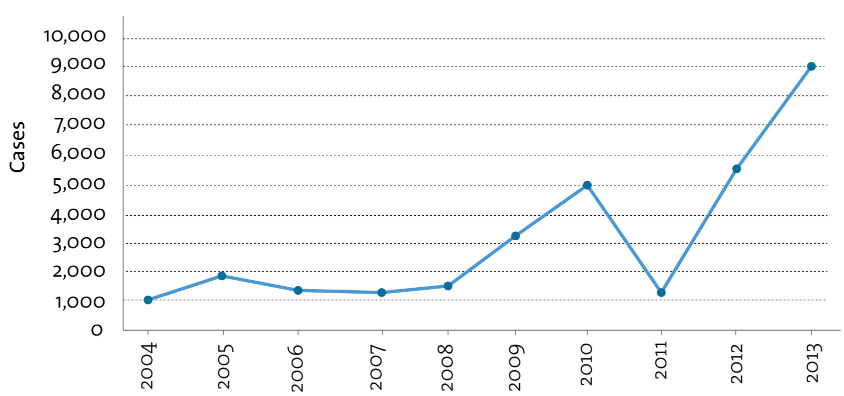
The increase in density in the last several years may be attributed to an increase in the risk due to the presence of the *A. aegypti* vector in peri-urban zones and rural locations with new population growth. The existence of a generalized epidemic in the region of the Americas also contributes to this behavior, where it is practically impossible to keep people from traveling between different countries.

The development of dengue in the city of Managua is shown in Table 5.3.

At the level of the city of Managua, District II was the district that had (without taking into account the epidemic in 2013) the highest number of dengue cases in the last five years. This district houses the historic garbage dump for Managua and borders on the coast of Lake Xolotlán.

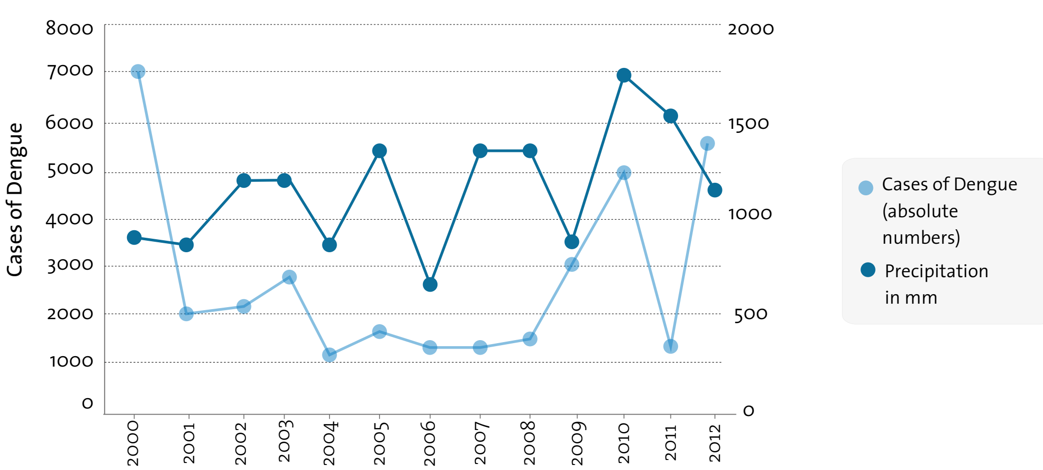
Rainfall (Figure 5.4) in the city of Managua in the first decade of the millennium (2000-2010) oscillated between 675 and 1,435.9 millimeters of annual rainfall. The highest number of dengue cases in the city of Managua did not always occur in the years with the highest rainfall. This leads to the conclusion that other factors exist that contribute to the proliferation of dengue in addition to rain.

Figure 5.3 Dengue Cases in Nicaragua, 2004–2013



Source: 1. Nicaraguan System of National Epidemiological Oversight (SISNIVEN). 2. PHO/WHO, Informational Bulletins, http://www.paho.org/nic/index.php?option=com_content&view=article&id=549&Itemid=286, reviewed August 21, 2014.

Figure 5.4 Relationship Between Rainfall and Dengue Cases in Nicaragua, 2000–2012



Source: Cases-Nicaraguan System of National Epidemiological Oversight (SISNIVEN); Precipitation-Nicaraguan Institute of Territorial Studies (INETER).

Table 5.2 Incidence Rates for Dengue and Severe Dengue, 2004-2013

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Dengue	1.86	3.16	2.33	2.52	2.56	5.7	10.03	2.53	10.77	17.34
Severe Dengue	0.17	0.32	0.10	0.021	0.009	0.021	0.015	0.002	0.10	NR
Population*	5,374	5,483	5,522	5,595	5,668	5,749	5,815	5,896	5,962	6,024

Source: Nicaraguan System of National Epidemiological Oversight (SISNIVEN). Rate Per 10,000 Inhabitants; NR: Not Reported by the Ministry of Health; *Population: Population expressed in thousands.

Table 5.3 Dengue Cases by District in the City of Managua, 2008-2012

District	2008 Percent	2009 Percent	2010 Percent	2011 Percent	2012 Percent	Total Percent
II	9120.6	46037.5	82046.6	15949.3	39263.9	192244.1
III	296.5	12310.1	1086.2	329.9	264.3	3187.3
IV	265.9	907.4	1578.9	144.3	111.8	2986.8
V	14432.6	35128.6	44425.2	5115.8	528.5	104223.9
VI	15234.4	20116.4	23013.1	6720.7	13221.5	78217.9
Total	442100.0	1225100	1759100	323100.0	613100.0	4362100

Source: The Ministry of Health.

One of the factors that is considered to be very important in the spreading of dengue is water storage in homes. The results of entomological surveys taken in different months of the year show that the vector prefers standing water in homes (76% positive for the presence of *A. aegypti*), with barrels rating 70.4% and sinks 28.6%. Non-usable items (old tires, unused bottles, etc.) represent 21% and natural breeding grounds represent 3% (The Nicaraguan Ministry of Health, 2009). According to the indicators to analyze the vector's presence, in 2008 the index for houses with breeding grounds nationally was 4.2. For the same period in 2009, the index for entomological surveys nationally was 4.0. This evidences that the values of the results of the entomological surveys taken by the SILAIS (Local Comprehensive Health Care System) did not vary significantly. However the cases of dengue in Managua went from 442 to 1,225 for that period. Therefore, the dengue epidemic does not have a close relationship with the entomological larva indices and urban areas nor with the intensity of rainfall.

In 2013, the vector was present in all of the main cities in the national territory (Table 5.4) and smaller towns. It had even been able to spread and colonize broad rural zones, especially areas on the sides of the country's main highways. This, plus the effects of climate change that are beginning to be felt in relation to environmental temperatures and the rain and drought cycle lead to predicting that dengue may spread to areas that historically have not suffered from the disease, such as rural and high regions, linked to favorable conditions for the vector to reproduce.

In the last four years, the six SILAIS with the highest population density (marked in Table 5.4) show the highest accumulated number of cases of dengue (72% of the total cases at the national level) where the city of Managua stands out.

Despite the high incidence of dengue in the Latin American region, Nicaragua has had relatively low rates in the last several years thanks to the health campaign to actively seek out and immediately take care of the fever cases that occur, in addition to the educational and awareness raising campaigns for the general population. Another issue that needs to be mentioned is training for health staff to properly handle dengue cases early.

In conclusion, a continuous water supply could contribute an important step to better control the vector. Broader programs are needed that include a more constant, permanent water supply in homes where families do not have to keep water in containers, functioning sewer systems, control of solid waste with the main emphasis on using and throwing away unused tires, in addition to proper entomological and epidemiological oversight inside and outside the home.

Malaria is a parasite-based disease that involves high fevers, chills, flu-like symptoms, and anemia. Malaria is caused by a parasite in the genus *Plasmodium*. The disease is transmitted from one human to another by Plasmodium infected mosquito (Anopheles) bites and blood transfusions. The parasites enter the bloodstream and infect the red globules. This disease is a major health problem in a large part of tropical and subtropical countries. The United States Center for Disease Control (CDC) calculates that every year 300 to 500 million cases of malaria occur and that more than one million people die because of malaria.

Environmental factors related to the availability of a water medium for the reproduction of the mosquito vector are involved in transmitting the disease. The factors also include socioeconomic, cultural, and lifestyle factors for the exposed human population. They are the determining factors in the transmission mechanism and, therefore, in its incidence and prevalence.

In Nicaragua, the strategies adopted by the country's government have had a positive impact on the fight against malaria. The number of cases of this disease has fallen dramatically in the last several years: from more than 70,000 cases reported in 1996 (Sequeira M, 2010) to 464 cases in 2012 (The Ministry of Health, 2013). It should also be pointed out that Nicaragua is one of 13 Latin American countries that, between 2010 and 2011, were able to reduce the cases of malaria by 75%, as reported by the World Healthcare Organization (WHO) (2012). These achievements have led the country to receive recognition as "Champion against Malaria in the Americas 2011" by the Pan-American Health Organization (PHO). Nicaragua is on the way to fulfilling the malaria pre-elimination criteria so the country is considered to be on the way to eliminating this disease and to fulfilling the Millennium Goals for 2015 and the socio-economic development goals established by the UN in 2000 (The Ministry of Health, 2013).

In relation to how malaria behaves in the districts in the city of Managua, District VI is the district with the highest percentage of reported cases (42.3%) for a total of 22 cases. It should be pointed out that, in these five years of malaria case review (2008-2012), in accordance with how the

Table 5.4 Dengue Cases and Rates Gathered by SILAIS in Nicaragua

SILAIS	2010		2011		2012		2013		Total Cases
	Cases	Rate	Cases	Rate	Cases	Rate	Cases	Rate	
Managua	2452	19.41	366	2.9	2351	18.61	3424	27.11	8593
Leon	443	12.45	74	2.08	165	4.64	852	23.95	1534
Chinandega	156	4.12	132	3.48	244	6.44	933	24.62	1465
Chontales	267	8.67	164	5.33	279	9.06	433	14.07	1143
Masaya	250	8.62	80	2.76	398	13.72	409	14.1	1137
Matagalpa	233	4.49	205	3.95	443	8.54	239	4.61	1120
Esteli	197	9.77	39	1.94	294	14.59	388	19.25	918
Carazo	294	17.7	22	1.32	73	4.4	396	23.84	785
Jinotega	100	3.02	35	1.06	394	11.89	111	3.35	640
Granada	96	5.71	27	1.61	329	19.56	139	8.26	591
Nueva Segovia	76	3.64	19	0.91	139	6.67	333	15.97	567
Boaco	93	6.17	16	1.06	104	6.9	282	18.72	495
Madriz	94	7.1	13	0.98	46	3.47	298	22.5	451
Rio San Juan	132	13.81	34	3.56	70	7.32	156	16.32	392
Rivas	158	10.11	6	0.38	80	5.12	126	8.06	370
RAAS	18	1.49	43	3.56	77	6.37	174	14.4	312
Las Minas	53	3.17	29	1.74	33	1.98	118	7.06	233
Bilwi	44	3.4			17	1.31	103	7.95	164
Country	**5156**	**10.03**	1304	2.536	**5536**	**10.77**	**8914**	**17.34**	**20910**

disease behaves nationally, in the Department of Managua, a sustained decrease in malaria cases has been observed.

In general terms, the drop in malaria cases in Managua is related to the government's policy on sanitation for the coast of Lake Xolotlán, community participation in eliminating puddles and standing water (mostly in the peripheral neighborhoods around the city) and in the Ministry of Health's actions taken to fumigate and find and treat people with fevers who are suspected of suffering from the disease.

6. Variability and Climate Change, its Impact on Water Resources in Cities

6.1 Climate Change and Variability in Nicaragua

Nicaragua occupies the center of the narrow strip of Central America. This geographic position makes the country naturally exposed to meteorological phenomena from both oceans to the Pacific and the Caribbean Sea. This natural situation is aggravated by the intensity and frequency of extreme climate change and variability events. The country's vulnerability is increased due to this situation.

The Climate Vulnerability Monitor, an evaluation done by the Spanish humanitarian research organization (DARA, 2010), places Nicaragua among the countries with acute to severe vulnerability with the variation from very severe to very acute for 2030, mostly for disasters for the economy and housing.

6.2 Cities in Dry Areas and How the Supply is Organized

According to the drought map from the Nicaraguan Territorial Studies Institute (INETER), for the period from 1970 to 1977, the cities that are vulnerable to these meteorological phenomena with a very severe degree of drought are: Chinandega, Somoto, Matagalpa, and Juigalpa. The following cities showed a severe degree of drought: León, Managua, Masaya, Granada, Jinotepe, Rivas, Estelí, Boaco, and San Carlos (Figure 6.1).

6.2.1 Cities in dry areas of Nicaragua

6.2.1.1 Climate variability

Figure 6.1 shows that both the coastal strip on the Pacific and part of the Central Region are threatened by drought. On the Pacific, anomalies were reported of -34.5% (-516.0 mm) in 1976; -32.7 % (-490.0 mm) in 1972 and -26.5 % (-397.0 mm) in 1997. They occurred mostly in the months of July, August, September, and October.

The highest rain deficits recorded in the northern region occurred in 1972 with -19.0% (-230 mm) and in 1976 with -18.0% (-214.0 mm).

Drought recurrence

The INETER, in its publication *Drought in Nicaragua*, determined the dry years in the 1970-2000 period for the whole national territory. In the Pacific region, where the cities of Chinandega, Managua, Masaya, Granada, Jinotepe, and Rivas are located, the years from 1971 to 1998 had four years of extreme drought: 1973, 1993, 1995, and 1998. The dry years were: 1972, 1976, 1977, 1987, 1989, 1990, 1991, 1992, 1994, and 1997. Most of these years were associated with the El Niño phenomenon.

The cities of Somoto, Estelí, Jinotega, Matagalpa, Boaco, Juigalpa, and San Carlos in the Central Region were considered to be under the influence of El Niño in: 1971, 1972, 1976, 1977, 1983, 1984, 1985, 1987, and 1992.

Access to water

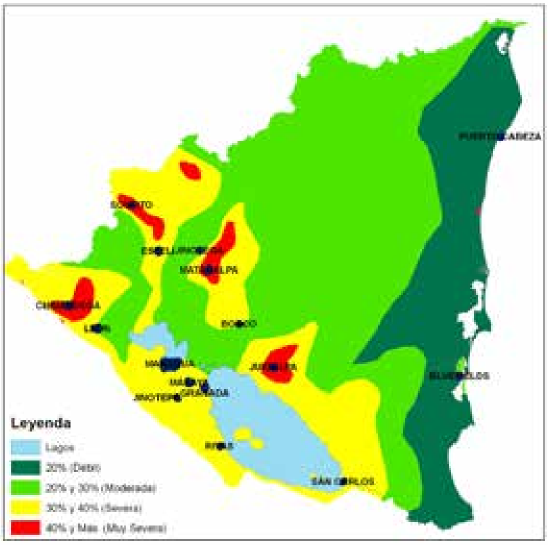
The cities on the Pacific have good aquifers that are the main source of access to potable water. In the cities in the Central Region, the supply is mostly from rivers and streams. Small towns are supplied by low productivity wells. In some cases, they turn to the transferof water from basin to basin or municipality to municipality.

6.2.1.2 Vulnerability

The current demand is not being satisfied due to the rapid increase in population. In addition, the wells are not fully penetrating so the aquifer is not used to its capacity. During the summer, the groundwater levels decrease, and during a drought, the wells drop to their minimum level or dry up.

The water quality deteriorates during droughts due to the accumulation of salts, organic matter, and different types of waste. These substances leach out into shallow aquifers.

Figure 6.1 Cities Affected by Drought and to What Degree



Source: Drought Map 1970-1977, Prepared Based on the INETER map.

6.2.1.3 Mitigation and Adaptation

Currently, the main means of adapting is the construction of new wells and transfer of water from aquifers and rivers. During the summer, or drought season, the municipal offices in many cities are in charge of supplying the water to the citizens using roving tank trucks, which regularly reach the most affected neighborhoods. In some places that have the best supply, special service stations for water are set up for the places where there are problems.

Some people have chosen more drastic measures by digging into the supply network and taking water directly from the pipe.

6.2.2 Cities in Areas with a Danger of Flooding in Nicaragua

The flooding risk map (INETER 2006), shows the main cities that have a threat of flooding: Managua, Estelí, Matagalpa, San Carlos, Bluefields, and Puerto Cabezas (Figure 6.3).

6.2.2.1 Climate Variability

Floods are one of the main climate variability threats in Nicaragua. A study carried out by UNAN-Managua (López, Reyes, Gutiérrez, Alfonso, and Alfonso, 2011) about climate change and human health shows that, due to the loss of more than 85% of the dry tropical forests, and 65% of the rainforest, the soils have deteriorated and are more vulnerable to the impact of climate change.

6.2.2.2 Recurring Floods

A non-valid source specified in the article "What is La Niña?" evalutes the extreme, abundant rains during the last 100 years (evaluation up to 2000).[1] The event that affected the country the most, Hurricane Mitch, took place in October 1998 and completely destroyed the town of Rolando Rodriguez, a small town of 2,000 inhabitants located to the east of Chinandega.

6.2.2.3 Vulnerability

The currents generated by torrential rains and hurricanes quickly run off to the lowest parts due to the deterioration in the **watersheds** (Figure 6.4).

Almost all the leading cities in the departments in Nicaragua are located on river plains or intermittent channels, which makes them highly vulnerable.

The German Watch Organization through the Climate Risk Index (CRI) (Sönke & Eckstein, 2014), which analyzes the quantitative impact of extreme events throughout the world, places Nicaragua, in 2014, in fourth place for vulnerability in relation to these events. The calculation of economic losses reflected in the German Watch Report goes over US $224.61 PPP.[2] The items are not broken down.

6.2.2.4 Mitigation and Adaptation

The direct causes of flooding are the result of complex phenomena that should be studied in

1. Note from this work

2. PPP - Purchasing Power Parities. Tool that compares the cost of goods and services in one country in relation to another country.

Table 6.1 Ranges and Values for the Vulnerability Attributes

Attribute	Range, (H, M, L) / Value (3, 2, 1)
Exposure (E)	High (3), Medium (2), Low (1)
Sensitivity (S)	High (3), Medium (2), Low (1)
Adaptation Capacity (AC)	High (3), Medium (2), Low (1)

detail. The main causes of flooding are an obsolete rainwater drainage system, depositing solid wastes into the sewer system and drainage channels, and soil mismanagement. Some cities use micro-dams to dissipate energy from the heavy currents, which decreases the danger of flooding. In many **watersheds**, reforestation work is underway, but they are oftentimes limited to small areas, so the change is low.

6.3 Analysis of the Vulnerability of the Principal Cities in Nicaragua

An analysis of vulnerability, adaptation to change and climate variability for the main cities affected in Nicaragua has been carried out, using the vulnerability equation. Equation:[3]

(1) **Vulnerability= Exposure + Sensivity - Capacity**

The vulnerability factors (exposure, sensitivity, and adaptation capacity) are evaluated in the formula by assigning them three ranges (high, medium, and low) and each range is assigned a value (1, 2, and 3). Table 6.1.

Exposure factors: Exposure factors refer to the recurrence of droughts or flooding, the effects of landslides, and the type of soil in the area.

Sensitivity factors: Sensitivity is related to the population's lifestyle and economic activities. The land use, condition of the rainwater drainage system, the population's type of housing, and population density in the city are taken into account

Adaptation capacity factors: The adaptation capacity has been measured based on how the population is organized in relation to the existence of risk plans, development plans in cities, and rainwater drainage plans.

The results of the vulnerability analysis indicate that, in general, the cities on the Pacific and some valleys in the Central Region are affected by drought events mostly, while the cities in the Central Region and on the Caribbean are subject to perennial flooding.

Exposure: The cities are exposed to flooding because they are located in the lower parts of the

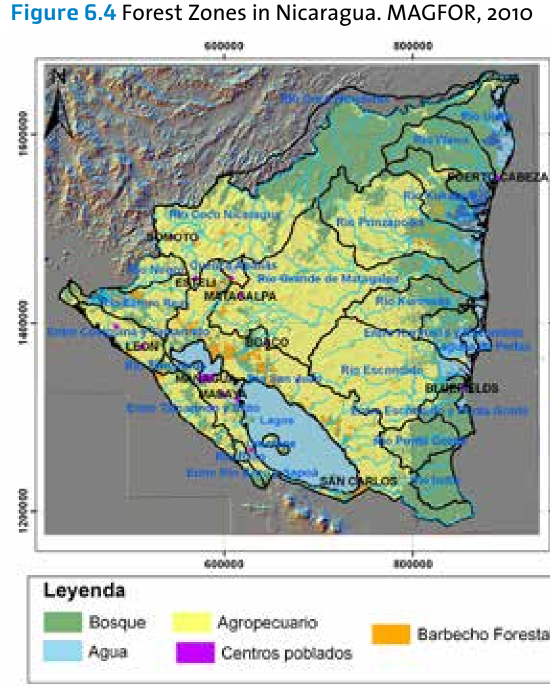
3. Preston et al., 2008; Allen Consulting, 2005; Metzger et al., 2005; Smit and Wandel, 2006.

Figure 6.2 Adaptation by the Population Due to Lack of Supply

Figure 6.3 Map of the Threat of Flooding in Cities

Source: Prepared based on the INETER Map

Figure 6.4 Forest Zones in Nicaragua. MAGFOR, 2010



Source: Prepared based on the INETER Map

watersheds where the land use is inappropriate. Drought affects mostly the water supplies, either in relation to the well infrastructure or the decrease in the aquifer level (Table 6.2).

Sensitivity refers to the anthropogenic factors that may provide an incentive for flooding or drought. An inadequate rainwater drainage system increases vulnerability to flooding. Deforestation increases runoff. The type of housing has an influence that is based on the construction materials and standards. The city's future development, whether it is planned or not, is highly sensitive because growth is accelerated and with little control. Table 6.3 summarizes the data obtained.

The adaptation capacity is believed to be almost the same throughout the country so, on average, the same results are obtained for the main cities in Nicaragua.

According to the evaluation, the vulnerability to climate change for the most affected urban areas in Nicaragua is obtained (Table 6.5).

Thus, what is observed is that Estelí and Matagalpa are the most vulnerable to climate change in all realms. The other cities (in general all the cities in Nicaragua) may have medium to high vulnerability.

Table 6.2 Exposure of the Most Affected Cities Due to Climate Events

City	Region	Floods	Drought	Land Slides	Soil Type	Average
Managua	The Pacific	3	2	1	1	2
Estelí	Central	3	2	3	3	3
Granada	The Pacific	3	2	1	1	2
Matagalpa	Central	2	3	3	3	3
Bluefields	The Caribbean	2	1	1	2	2
Puerto Cabezas	The Caribbean	2	1	1	2	2

Table 6.3 Sensitivity of the Most Affected Cities in Nicaragua

City	Rainwater Drainage System	Land Use High Part	Type of Housing	Future Development	Sensitivity
Managua	3	2	2	3	3
Estelí	3	2	2	3	3
Granada	3	2	1	3	2
Matagalpa	3	2	2	2	2
Bluefields	3	2	3	2	3
Puerto Cabezas	3	2	3	2	3

Table 6.4 Adaptation Capacity of the Affected Cities in Nicaragua

City	Conservation Measures	Database	Organizational Capacity	Policies Related to Climate Change	Warning Systems	Average
Managua	2	2	1	2	3	2
Estelí	3	2	1	2	3	2
Granada	2	2	2	2	3	2
Matagalpa	3	2	2	2	3	2
Bluefields	1	2	2	2	3	2
Puerto Cabezas	1	2	2	2	3	2

Table 6.5 Vulnerability of the Affected Cities in Nicaragua

Municipality	Exposure	Susceptibility	Adaptation Capacity	Vulnerability
Managua	2	3	2	2
Estelí	3	3	2	3
Granada	2	2	2	2
Matagalpa	3	2	2	3
Bluefields	2	3	2	2
Puerto Cabezas	2	3	2	2

7. Conclusions

In Nicaragua, although the per inhabitant availability of water in the urban areas is high, the surface and groundwater sources have been exposed to impact on the water quality by different factors related to urbanization such as: lack of solid waste management, contamination by industrial and domestic wastewater, intensification of agriculture along with deforestation in the recharge zones for the groundwater that are sources of water for the cities, lack of adequate solutions for drainage which causes large quantities of sediment to enter with the rainwater into the surface waters, informal urbanizations and residential developments that do not have adequate domestic water treatment, and service station spillage resulting in contamination of groundwater. Due to this type of impact on water quality, two major surface waterbodies have been lost: Lake Xolotlán and Lake Tiscapa, as possible sources of water for consumption for the city of Managua.

Due to investment programs to improve the access to potable water, Nicaragua has achieved a 98% coverage in the urban zones. There are still problems with the continuity of the service and, due to the lack of maintenance on the supply networks, water is still lost due to leaks that may interrupt the service or lower its efficiency

Despite the many investment efforts to improve sanitation coverage, Nicaragua has not been able to achieve the Millennium Development Goals. However, currently most of the cities are in the planning process or undertaking sewage system expansion and improvement programs or installation of treatment plants. There exists iniciatives to install new systems of treatment such as condominial sewerage systems. In the analysis of the health situation for the people living in Managua due to water transmitted diseases, an improvement has been seen in relation to the number of cases of water transmitted diseases, such as acute diarrhea diseases, dengue, and malaria in the last 10 years. This may be associated with the efforts made related to sanitation in Managua to reduce the epidemiological risk that Lake Xolotlán implied prior to the installation of the treatment plant and greater access by the population to public health services. However, improving the continuity of access to water may reduce the risk even more, since it would eliminate the need to store water in ways that transmit dengue and other vectorial diseases.

The cities in Nicaragua are vulnerable to extreme events, due to uncontrolled growth, the lack of modernization in the water and sanitation networks, failure to prepare for extreme events with improvement in urban drainage systems and infrastructure in general. The lack of intervention measures in an adecuate management of the watersheds located around and in urban zones increases the deforestation and provides an incentive for the effects of droughts and floods.

8. Recommendations

- Establish drainage systems in the urban zones that are adapted to extreme events related to intensive rainfall, taking sedimentation into account, along with the geomorphological and topographic issues in the urban zones. It is important to pay attention to managing land use, taking into account the special properties per micro-watershed to prevent erosion that causes problems in the cities and their sources of water.

- Prioritize the investment in sewage systems in urban zones parallel to improving or installing treatment systems that do not affect surface waterbodies.
- Make more progress in investment programs to achieve continuity in the access to water and remediate and prevent the increase in leaks in the system. Therefore, it is necessary to reinforce financial sustainability and the ENACAL's capacity to ensure success for its investment programs.
- Introduce regulations for urbanization projects which require planning for adecuate access to water and sanitation.
- The solution to the effects of climate change on cities, both due to flooding and droughts, requires studies that detail the hydrological, hydrogeological and soil-related scientific base. This way, the land zoning plans would focus on a direct solution.
- Guide the urban development programs to stimulate reforestation and protect the recharge areas to conserve the aquifers that supply water to the cities.

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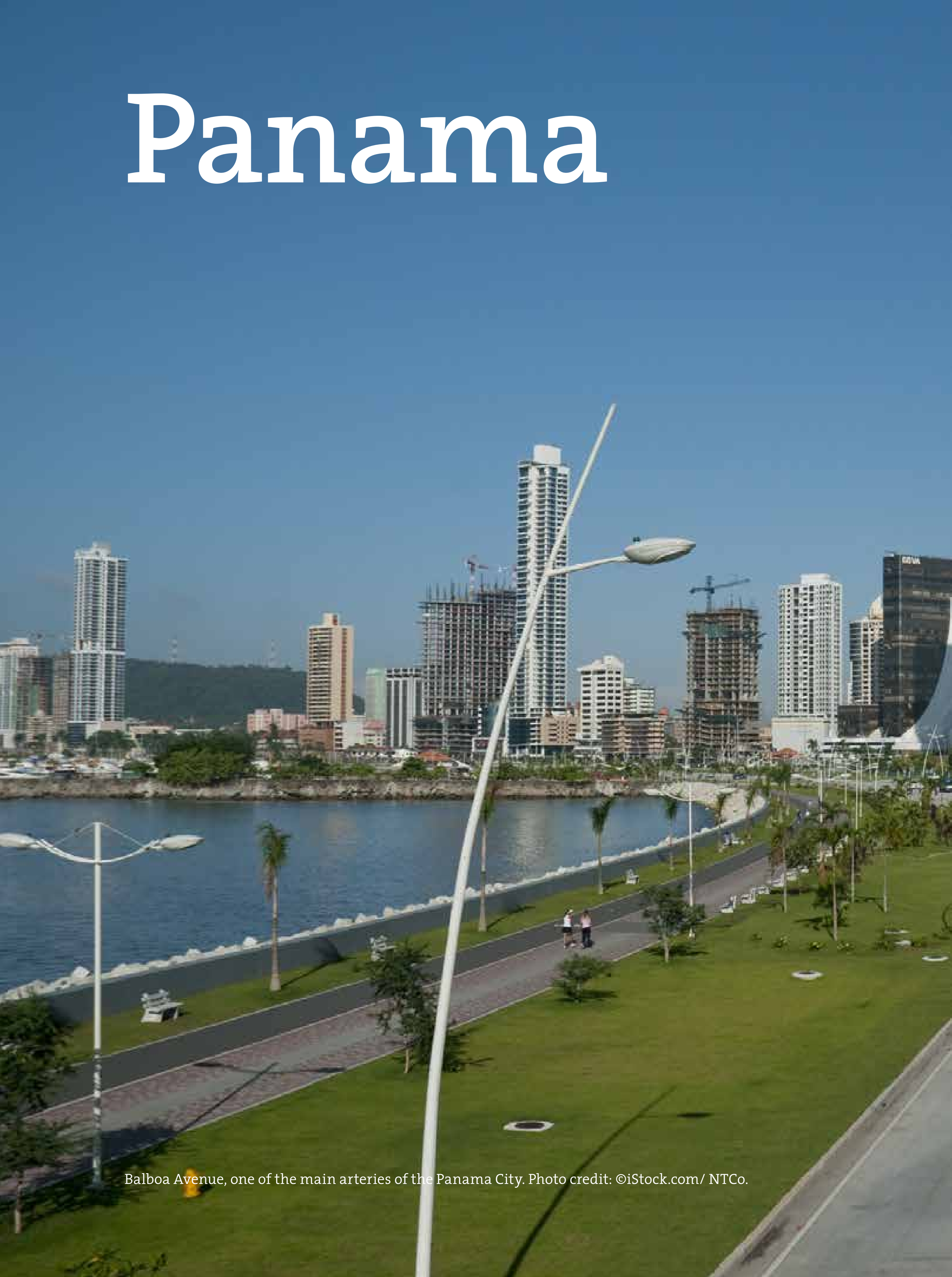
Panama



Balboa Avenue, one of the main arteries of the Panama City. Photo credit: ©iStock.com/ NTCo.

"Panama is a country with abundant water resources with over 90% of the population having access to potable water in general. However, drinking water sources for urban areas focused almost exclusively on surface water sources, the existence of regions (particularly indigenous areas) where less than half the population has access to potable water, appropriate resources to manage the increasingly larger water related infrastructures, and climate change are the main challenges to be addressed in the near future"

Urban Waters. Panama

José R. Fábrega D., Miroslava Morán M., Elsa L. Flores H., Icela I. Márquez de Rojas, Argentina Ying, Casilda Saavedra, Berta Olmedo, and Pilar López

Abstract

Panama is a country with abundant water resources and an average annual rainfall of 3000 mm. However, 66% of the population live in populated areas with more than 1,500 inhabitants, considered urban zones, hence the importance of good urban water governance and management in Panama. Most of the urban population uses surface water (rivers and lakes) as a source of water to meet its needs, with groundwater sources being rarely used to supply urban communities.

In Panama, drinking water is administered by two entities: on the one hand, the Institute of Aqueducts and Sewerage (IDAAN), which serves populations with over 1,500 inhabitants, and on the other, the Ministry of Health (MINSA), which, through the Rural Water Management Boards (JAAR), serves towns with under 1500 inhabitants, especially in rural areas. There are isolated cases in peri-urban areas where water is managed by JAAR. In general, according to the last census (2010), over 90% of the population have access to potable water. However, this figure does not represent the reality of certain marginalized areas, as in the case of indigenous regions, where figures can be as low as 28%.

Regarding wastewater treatment, and according to World Bank indicators, in 2012, 80% of the population had access to improved sanitation facilities. In urban areas, under the administration of IDAAN, 57% of the population have sewerage which translates in total terms of the population into 45%. Regarding wastewater treatment, thanks to a series of rules approved in the late last century and at the beginning of this one, there are now approximately 100 wastewater treatment plants (WWTP) with secondary treatment. Likewise, the "Panama City and Bay

Sanitation Project" is currently underway. Launched in 2006, it is designed to restore the health and environmental conditions of the metropolitan area and to remove the pollution caused by untreated wastewater in urban rivers and the coastal areas of Panama Bay. Thanks to this project, the only WWTP in the country providing tertiary treatment for the waters it receives is already operating, with a capacity of up to 2.2 m^3/s. By 2035, this plant is expected to meet the demands of approximately 1.2 million people and achieve a volume of treated water of approximately 6.4m^3/second.

With respect to vector-borne diseases that develop in water, it is important to note that **dengue** in urban areas is one of the main public health problems in Panama. Isolated studies on raw water used by water treatment plants in certain urban centers have found *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts in the dry season. In the rainy season, results were negative, except for a study that found *Cryptosporidium* spp. in treated water. On the other hand, in the Chilibre treatment plant, which supplies water to most of the urban population in the capital city, the presence of these parasites was not detected. However, studies undertaken in the city of La Chorrera seem to indicate a relatively high prevalence of *Cryptosporidium* spp. and *Giardia* spp. in children.

Lastly, the link between urban water and climate change is becoming increasingly important, mainly due to the rapid growth experienced by the Panama City. Various studies and analyses point to an increase in the frequency of extreme events and the vulnerability of urban areas, reflected not only in the increase in the number of floods, but also in the number of people affected by these events. In order to address climate change in Panama, with regard to both adaptation and mitigation, institutional and legal developments include the adoption of the National Policy on Climate Change, within the National Environmental Authority (ANAM) and the creation of the National Committee on Climate Change, which has representatives from 27 public sector institutions including the academic sector. There are various alternatives designed to increase urban resilience to climate change. One of the most important alternatives being promoted worldwide are green buildings. In this regard, Panama ranks second in Central America and the Caribbean in terms of LEED certified buildings. In addition to structural solutions, urban resilience to climate change depends on sensitizing the public and awareness of the role each plays in both the problem and the solution.

1. Water Sources in Urban Areas and the Impacts Caused by Urbanization

Panama is a country with abundant water resources, with a maximum annual average rainfall of around 3000 mm, a minimum of 1000 mm and up to 7000 mm in some areas of the country. On its surface, the rains form a network of short rivers that rise in the continental divide and flow into one of the two coasts (150 rivers in the Atlantic and 350 rivers in the Pacific). Panama also has 67 lake systems, including reservoirs, ponds and wetlands. Panamanian groundwater has not been studied in detail, although it is known that there are three main types of aquifers: predominantly intergranular aquifers, predominantly fissured aquifers and areas with local intergranular or fissured aquifers with limited productivity.

With regard to the population, the latest census indicates that 66% of the population in the country (2,249,394 people) live in 224 urban locations (towns with over 1500 inhabitants), while 34% (1,155,884 people) live in 11,391 places with fewer than 15 hundreds inhabitants, defined as rural (Table 1).

Table 1. Population distribution in Panama

Type of Population	Population	%	Populated places	%
Urban Population	2,249,394	66	224	2
Rural Population	1,155,884	34	11,391	98
Total	3,405,813	100	11,615	100

Source: Compiled by the author based on the 2010 Census of the Comptroller General of Panama.

1.1 Regions in the Country with a Predominance of Use of Surface / Ground / Combined Waters

As seen in Table 2, and only using treatment plants administered by IDAAN, urban zones in Panama (99.9%) mainly use surface water for human consumption. Groundwater is used slightly more often in rural areas.

1.2 Water Sources Relative to Urban Population Distribution

Most of Panama´s economic activity (that includes 75% of the population) is concentrated in 5.3% of the territory in a few cities on the Pacific slope. In contrast and according to the Environmental Atlas of Panama (National Environmental Authority -ANAM-, 2010), a quarter of the population, occupying slightly less than 95% of the country, lives in scattered villages, poverty and without access to the most basic services.

The three largest municipalities with the greatest economic activity in the country (Panama, San Miguelito and Colón), accounting for over 62% of the urban population (2010 census), are mainly supplied by water from the Panama Canal Watershed administered by the Panama Canal Authority, with high control and management standards. The basin, covering an area of 2,982 Km^2, constitutes a huge water potential (Panama Canal Authority -ACP-, 2006).

1.3 Overexploitation of Surface and Groundwater Sources

The Panama National Plan for Water Resources (PNGIRH) (ANAM, 2011) reports the results of the water balance achieved in ten priority watersheds located on the Pacific coast in 2008. These basins were prioritized on the basis of population density, water demand, conflict scenarios, vulnerability to climate change and so on. It was reported that only the Antón River has a water shortage, while the other basins experience a situation ranging from equilibrium to abundance. Seasonal analysis showed that the Tonosí and La Villa basins have water availability problems during the dry season.

The same report mentions that although groundwater concessions seem insignificant, the uses and extractions observed in the basins, especially in the area called Arco Seco (which includes the provinces of Herrera, Los Santos, Coclé and part of Veraguas), tend to be intensive.

1.4 Impacts of Urbanization on Water Quantity and Quality in the Various Sources. Specific and Diffuse Sources of Pollution Inside and Outside the City

The National Environmental Authority (ANAM), the organization responsible for the environment in Panama, estimates that over 80% of wastewater discharges come from the domestic and commercial sector, with the remaining 20% correspond to the industrial sector (ACP, 2006). It should be pointed out that for the industrial sector, although the discharge volume is lower, the pollutant load is much higher than the domestic contribution, which is critical, since ANAM reports that few companies submit requests for permission to discharge water into either surface water bodies or sewerage (ANAM 2011).

ANAM (2011) has found a link between the water quality degradation of the country’s rivers and population concentration: out of a total of 17 rivers monitored in the province of Panama, ten range from “polluted to highly polluted.” These include

Table 2. Water source of treatment plants administered by IDAAN

Type of supply plant	Number	Nominal Capacity (Mm^3/day)	Actual production (Mm^3/day)	Population benefiting(a)
Reservoir	5	1.022	0.885	1,294,566
River or stream	47	0.541	0.408	943,713
Well and river	1	0.003	0.001	2,652
Total plants operating	53	1.57	1.29	2,240,931

(a) Up to 2014. Source: http://www.idaan.gob.pa/detalle.php?cid=2&sid=31&id=38

Mataznillo, Curundú and Río Abajo, located in the capital (Figure 1). PNGIRH attributes water pollution to several factors: i) Wastewater discharge with no or insufficient treatment (domestic and industrial) of solid waste discharges, ii) use of chemical products: agrochemicals and detergents, iii) Oil and other polluting material spills, and iv) Deforestation and extreme rainfall that contribute sediments.

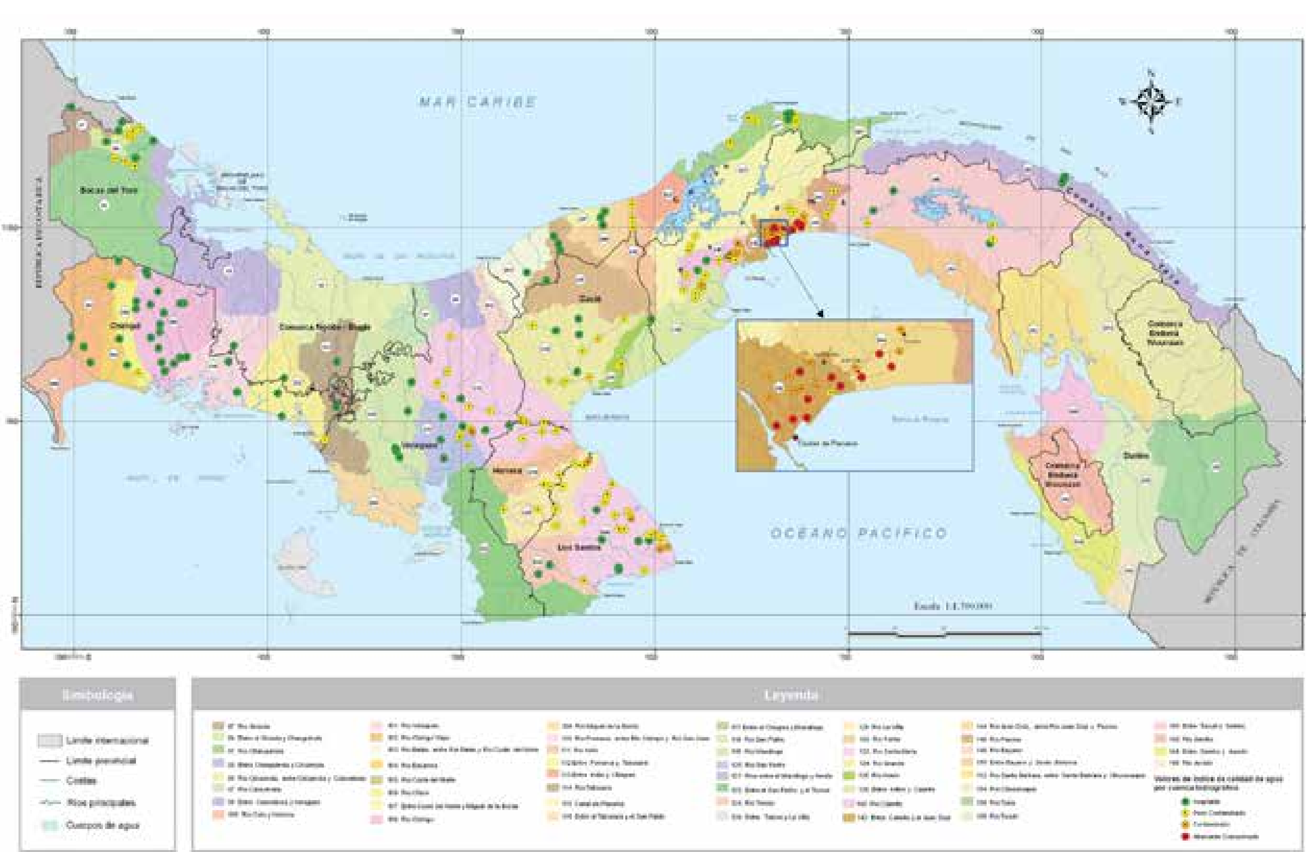
At least two important cases of water source pollution have been reported in the country. One was caused by heavy rains in December 2010[1] that led to a high concentration of sediments in water, causing the collapse of purification plants that supply Panama City and a water crisis. A second case is currently taking place due to the discharge of the herbicide Atrazine above the water purification plant intakes, which also supply several rural aqueducts and other uses, affecting tens of thousands of people in the provinces of Los Santos and Herrera.

1.5 How Water Quality Problems Have Been Addressed in Urban Areas

It was known (ANAM, 2011) that the Curundú, Matasnillo, Río Abajo, Matías Hernández, Juan Díaz, Tapia, Tocumen and Cabra rivers (within Panama City or in its surroundings) received domestic wastewater and liquid discharge from 674 compa-

1. The hydrological yearbook of the Panama Canal Authority reported that according to records in the hydrometric stations, the flow for December 2010 in all the major rivers in the basin exceeded the historical average for that month by 200% to 400%.
Study available at: https://micanaldepanama.com/wp-content/uploads/2012/06/Anuario/2010.pdf

Figure 1. Water Quality Index by Watershed



Atlas ambiental de la República de Panamá (ANAM, 2010) nies (including slaughterhouses, poultry, dairy and sausage processing plants, metallurgical companies, paint and car battery factories, construction material, non-metallic mineral extraction, petroleum derivative processing companies, sawmills, tanneries, workshops and sheet metal plants). These rivers flowed into Panama Bay, opposite the city, causing unpleasant odors and making it unsuitable for recreational purposes.

In order to restore the health and environmental conditions of the metropolitan area and eliminate the pollution due to untreated wastewater in urban rivers and the coastal areas of Panama Bay, the Ministry of Health has implemented the Panama City and Bay Sanitation Project. In addition to this, in recent years, residential projects have been obliged to include private wastewater treatment systems, although they often fail to comply with regulations (ANAM, 2011).

Since 2002, the National Environmental Authority (ANAM) has monitored 95 rivers nationwide through 519 points and uses a water quality index (ICA) to classify water quality (Figure 1). Likewise, ANAM has developed a series of programs and projects for watershed management, designed to halt and reverse the environmental degradation to which they are subjected. However, this institution also has greater responsibility for enforcing water discharge standards, although it has admitted having achieved limited success (ANAM, 2011).

1.6 Specific Problems Related to Water Sources for Peri-Urban Areas and Informal Settlements

The It also notes the deterioration of health conditions and public services. Shows the growth rate of Panama City in the past 30 years, where peri-urban areas have grown considerably. The towns of Chilibre and Arraiján are peri-urban sites studied with respect to their links with water resources located within the Panama Canal Watershed.

The study on "Socio-demographic and economic characterization of the basin" (TETRATECH, 2010) links peri-urban settlements to environmental changes and their effects on water quantity and quality, such as plant cover loss, the reduction of water infiltration into the soil, pollution from solid, liquid and gaseous, sometimes toxic waste, and the modification of waterways and the landscape in general. It also notes the deterioration of health conditions and public services.

2. Drinking Water Service in Urban Zones

2.1 Drinking Water Management in Panama

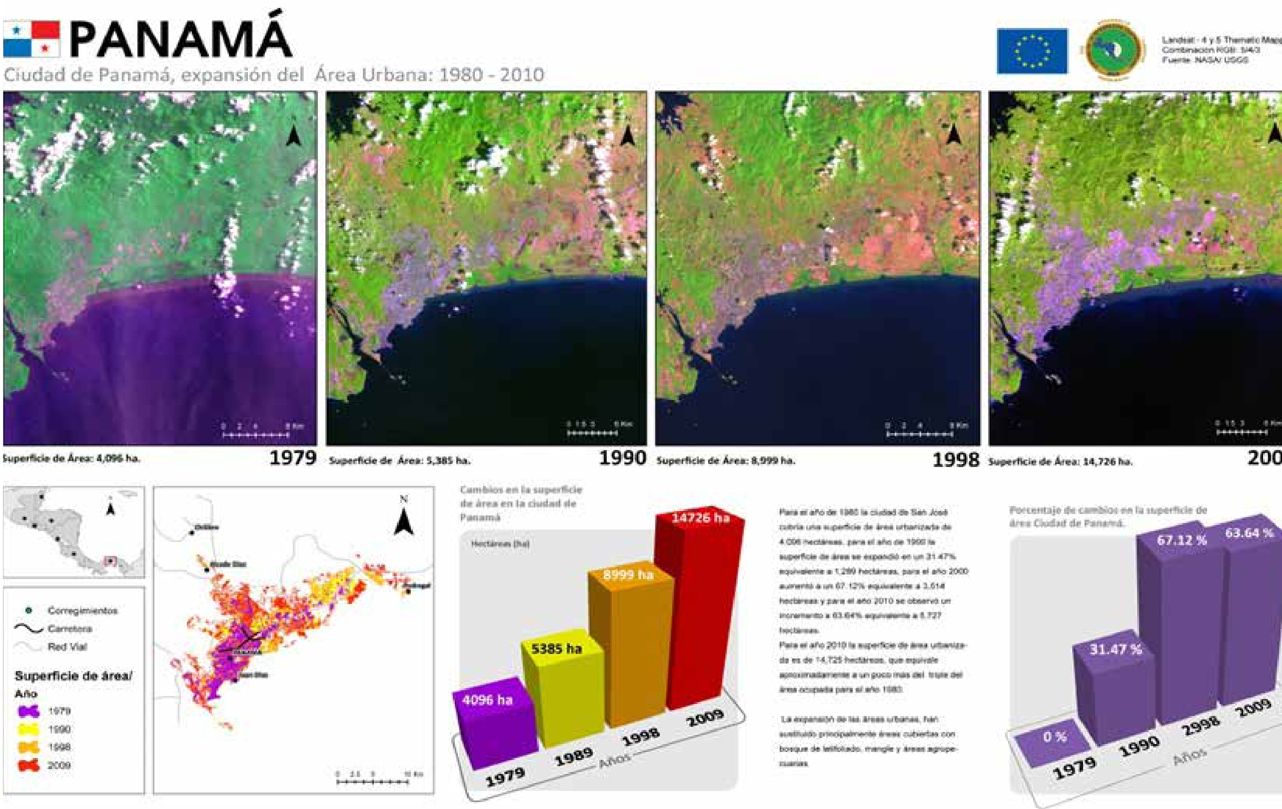
In Panama, drinking water is administered by two entities: on the one hand, the Institute of Aqueducts and Sewers (IDAAN), which serves populations with over 1,500 inhabitants, and on the other, the Ministry of Health (MOH), which serves towns with under 1,500 inhabitants, especially in rural areas, through Rural Water Management Boards (JAAR). However, despite this distinction, there are urban areas where administration is undertaken by a JAAR, as in the case of the community of Génesis, in Las Mañanitas de Tocumen, east of Panama City.

Given this separation of powers by population, IDAAN currently manages 124 water systems nationally (Cano, 2013), and serves a population of 2,644,464 inhabitants, with 93% coverage (Figure 3). In terms of population, this coverage represents an increase of approximately 70% compared with 1987, when IDAAN managed 135 water systems throughout the country to meet the demands of 1.5 million inhabitants, through 25 water treatment plants, 2 slow filters, 317 wells, six infiltration galleries and five waterwheels (Fábrega, 1992).

The IDAAN set rates for metered consumption, which differ from one urban area to another. In other cases, the IDAAN has contracted water supply through tanker trucks, especially for populations located on the outskirts of the capital of Panama such as Las Garzas de Pacora, Altos de la Torre, La Paz, Jalisco, Alto Lindo and Guarumalito. In this respect, although tanker tanks distribute nearly 190,000 gallons a day, there are almost daily protests due to the lack of supply.

This is compounded by the fact that, according to the IDAAN's Statistical Bulletin No. 24 (2008-2010), water bills are sent to users on the basis of: meter reading (34.1%), averaged calculations (20.6%) or without using a meter (44%). Similarly, 41.4% of water is unaccountedfor, which is an indicator of serious physical and commercial losses accentuating the institution's financial crisis.

Figure 2. Change of urban area in Panama City



Source: CATHALAC (2011) as part of the PREVDA project

Figure 3. Location of the country's 124 aqueduct systems administered by IDAAN

Source: Cano, Ivan. Oral presentation: "Descripción de los Sistemas de Acueducto Panamá Metro y Panamá Oeste, Instituto de Acueductos y Alcantarillados Nacionales (IDAAN). Dirección de Operaciones. 2011

At the same time, MINSA has registered 2,673 JAARs throughout the entire country, with legal status. In JAARs, regularity means charging a fixed fee, which varies regardless of per capita consumption. Rarely have micrometers been installed for the purpose of having a rate for metered consumption (MINSA, 2014).

Table 3. Percentage distribution of drinking water sources among the population: 2010 Census

Sources	Porcentaje
IDAAN Public Aqueduct	70.8
Community Public Aqueduct	19.8
Scoophole	2.1
River, stream or lake	2.0
Health Pit	1.6
Private Aqueduct	1.1
Unprotected covered well	1.0
Tanker Truck	0.7
Rainwater	0.5
Bottled water	0.3
Other	0.1
TOTAL	100.0

Source: National Institute of Statistics and Census. Comptroller General's Office

2.2 Drinking Water Coverage in Urban Zones

Although the Panamanian Constitution does not recognize the human right to water, it does have a policy and plan for drinking water supply in urban areas, which has been partially implemented (MINSA, 2013). This plan is expected to achieve 97% coverage in urban areas by 2014.

At present, according to data collected in the Population and Housing Census 2010 (Table 3), 91.7% of the population have access to safe drinking water through household connections such as IDAAN public aqueducts, or community or private aqueducts. At the same time, 6.7% have access without household connections and 1.6% rely on other types of supply such as rain or tanker trucks. Likewise, drinking water access coverage varies according to the type of source (Table 4). These values assume that approximately 3.1 million people in the country have a reliable supply of healthy water. However, figures show that by geographic area, the indigenous regions of Embera and Ngobe Bugle have the worst conditions for water use and consumption (Tables 4 and 5). Factors such as scattered villages, limited road access and cultural influences contribute to these results.

Table 5. Population with or without access to drinking water, by province and indigenous region: 1990, 2000 and 2010 Censuses (as a percentage)

Provinces and indigenous regions	Population with or without access to drinking water by Census					
	1990*		2000		2010	
	Yes	No	Yes	No	Yes	No
TOTAL	81.2	18.8	90.2	9.8	92.9	7.1
Bocas del Toro	60.2	39.8	74.1	25.9	74.6	25.4
Coclé	75.9	24.1	91.5	8.5	95.1	4.9
Colón	83.3	16.7	92.0	8.0	93.5	6.5
Chiriquí	65.3	34.7	82.3	17.7	87.9	12.1
Darién	31.9	68.1	58.4	41.6	72.4	27.6
Herrera	78.4	21.6	93.6	6.4	96.6	3.4
Los Santos	85.7	14.3	96.1	3.9	98.6	1.4
Panama	93.7	6.3	97.1	2.9	98.6	1.4
Veraguas	57.4	42.6	83.3	16.7	88.8	11.2
Kuna Yala			67.7	32.3	77.8	22.2
Emberá			10.7	89.3	27.6	72.4
Ngobe Buglé			29.9	70.1	38.6	61.4

*Since indigenous territories had not been created, indigenous areas were included in the provinces surrounding these regions.

Table 4. Dwellings by source of water supply, province and indigenous region: 2000 and 2010 Censuses

Provinces and indigenous regions	Total	IDAAN Public Aqueduct	Community's Public Aqueduct	Private Aqueduct	Health Pit	Unprotected covered well	Rain water	Scoopho le	River, stream or lake	Tanker Truck	Bottled water	Other
						2000						
TOTAL	681,928	459,803	143,390	9,132	9,067	9,698	1,929	23,001	19,307	2,748	3,853	-
Bocas del Toro	16,999	2,394	9,756	454	781	112	732	968	1,562	-	240	-
Coclé	44,496	18,189	21,171	1,333	496	269	6	1,810	978	-	244	-
Colón	49,716	36,966	8,188	608	612	97	111	1,112	1,697	-	325	-
Chiriquí	87,509	48,161	21,619	2,238	3,017	7,730	80	2,739	1,038	-	887	-
Darién	9,088	1,577	3,660	70	276	178	421	529	2,311	-	66	-
Herrera	27,202	16,034	9,052	382	178	71	3	972	322	-	188	-
Los Santos	25,052	14,778	8,693	602	242	116	1	241	193	-	186	-
Panamá	350,472	304,555	30,212	2,750	2,266	713	286	3,272	2,165	2748	1,505	-
Veraguas	49,103	17,149	23,195	545	867	267	8	4,887	2,003	-	182	-
Kuna Yala	4,281	-	2,894	4	65	5	5	73	1,229	-	6	-
Emberá	1,498	-	157	3	83	1	135	4	1,113	-	2	-
Ngobe Buglé	16,512	-	4,793	143	184	139	141	6,394	4,696	-	22	-
						2010						
TOTAL	896,068	634,780	177,840	9,850	14,005	8,816	4,711	18,497	17,650	6,588	2,207	1,124
Bocas del Toro	24,628	11,500	5,769	463	891	577	2,708	474	1,606	41	563	46
Coclé	57,193	24,608	27,946	1,514	567	430	13	1,123	693	113	46	140
Colón	63,502	48,747	9,745	403	694	894	155	647	1,733	160	154	170
Chiriquí	113,012	63,704	32,935	2,040	7,559	3,623	153	1,449	915	166	334	134
Darién	11,906	2,312	5,688	237	234	172	635	262	1,983	219	132	32
Herrera	32,591	20,414	10,505	456	113	111	17	516	357	44	43	15
Los Santos	29,363	18,021	9,884	934	166	68	0	99	75	9	27	80
Panamá	470,466	420,837	33,602	2,373	2,492	791	219	1,260	1,814	5,822	856	400
Veraguas	60,209	24,637	27,668	1,055	484	687	38	3,503	2,055	4	10	68
Kuna Yala	4,999	-	3,840	28	2	86	4	70	948	-	12	9
Emberá	1,940	-	519	1	27	1	328	-	1,048	1	12	3
Ngobe Buglé	26,259	-	9,749	346	776	1,376	441	9,094	4,423	9	18	27

Source: National Institute of Statistics and Census.

In the Panamá Metro region, the main problem is demographic pressure, which creates a constant demand for services from IDAAN, whose system and equipment continuously break down, affecting storage levels, water pressure or distribution to the high sectors located far away from the metropolitan aqueduct network (Fabrega, 1992). The improvised, uncontrolled settlement of certain communities in districts located on the peripheries of urban areas has triggered a series of socio-economic problems, including the lack of drinking water. This is compounded by the lack of indicators for measuring equitable service coverage according to the location of the populations and the various economic groups (MINSA, 2013).

On average, dwellings with household connections have water supplies 6.4 days per week and 19.5 hours a day during the dry season (6.6 and 20.5 in the rainy season, respectively) (Ministry of Economy and Finance, 2012). As for drinking water treatment, Panama's main treatment plant (Figure 4), located in Chilibre within the Panama Canal Watershed, has its outlet at Lake Alhajuela, one of the lakes that enables the Panama Canal to function. This plant has an installed capacity of 0.95 million m^3/day, used to supply much of Panama City.

3. Water Treatment in Cities

Management and final disposal of wastewater, whether domestic or industrial, and the regulation of sewerage service provision pose a major challenge to be achieved in the XXI century in the world in general and Panama in particular. According to World Bank indicators (http://data.worldbank.org/indicator/SH.STA.ACSN.UR) for 2012, the urban population in Panama had 80% access to improved sanitation facilities.[2]

2. In addition to health services (sewerage systems, septic tanks or pit latrines), these include solutions such as improved ventilated pit latrine, pit latrine with slab and composting toilet.

Figure 4. Chilibre water treatment plant with a capacity of 250 MGD, the largest in Panama

Source: Cano, Ivan. Oral presentation: "Descripción de los Sistemas de Acueducto Panamá Metro y Panamá Oeste, Instituto de Acueductos y Alcantarillados Nacionales (IDAAN). Dirección de Operaciones. 2011

3.1 Legal Framework of Domestic and Industrial Wastewater

In 2000, Panama passed various guidelines and technical regulations on various aspects of wastewater such as: i) reuse of treated wastewater (DGNTI-COPANIT, 24-99),[3] ii) discharge of liquid effluents directly into surface and groundwater (DGNTI-COPANIT, 35- 2000), iii) discharge of liquid effluents directly into wastewater collection systems (DGNTI- COPANIT, 39-2000), and iv) use and final disposal of sludge (DGNTI-COPANIT, 47-2000), in order to ensure their implementation and achieved the goal of restoring natural water bodies that had been heavily polluted, not only physically, chemically and microbiologically, but also as a result of the disposal of wastewater into surface and underground streams without proper treatment.

3.2 Drainage and Sewerage Systems

Panama is currently experiencing one of the greatest periods of economic growth in its history. For example, according to data from the CIA Worldfactbook (https://www.cia.gov/library/poublications/the-world-factbook/geos/pm.html), averaging the growth of Panama's GDP from 2011 to 2013 shows that it has grown by 9.7% annually. However, this growth is not fully reflected in its sanitation figures. For example, the IDAAN Statistical Bulletin No. 26 (2010-2012) shows that the percentage of the population with sewerage service, which is the responsibility of IDAAN (populations of over 1,500) is 57%. In terms of Panama's total population, this percentage translates into approximately 45%. This same document indicates that this coverage is achieved through 21 sewerage systems representing 312,696 residential connections, in addition to housing units in communities with over 1,500 inhabitants.

According to the Central American and Dominican Republic Forum on Drinking Water and Sewerage (FOCARD-APS) 2013, the most commonly used technologies for the management of excreta are sewer systems (collection with and without treatment including oxidation ponds, septic tanks, Imhoff tanks and treatment plants). This document also states that the type of technology is associated with batch size, as regulated by the Ministry of Housing and Land Management (MIVIOT). However, this rule is not fully observed in areas where there are informal settlements, especially in peripheral areas of cities, where the system used is latrines (FOCARD-APS, 2013).

The first sewerage systems in Panama, dating from the early 20th century, were combined systems. It is not until the middle of last century that sewerage networks emerged in the cities of Panama and Colón. However, these systems ended in direct discharges into water bodies. Nowadays, as a result of the Panama City and Bay Sanitation Project, described elsewhere in this chapter, recent years have seen the construction of approximately 138.7 kilometers of sewerage networks representing 13,978 household connections at a cost of $29.6 million USD (FOCARD-APS, 2013).

In the case of wastewater discharges on the banks of the Panama Canal and the adjacent sea (downstream of the Miraflores Locks on the Pacific and of the Gatún Locks on the Atlantic), Rojas-Márquez (2006) counted over 80 discharge points, which are characterized by directly contaminating the area into which they are discharged, and producing an unpleasant odor, leading to environmental deterioration. Given this scenario, urgent action is required to improve the quality of wastewater discharged into this important area in the country and ensure that the plants' collection and pipeline systems are in good working order. This would prevent the aquatic, mainland and marine area surrounding the Panama Canal from continuing to be polluted and destroyed (Rojas- Márquez, 2006). In response to this situation, the Panama Canal Authority (ACP) is seeking to implement solutions to treat the wastewater flowing into the Canal, which would solve the problem of large towns in the area such as: Albrook, Clayton, Cárdenas, Balboa, Amador, among other towns.

3.3 Wastewater Treatment Systems

The technologies traditionally used for waste-water treatment in Panama, registered by IDAAN, are septic tanks, Imhoff tanks and oxidation ponds with final discharge into rivers and oceans. However, in

3. Directorate General of Standards and Industrial Technology of the Ministry of Commerce and Industry of Panama (ICIM). COPANIT: Panamanian MICI Commission for Industrial and Technical Standards.

recent years, largely as a result of the adoption of the standards mentioned in section 3.1, nearly 100 secondary treatment plants have been introduced (WWTP) mainly in districts with a high urban concentration in the provinces of Panama and West Panama (La Chorrera, Arraiján and Panama), representing about 100,000 beneficiaries. However, according to information from IDAAN, only 40 of those 100 treatment plants comply with the requirements to be transferred by their builders to IDAAN (FOCARD-APS, 2013).

3.4 Panama City and Bay Sanitation Project

The Panama City and Bay Sanitation Project is the country's largest investment in environmental health. This public infrastructure work was begun in 2006, at a cost of $655 million USD. The project seeks to restore the health and environmental conditions of the metropolitan area and eliminate pollution due to untreated wastewater in urban rivers and the coastal areas of Panama Bay. This project, implemented by the Ministry of Health, will be carried out in three stages and comprises four components: i) Construction of Sewerage Networks, ii) Construction of Collecting Lines, iii) Construction of the Interceptor system, and iv) Construction and Operation of a Wastewater Treatment Plant. At present, the first phase of the project is well advanced. The year 2013 saw the launch of the first phase of the Wastewater Treatment Plant, which currently receives 1.8 m^3/s, (Figure 5), previously discharged into the Matías Hernández and Matasnillo rivers (http://www.saneamientodepanama.com/planta-de-tratamiento-de-aguas-residuales). This plant is the only WWTP in the country to perform tertiary treatment on the water it receives. With the first phase completed, this plant is expected to handle up to 2.2 m^3/s. By 2035, it is expected to meet the demand of about 1.2 million people. Once the three phases have been completed, the volume of treated water will total approximately 6.4m^3/sec of water. (FOCARD-APS, 2013).

This project is expected to greatly contribute to compliance with current discharge regulations. Moreover, it will feature a cogeneration process, which will allow the project to be registered as a clean development mechanism and enter the carbon sales market .

4. Water and Health in Cities

According to the "State of Health of Panama" report (MINSA, 2013), expansion of potable water and sanitation in Panama has meant that most of

Figure 5. Wastewater Treatment Plant in Panama Bay Sanitation Project

http://www.saneamientodepanama.com/planta-de-tratamiento-de-aguas-residuales the urban population now has access to improved drinking water sources. However, there are frequent protests over deficiencies in the distribution and quality of the water received as well as complaints relating to the collapse of urban sewerage exposing wastewater. Official figures state that access to drinking water increased by approximately 11.5% from 1992 to 2010, achieving 92.9% coverage. This same report states that in urban zones, sanitation coverage is 98.9%, while acknowledging that weak points as regards sanitation include coverage, quality of service and urban wastewater treatment, the latter being regarded as the main cause of serious pollution problems in many parts of the country.

The infant mortality rate in children under five, an important indicator of the interaction of multiple factors, including the increase in basic service coverage, especially as regards drinking water and sanitation, decreased from 24.5 deaths per thousand live births in 1990 to 16.6 in 2011. However, urban areas have not seen an improvement in this indicator, which may be related to the migration of people to the city in search of work and the consequent formation of pockets of poverty around urban areas, where safe drinking water and sanitation is almost nil.

4.1 Water-Related Diseases

With respect to diseases transmitted by vectors that develop in water, it is important to note that **dengue** in urban areas is a major public health problem in Panama, because of the complexity of factors that simultaneously interact, such as poverty, population growth, uncontrolled or unplanned urbanization, migration, environmental degradation, tire selling without sustained recycling, lack of access to safe drinking water, inadequate disposal of solid waste that collects water, an increase in the amount of scrap and plastic (non- biodegradable), climate change, poor environmental sanitation education, lack of an ecosystem approach (Ecohealth) for addressing the control of vector-borne diseases, a tropical climate with over nine months of rain and the lack of coverage and useful breeder control policies that would be useful for institutions, Panama has reported *Aedes aegypti* and *Aedes albopictus*, both vectors capable of transmitting the **dengue** and **chikungunya** viruses in urban and rural areas. Currently, 80% of the breeders reported are useful, usually containers for storing drinking water, while only 20% are useless containers such as waste or scrap. These data indicate that the main risk factor associated with the development of the epidemic in Panama is related to water supply problems (http://www.minsa.gob.pa/informacion-salud/boletines-semanales-2012).

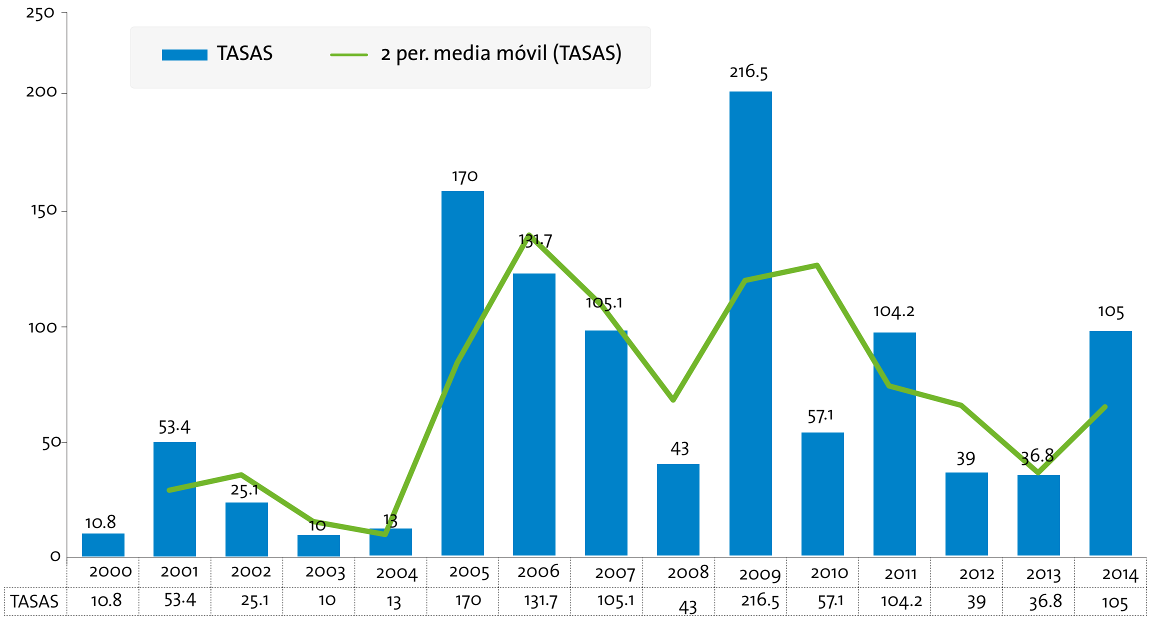
The annual incidence of **dengue** fluctuated between 2005 and 2013 (Figure 6), with the lowest rate per 100,000 inhabitants being reported in 2013 (36.8) with six severe cases of **dengue** and no deaths. During this period, the highest rate was reported in 2009 (216.5), with 46 severe cases of **dengue** and seven deaths. It is striking that in 2011, with 51% of the number of cases reported in 2009 and a rate of 104.2 cases per 100,000 inhabitants, there were 38 severe cases of **dengue** and 17 deaths, making it the year with the highest number of deaths since 1993, when the first case of indigenous **dengue** was reported. That year (2014), the number of cases exceeded the figure reached in 2011, indicating the lack of sustainability in **dengue** control in Panama. By June 2014, the surveillance system had detected three imported cases of **chikungunya**, from Dominican Republic and Haiti (http://articulos.sld.cu/dengue/tag/panama/).

With regard to **malaria**, from 2005 to 2013, morbidity rates experienced a sustained decline from 113.6 cases per 100,000 inhabitants in 2005 to 9.5 in 2011 with a slight increase in 2012 (23.4). In recent years, the mortality rate has remained low with a stable trend. It is important to note that **malaria** cases do not occur in urban areas, except for certain sporadic imported cases. Endemic areas include Darién, the Guna Yala region, Bocas del Toro and the Ngäbe Bugle region. Lastly, the last cholera outbreak in Panama was reported from 1991 to 1993, since when no further cases have been reported.

4.2 Algae, Cyanobacteria and Toxins in Water Treatment Plants

In the urban area of Panama City, there are two water treatment plants: in Chilibre and Miraflores; the former run by the Institute of Aqueducts and Sewers (IDAAN) and the second by the Panama Canal Authority (ACP).

Figure 6. Dengue incidence rates in Panama, 2000-2014



Data from the Panamanian Ministry of Health, 2014

According to Guerra and Marciaga (2012), since 2012, the IDAAN Water Quality Laboratory has performed tests to detect the presence of algae, cyanobacteria and toxins in supply sources and treated wastewater in the Chilibre, Rufina Alfaro Los Santos, Roberto Reina Chitre and Santiago de Veraguas plants. Guerra and Marciaga (2012) they also note that the Chilibre plant has algae that produce a distinctive taste and odor, such as *Staurastrum* and cyanobacteria such as *Gomphosphaeria, Anabaena, Oscillatoria, Cylindrospermum*, the latter being one of the most toxic cyanobacteria.

The ACP has various water quality monitoring programs, in both the basin and the water treatment plants in Miraflores, Monte Esperanza and Mendoza. The water quality index (WQI) in the Gatún and Alajuela reservoirs ranges from good to excellent. In the raw water intake in Paraíso and Gamboa, there are green algae and diatoms that are sometimes displaced by cyanobacteria, as happened in 2011, when the nontoxic cyanobacteria Cyanogranis ferruginea was identified in the Gamboa water intake. The ACP maintains a surveillance system for detecting cyanobacteria outcrop with a sensor attached to the HIDROLAB DS5 probe, with a neighborhood watch system, and monitors microcystins in water intakes and certain points of the purification process, in addition to using techniques for the detection of potentially toxic cyanobacteria genes.

4.3 Biological Water Quality in Water Treatment Plants

4.3.1 Detection of *Giardia* spp. and *Cryptosporidium* spp. in Water Treatment Plants

Annual ACP reports since 2005 state that monitoring of the presence of *Giardia* spp. and *Cryptosporidium* spp. in the Miraflores (Panama) and Monte Esperanza (Colón) treatment plants continues as part of water quality monitoring. At the same time, the functions of the Public Services Authority (ASEP) and prior to that, the Public Services Regulator in 2003 as an external entity, include monitoring water quality from the biological point of view and ensuring that treatment plants in Panama City monitor the presence of cyanobacteria, toxins and protozoa.

Studies on treatment plants in communities around the capital by Rivera et al. (1991) reported *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts in raw water treatment plants in La Chorrera, Chitre and Chepo during the dry season although results for the rainy season in the three treatment plants were negative. Similarly, the study by de la Cruz et al. (1997) indicates the presence of *Giardia* spp. and *Cryptosporidium* spp. oocysts in raw and treated water from the treatment plant in La Chorrera in the dry season, and only *Cryptosporidium* spp. in treated water in the rainy season. The Colón purification plant reported the presence of *Cryptosporidium* spp. in raw water during the rainy season. However, in the Chilibre treatment plant, which supplies water to most of the urban population in the capital city, the presence of these parasites was not detected.

4.3.2 Studies on the Microbiological Quality of Water in Treatment Plants

Herrera et al. (2005) studied the microbiological quality of drinking water from the distribution networks of the metropolitan area and La Chorrera and failed to detect the presence of fecal coliform. It was also found that the concentration of heterotrophic bacteria was within the quality parameters. In a similar study on the purification plants of Monte Esperanza, Sabanitas and Rio Gatún, Abre et al. (2008) reported that water quality in these water treatment plants met COPANIT-DGNTI 1999 standards. In a study undertaken at the Mendoza water treatment plant in La Chorrera and its distribution networks, Barranco and Gonzalez (2010) proved the presence of total coliforms, fecal coliforms and heterotrophic of above acceptable values during the first three months of operation, with variability according to the month and point of sampling.

4.4 Studies on the Water Quality of Natural and Recreational Urban Sources

Pimentel et al. (2007) conducted a study on the microbiological water quality of Lago de las Cumbres with regard to the presence of fecal and total coliforms, finding a fluctuation in the density of these entities with a greater presence in September, when the highest rainfall was recorded. In a similar study on the Juan Díaz river, Acevedo and Sánchez (2009) determined that the highest level of pollution in the river is at the bottom near the mouth, the greatest incidence being in October. Chifundo and Hughes (2011) reported that in Gatún Lake, the presence of total and fecal coliforms is higher in places associated with increased anthropogenic activity during the rainy season. Lastly, no studies have been conducted in Panama to determine the presence of free-living amoebae in recreational waters nor have cases of primary amoebic meningoencephalitis, or granulomatous amoebic encephalitis been documented.

4.5 *Cryptosporidium* and *Giardia* in children under five

Álvarez et al. (2010) found that *Cryptosporidium* spp. has a prevalence of 6.4% in children under five in a study covering various parts of the country, adding that Chorrera had the highest prevalence (16%), followed by Panamá Metro (11%). It is striking that although the studies by De la Cruz et al. 1997 and Rivera et al. (1991) were undertaken several years ago, they coincide as regards the high incidence of cryptosporidiosis in children under five in La Chorrera. Álvarez et al. (2010) found a relatively high prevalence of *Giardia* spp. (10%) in the same population, although this was not the highest rate recorded.

5. Variability and Climate Change, their Impact on Water Resources in Cities

5.1 Climate Change in Panama: Observations with an Emphasis on Cities

According to the IPCC (2013), climate change is unequivocal and its impact tends to increase over time. The Fifth IPCC Report has placed particular emphasis on the assessment of climate change in urban areas, acknowledging that many climate change risks worldwide are concentrated there: heat waves, extreme precipitation events, floods, landslides, air pollution, drought and water shortage (IPCC, 2014). The IPCC also indicates (2014) that Latin America is one of the geographical regions with the highest percentage of urban population (82%). This percentage far exceeds the world average of urban population, which, according to the Millennium Ecosystem Assessment, was approximately 50% in 2005. The high percentage of urban population, along with other factors that increase the vulnerability of such populations, has underlined the importance of focusing on adaptation to climate change in urban areas.

Patterns of human settlements around the world, the dynamics of urbanization and unequal economic conditions have contributed to the current trends in vulnerability to extreme events and impacts related to climate change (IPCC, 2012). As indicated by the IPCC (2014), rapid growth of urban areas has led to the emergence of areas that are highly vulnerable to extreme weather events, especially in developing countries. The metropolitan area of Panama City is experiencing rapid growth. Panama's urban population has increased exponentially, from 36% in 1950 to over 62% in 2000 (ANAM, 2012). This population growth, coupled with poor urban planning and an unprecedented rise in the frequency of extreme events increases vulnerability and the magnitude of impacts. These facts point to the need to implement strategies to address climate change, both as regards adaptation and mitigation, but especially adaptation, since the impacts of climate change are affecting the quality of life and ecosystems in Panama.

5.2 Climate Variability and Climate Change

Olmedo and López (2014), in the "GEO Report 2014: Behavior of some aspects of the climate in Panama," analyzed the variables of precipitation and temperature for five weather stations nationwide. Analyses of precipitation (for the periods from 1970 to 2012 or 1974 to 2012) and wind temperature for the period from 1971 to 2012 were undertaken.

In general, an upward trend in both precipitation and wind speeds was observed over time. An example of these trends can be seen in Figures 7-9, corresponding to the Tocumen Station in Panama City. This station was chosen because it was the only one in the study in the metropolitan area. As one can see from these figures, both maximum and minimum temperatures experienced an increase of approximately one degree in approximately 40 years. Likewise, total annual rainfall during this period rose by about 55 mm (Figures 7-9).

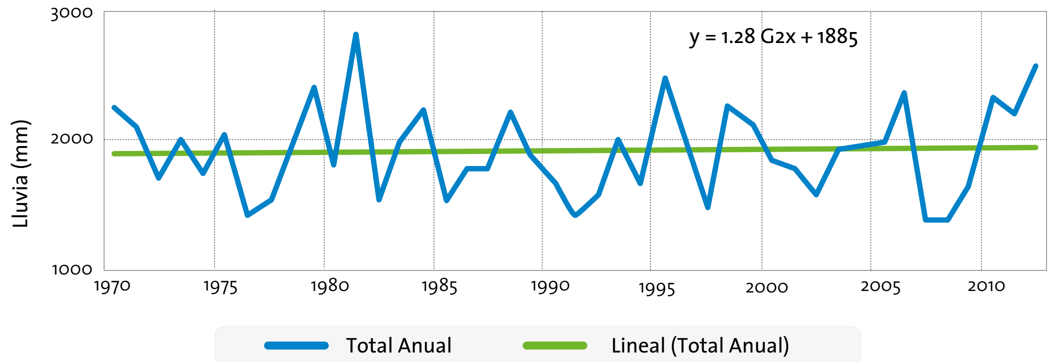
5.3 Extreme Hydrometeorological Events and their Impacts

According to the IPCC, there is a "statistically significant trend of extreme precipitation events in some regions" (IPCC, 2012, p.6). Climate change involves changes in the frequency, intensity, duration and spatial and temporal distribution of extreme events, which may cause disturbances in the functioning of natural and human ecosystems (Marengo, 2013). Over the past 30 years, Central America has seen a significant upward trend in temperature and an increase in extreme events including storms, floods and droughts (IPCC, 2014). In this respect, Garlatti (2013) indicates that during the period from 1987 to 1998, the annual number of disasters related to climate change in developing countries was 195, whereas in the period from 2000-to 2006, this figure rose to 365. These statistics indicate an increase of 87%. Garlatti also maintains that 75% of the disasters in the 1990s were related to climate events, with the largest number of events being in the category of floods and droughts, while more than 95% of the deaths caused by natural disasters occurred in developing countries.

Observations of climate variability and change, like the associated impacts, indicate that the most important consequences for Central America are related to extreme weather events, including floods, landslides and droughts (Garlatti, 2013). The Central American Integration System (SICA) has acknowledged that there is high variability of annual precipitation in the region, where intra-annual patterns have disrupted the temporal and spatial distribution of precipitation. In this respect, Aguilar et al. (2005) argue that although there are no significant differences in the total amount of annual rainfall in the region, there has been an increase in the periods of wet and very wet days, indicating a rise in the number of extreme precipitation events.

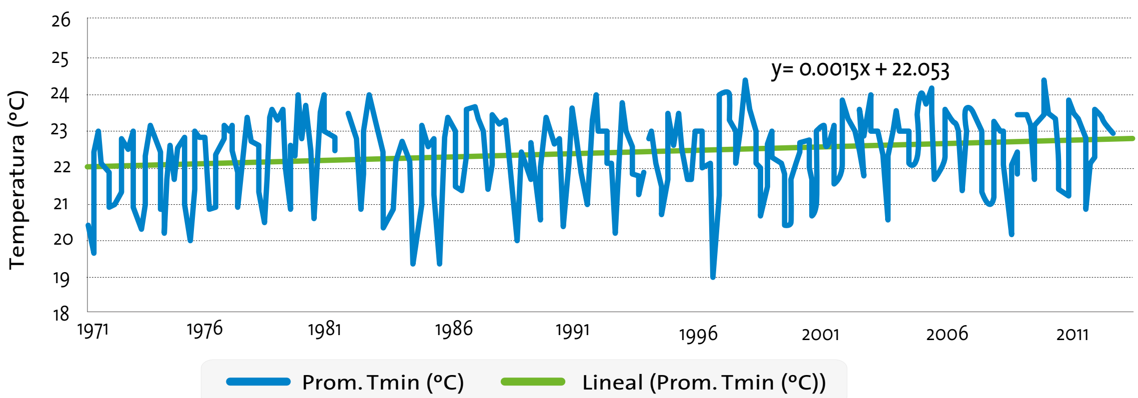
In the case of Panama, Fábrega et al. (2013) reported an increase in the frequency of extreme precipitation events. The main impacts of climate change in Panama are related to the occurrence of extreme precipitation events and the consequent flooding and landslides due to the saturation of slopes and the increased incidence of vector-borne diseases such as **dengue**. ANAM indicates, for example, that

Figure 7. Dengue incidence rates in Panama, 2000-2014



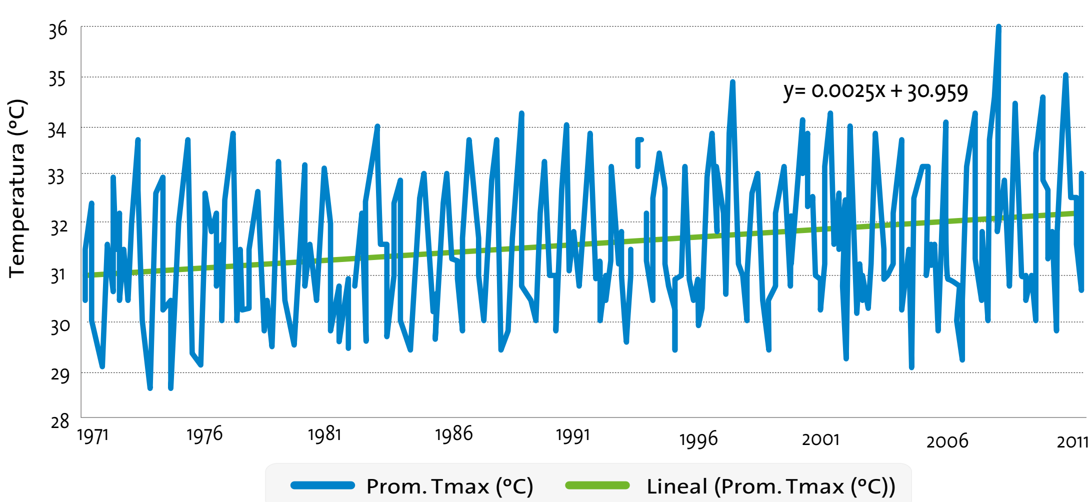
Olmedo and López, 2014

Figure 8. Average Minimum Temperature at Tocumen Station. Period from 1971-2012



Olmedo and López, 2014

Figure 9. Average Maximum Temperature at Tocumen Station. Period: 1971-2012



Olmedo and López, 2014

since 2004 there has been an unusual increase in the magnitude and frequency of extreme events, especially hydro- meteorological events (2011). This is confirmed by data obtained from international disaster databases.

The most important extreme precipitation event for the metropolitan area occurred in December 2010. This storm is known as "La Purísima," a name that refers to recent rainfall in the rainy season occurring about five days before or after December 8, the feast of the Immaculate Conception of the Virgin Mary (Espinosa, 2010). According to ACP records (Espinosa, 2010), La Purísima was the largest, three-day storm in the history of the Panama Canal watershed, producing a record 760 mm of rain in 24 hours. The rainfall recorded from December 7 to 9 2010 was between two and five times greater than normal precipitation in December, corresponding to a return period of 400 years (ACP, 2011a). Moreover, in all the major rivers in the Panama Canal watershed in December 2010, there were higher than average flows for the month, exceeding the latter by between 200% and 400% (ACP, 2011a). As a result of this precipitation event, the flooding of major rivers that flow into Lake Alajuela and over 500 landslides produced excess sediment in the water bodies (ACP, 2011b).

One of the main impacts of climate change in the urban areas of Panama are floods. These are likely to become more common over the next 100 years in regions with high precipitation levels. In addition to the human and economic losses associated with flooding, these events pose a risk to human health through the spread of infectious, water- borne and vector-borne diseases.

Figure 10. Location of Panama's five major cities

DesInventar, 2014

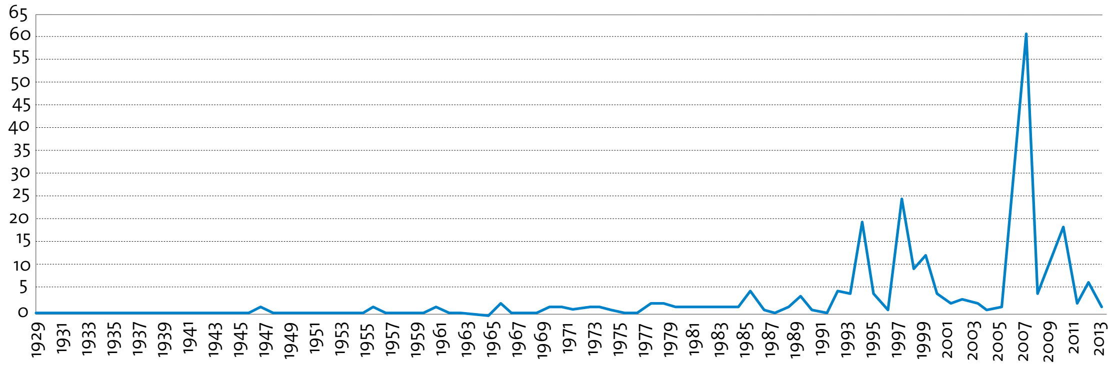
The "DesInventar" database was used to analyze the occurrence of floods in major cities in Panama: Panama City and San Miguelito, Colón, Santiago de Veraguas and David, shown in Figure 10. The "DesInventar" database was developed in 1994 by the Network for Social Studies on Disaster Prevention in Latin America (The Network), to provide decision makers with data on disaster events and the number of people affected. This database contains information on medium- and large-scale disasters in Latin America over the past 40 years. In Panama, the organization responsible for updating the database is the National System of Civil Protection (SINAPROC).

The historical records in "DesInventar" indicate an increase in recent decades in flood events and the number of people affected by these events, as can be seen in Figures 11 and 12. A comparison of the number of people affected in each city shows that Panama City has the highest proportion of people affected by floods in urban areas of Panama (Figure 13).

Another important impact of extreme precipitation events and landslides experienced in the urban areas of Panama is the disruption of the functioning of water systems. The clearest example is the La Purísima event in 2010. Landslides caused by the storm had resulted in the excessive sediment in suspension in Lago Alajuela, which increased turbidity to values of over 700 Nephelometric Turbidity Units (Espinosa, 2010). Lake Alajuela captures water from the main water treatment plant for human consumption supplying Panama city. This plant collapsed, since it was unable to handle the high levels of turbidity, leaving much of Panama City without drinking water for approximately 50 days (Espinosa, 2010). Another important impact of this extreme event was the interruption of the passage of ships through the Panama Canal for 17 hours (www.laprensapanama.com).

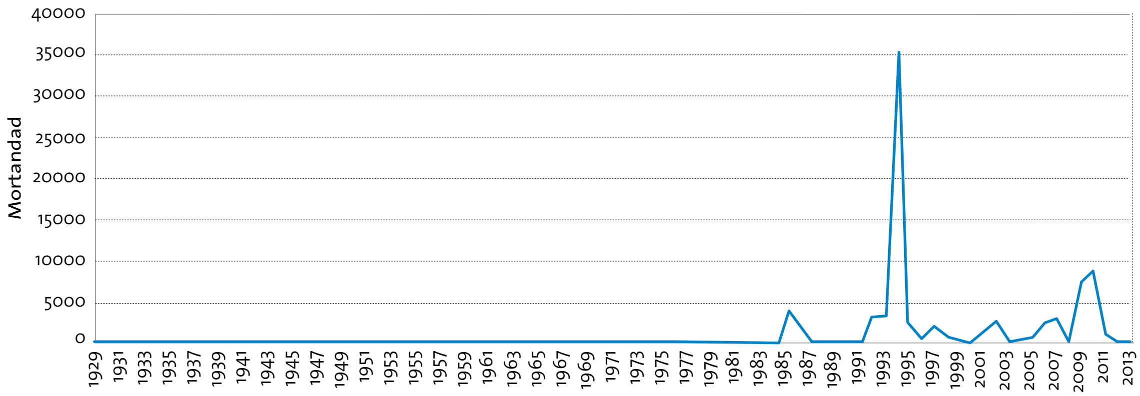
The alteration of water resources due to climate change also has implications for hydropower generation. Panama's energy matrix consists of approximately 60% of hydropower. Panama City has suffered the impacts of drought in watersheds that feed the main hydropower generating plants. One example was the suspension of classes for three days at schools and universities in Panama in May 2013. In 2014, it was also necessary to implement energy saving measures to cope with the low levels

Figure 11. Floods in five cities in Panama, from 1929 to 2013



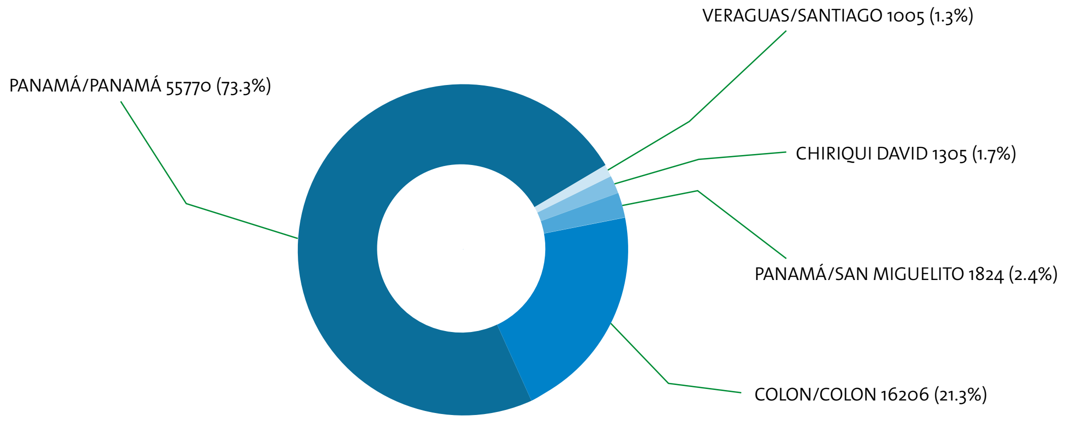
DesInventar, 2014

Figure 12. Number of people affected by floods in five cities in Panama, from 1929 to 2013



DesInventar, 2014

Figure 13. People affected by floods in five cities in Panama



DesInventar, 2014

of hydroelectric generation due to lack of water in the reservoirs, because the dry season extended beyond the normal limit.

5.4 Increased Incidence of Vector-Borne Diseases

Global warming and climate change and variability are producing significant impacts on human health in Central America (IPCC, 2014). Specific impacts reported by the Fifth IPCC Report include: respiratory and cardiovascular diseases, waterborne diseases and those transmitted by vectors such as **malaria**, **dengue**, yellow fever and hantavirus. Climate change will exacerbate existing risks and vulnerability due to population growth, health services and sanitation, including waste management and environmental pollution (IPCC, 2014).

One disease that has affected Central America in recent decades is **dengue**. Epstein (2000) argues that **dengue**, a disease that had been virtually eradicated in the Western Hemisphere, re-emerged with more than 200,000 cases in 1995. Statistics show that these numbers have tended to increase over the years. The proliferation of *Aedes aegypti* and **dengue** incidence has been such in recent decades that the World Health Organization has listed it as one of the major public health problems, because in the past 25 years, it has reached epidemic proportion in some countries in the Americas (San Martin and Brathwaite, 2007). These authors reported **dengue** cases in at least 30 countries in the Americas, with approximately 3 million cases between 2000 and 2005, of which 65,235 were severe cases, causing approximately 800 deaths.

5.5 Addressing Climate Change Issues Through an Appropriate Legal and Institutional Framework

Around the world, all levels of government are accumulating experience concerning climate change adaptation and there are a number of cities that are taking the route of resilience seriously (Newman et al., 2009). However, the experiences reported for Central America focus very little on urban resilience and are related more to the management of natural areas, crops and integrated water resource management (IPCC, 2014). Increasing urbanization of the region, coupled with the need for improved infrastructure systems such as aqueducts, sewerage and other basic systems means that there is an urgent need to increase adaptation measures in urban areas. Among the strategies for addressing climate change, the legal and institutional framework plays a very important role, as do capacity building, research and structural and non-structural solutions.

To address climate change in Panama, with regard to both adaptation and mitigation, institutional and legal developments include the adoption of the National Policy on Climate Change within ANAM and the creation of the National Committee on Climate Change, with representatives from 27 public sector institutions including the academic sector.

To meet international commitments on the issue of climate change, Panama has submitted two National Communications to the United Nations Framework Convention on Climate Change. The Second National Communication, submitted in 2011, states that according to the greenhouse gas inventory using 2000 as the baseline, Panama is a carbon fixing country. The Panama National Plan for Integrated Water Resource Management 2010-2030, designed to guide decision-making "to maximize the economic, environmental and social role of water" (ANAM, 2011), was recently passed. This plan includes climate change analysis, risk management and vulnerability and considers climate scenarios for Panama, extreme events and their impact on water resources and mitigation and adaptation options, among other aspects.

5.6 Factors of Urban Resilience to the Impacts of Climate Change

Various alternatives have been designed to increase urban resilience to climate change. One of the most important alternatives being promoted worldwide are green buildings. In Panama, buildings with LEED (Leadership in Energy and Environmental Design) certification are promoted through the Panama Green Building Council, affiliated to the World Green Building Council. The Panama Green Building Council was formed in 2009 to promote sustainability in Panama through the design, construction and operation of buildings with LEED certification (www.panamagbc.org).

According to information provided by the Panama Green Building Council, there are currently 10 LEED certified buildings in Panama City and 60 registered projects. Panama ranks second in Central America and the Caribbean in terms of LEED certified buildings. It is important to note, however, that in Panama there are currently no incentives for sustainable construction. Another structural solution that helps increase resilience to flooding are permeable pavements, whose use in Panama requires further study.

In addition to structural solutions, urban resilience to climate change depends on sensitizing the public and awareness of the role each plays in both the problem and the solution. A change in lifestyle that includes a reduction of consumption patterns and the promotion of healthy lifestyles is needed since a population with adequate health conditions are more likely to cope successfully with the disruption of systems caused by extreme weather-related events.

6. Final Considerations

We can infer from this chapter that Panama is a country with abundant water resources. However, their use as a source of drinking water for urban areas has focused almost exclusively on surface water sources. Likewise, although over 90% of the population has access to potable water in general, there are still regions (particularly indigenous areas) where less than half the population has access to potable water.

In the case of wastewater management, the past few years have seen enormous progress in both the legal framework and operational aspects. In recent years, nearly 100 wastewater treatment plants (WWTP) with secondary treatment have been built, particularly in new urban developments. At the same time, there has been heavy investment by the state since 2006 through various governments with the "Sanitation of Panama City and Bay," project which includes a WWTP, which, once the three phases of the project have been completed, will collect approximately 70% of the sewage from Panama City, with tertiary treatment to be provided in Panama. It is a matter of concern, however, that this investment is not accompanied by providing IDAAN, the institution ultimately responsible for financing these WWTP, with the management capacity (human and financial resources) required to accomplish this task.

With regard to health, dengue can currently be said to be one of the major public health problems in Panama. Studies show that the presence of Giardia spp. and Cryptosporidium spp. has been detected in sources of raw water for treatment plants in urban centers, particularly in the dry season. This situation requires increased surveillance of the presence of these parasites to prevent a possible outbreak of related diseases.

Finally, the relationship of urban waters with climate change is more important every day. Two aspects should be noted here: first, the increase in extreme events and the vulnerability of urban areas to these phenomena, and second, the need not only for structural responses that require the investment of resources, but also greater awareness on the part of citizens about the role we all play in the problem.

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Peru

The Plaza de Armas or Plaza Mayor in the historical centre of Lima. Photo credit: ©iStock.com/Holger Mette.

"The challenge of the future of Peru will be decided in its cities. Old urban societies learned to care the gift of water, as well as Caral, Cuzco, Macchu Picchu, Kuelap... Today, our cities turn the rivers into sewers. Alluvial cones and channels are occupied by housing. The uncontrolled waste of water reflects the lack of solidarity among ourselves and with nature. In spite of possessing 4.6% of the world's surface water, social inequalities and pollution make urgent a sustainable urban water management"

Urban Water Supply in Peru

Nicole Bernex Weiss, Víctor Carlotto Caillaux, César Cabezas Sánchez, Ruth Shady Solís, Fernando Roca Alcázar, Mathieu Durand, Eduardo Ismodes Cascón, and Julio Kuroiwa Zevallos

Abstract

After outlining the engineering works and expertise of the ancient Peruvians in securing water for their cities, this chapter describes the status of urban water in contemporary Peru. It focuses on the Metropolitan Region of Lima-Callao, which, despite concentrating a third of the country's population, still has approximately 11% of its population without access to water and 16% without access to sanitation. It emphasizes the gaps between the peripheries of poverty and the centers as regards access to and continuity of service and rates. It details the links between lack of water and sanitation, waterborne diseases and quality of life. Another two cases of cities are studied: Cusco, the "navel of the world," with its extremely deficient water system and vulnerability to disaster risks, and Iquitos, the capital of the Peruvian Amazon. Lastly, the chapter shows how despite certain institutional strengths, the water and sanitation sector still presents serious problems (such as political instability, lack of continuity, limited human resources) and requires more sustainable water management as part of a green economy to provide equitable access and quality in water services and resources. Hence the importance of launching an integrated urban water management process to properly combine the 5 "Is" of management (Integration, Investment, Information, Institutions and Infrastructure) in order to achieve and sustain water security and consequently urban sustainability.

1. Introduction

The world's 20th largest country, with an area of 1,285,000km^2, Peru experienced significant urban growth during the second half of the 20th century. Nowadays, 76% of a population of 30,814,175 live in urban areas and 24% in rural areas (INEI, 2014).

The link between the social collective, organized by the authorities of the ayllus and the State, composed of a hierarchy of curacas remained as the social and political system from the Caral civilization until the end of the Inca Empire. Ceremonies, rituals and offerings were periodically organized for the earth and water out of gratitude for the benefits received from them as the deities that permitted the survival and continuity of their social system. On the coastal strip, they dug in the sand and built "sunken farms" to take advantage of the moisture in the soil. Meanwhile, in the flooded zones or wetlands, in some cases they built raised fields or ridges whereas in other settings, they drained the land through ditches or drains, channeling the water into reservoirs or huachaques.

The inhabitants of the valleys implemented fields irrigated by a canal system administered by basin. Productive lands were respected and urban centers or dwellings located on unproductive terraces and specially conditioned spaces on the hillsides. In the hilly, rocky Andean space, with very little productive land, the inhabitants built terraces on the slopes or constructed platforms on the rough slopes, with a corresponding system of irrigation canals.

An advanced geohydrological management system was provided by amuna technology, implemented in the central coast valleys and rivers

Figure 2. Huachaque (left) and excavated puquios (springs of water, right)

Photos: Ruth Shady

Figure 1. Five thousand years ago, the populations in Supe Valley on the north-central coast of Peru had already achieved productive, agricultural and fishing conditions. A complementary agricultural-fishing economy supported the formationof the Caral civilization, the oldest on the continent (dating back over 5,000 years). Photo: R. Shady

with a low or temporary flow. These measures solved the water shortage problem. Water was "sown" in the High Andean territory by channeling it from the lagoons to geologically permeable places into which it filtered, and was subsequently extracted in springs or puquios, dug at regular intervals throughout the basin. Similar technology was used on the south coast through "infiltration galleries." This extraordinary water management system made it possible to supply the citadels, characterized by having tanks and wells. Thus Chan Chan was supplied by water from over 140 wells (Tavera). Although the area where Cajamarquilla is located is now completely dry, a city that size obviously required a continuous, copious water supply, both for everyday use and for building adobe bricks, the technique of choice for pyramids and buildings. Studies conducted by Mogrovejo and Makowski (1999) conclude that at one time the Huaycoloro River carried water permanently, as borne out by the canals and reservoirs located in Cajamarquilla (Tavera).

Likewise, when they built the city of Machu Picchu (2000 440 m), the Inca were confronted with extremely steep slopes. They managed to gain access to water by pinpointing the exact location of the source and determining whether it would meet the population's expected needs. On a sharp mountain slope north of Machu Picchu, the source was fed by a tributary river basin of 16.3 ha, which in turn was supplied by drainage from a much larger hidrogeological basin (Wright, in Brown, 2001). The

Table 1. Distribution of Water Resources in Peru

Hydrographic Region	Area		Population		Water recourses		Ratios	
	103km²	%	Inhabitants	%	Hm³/year	%	Hm3/year	M³/Inhab/ year
Pacific	278.48	21.67	18,801,417	62.53	34,136	1.76	0.12	1,815.61
Amazon	957.82	74.53	10,018,789	33.32	1,895,226	97.91	1.98	189,167.18
Titicaca	48.91	3.81	1,246,975	4.15	6,259	0.32	0.13	5,019.35
Total	1,285.21	100	30,067,181	100	1,935,621	100	1.51	64,376.54

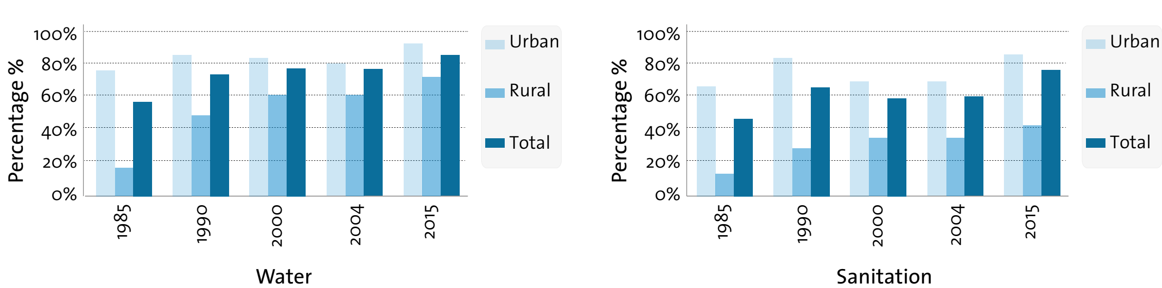
Source: ANA, 2013: 28.

Table 2. Potable water and sewerage coverage and installation time for home connections by size of provider, 2012

Type of PA and S provider	Urban population served (2012)			
	Population Total	% Water coverage	% Sewage coverage	Hook up time in business days
SEDAPAL	9,256,885	94.59	89.86	15
Large	6,512,192	89.04	77.43	15
Medium	2,030,107	83.47	72.47	38
Small	805,669	80.81	66.20	18
Total	18,604,853	91.00	82.72	16

Source: SUNASS, 2012.

Figure 4. Evolution of drinking water and sanitation coverage



Source: For 1985: MVC 1986; for 1990: WHO and UNPF 2000; for 2000: MVCS 2000; for 2004: MVCS 2004, for 2015: WSP 2005, in Marmanillo, 2006.

thousand inhabitants of Machu Picchu not only had access to water but also to an effective rainwater drainage system (Wright et al., 1999).

2. Water Sources and Accessibility

Although Peru is one of the richest countries in water resources, possessing 4.6% of the world's surface water, with water availability of 64,376.54 m³/capita/year, it has severe problems concerning the territorial distribution of the population, which is exactly opposite to that of water, coupled with poor water management.

Peru has a long history of water development and management. It is a history that goes back to the Caral Civilization more than 5000 years ago (see Figure 1). The illustrations in Figure 2 attest to the fact that the ancients in Peru knew how to manage ground water as well as surface water. Today, population pressures coupled with spatial variability in precipitation and the need to provide adequate sanitation services, confront modern generations of Peruvians with challenges that their ancestors could not have imagined. The challenges are especially daunting and complex in Peru's urban areas.

3. Drinking Water and Sanitation Services

3.1. Drinking Water and Sanitation Services in Urban Peru

Peru is one of the 189 countries that have signed the Millennium Development Goals. Meeting these goals has become state policy. One of the Peruvian government's most important programs was the "Water for All" Program, presented in 2006. During the official launch of the program, historical drinking water coverage and that projected for 2015 were indicated, according to the World Bank Water and Sanitation Service (Figure 4).

The National Sanitation Services Superintendence (SUNASS) (2012) analyzed the drinking water and sanitation provided by small, medium and large drinking water and sanitation Services Provider Companies (EPS). The Lima Potable Water and Sewerage Service Company (SEDAPAL), which provides water and sanitation services for the metropolitan areas of Lima and Callao, is a special case. An EPS is regarded as small when it serves fewer than 15,000 households. Medium EPSs provide services to between 15,001 and 40,000 households. Large EPSs serve over 40,000 homes. By late 2012, EPSs had achieved 91% potable water coverage and 83% sewerage coverage. Continuity of service stood at 18.43 hours/day. The information provided in Tables 2 and 3 is based on data collected by SUNASS in 2011 (2012).

The total volumes and percentages of treated and untreated wastewater are shown in Table 3.

A large amount of sewage is not treated. In most cases, water is discharged directly into water courses and bodies, polluting the environment.

Figure 3. Distribution of the urban population in Peru

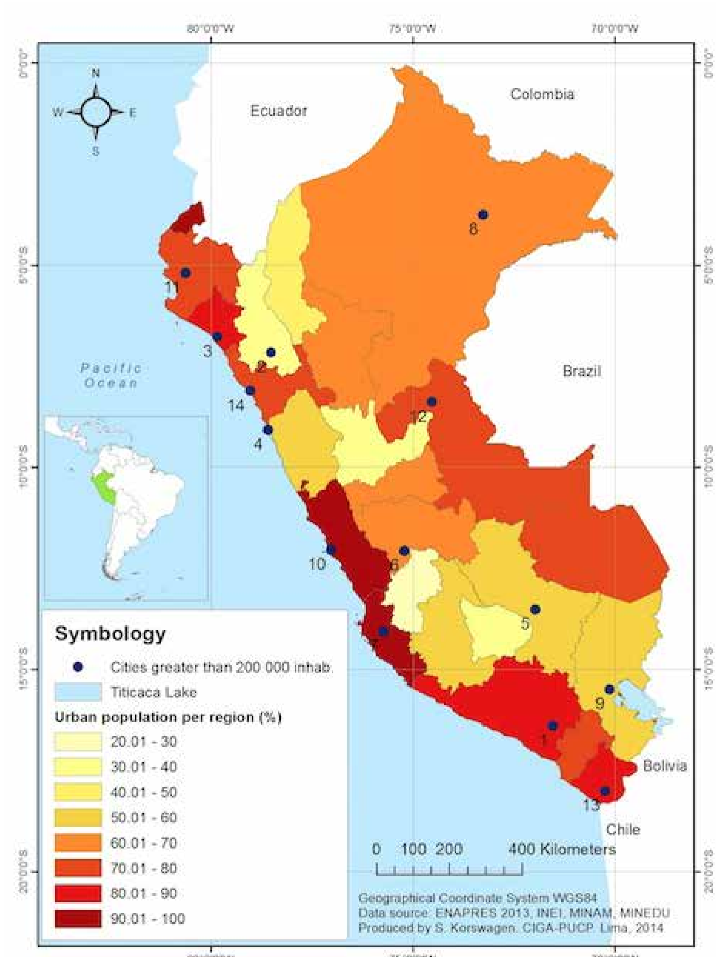
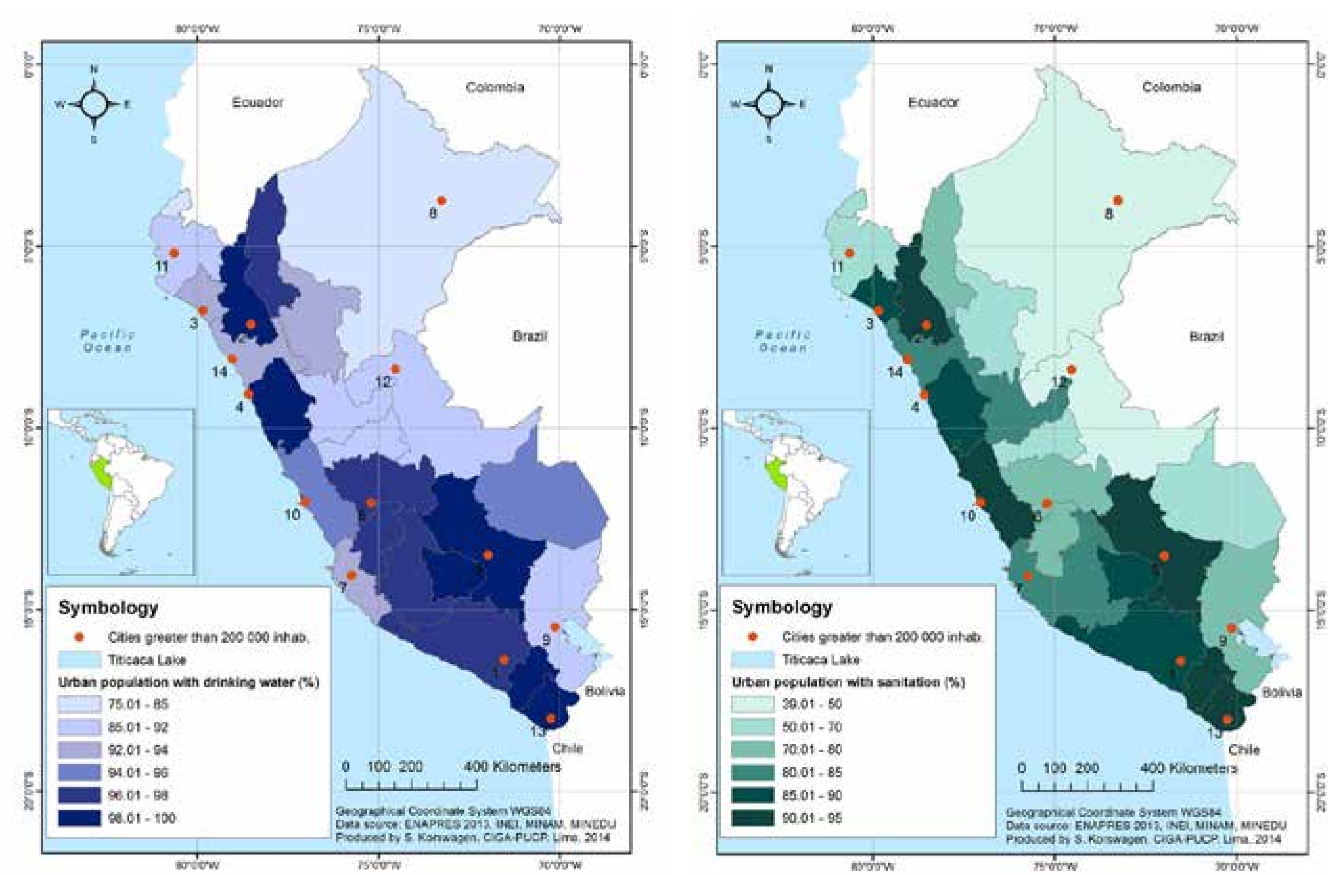


Table 3. Volume of wastewater produced and processed by size of potable water and sewerage provider

DW and S Provider	Total Volume (MMC)	Treated volume (m³)	Percentage (%)
SEDAPAL	428.48	88.48	20.6
Large	252.83	145.27	57.5
Medium	82.56	18.84	22.8
Small	34.68	8.33	24.0
Total	**798.54**	**260.92**	**32.7**

Source: SUNASS, 2012.

Figures 5 and 6. Urban population served with potable water and sanitation at the department level



Source: for 1985: MVC 1986; for 1990: WHO and UNPF 2000; for 2000: MVCS 2000; for 2004: MVCS 2004, for 2015: WSP 2005, in Marmanillo, 2006.

The percentage of water supply and sewerage coverage by the EPSs responsible for these services is given below for the main cities in Peru. In late 2012, wastewater treatment nationwide stood at 32%, showing very little variation from previous years. This situation changed in April 2013, due to the coming into operation of the Taboada wastewater treatment plant (SEDAPAL), which has increased sewage treatment in Lima from 21% to approximately 60%.

As regards micrometering and unbilled water, both indicators have shown improvements: micrometering has increased to 63% while unbilled water was reduced to 37%. Table 6 shows the percentage of micrometering and unbilled water according to the EPSs responsible in the country's major metropolitan areas.

It should be noted that although the Lima-Callao conurbation is the most highly populated region of Peru, only 13.3% of wastewater was treated in 2007 and 21% in 2010. The coming into operation of the Taboada wastewater treatment plant (SEDAPAL) increased wastewater treatment to approximately 60% (SUNASS, 2013:6). Untreated water is discharged into the Pacific Ocean and the Rímac and Chillón Rivers, polluting oceanic and inland water resources and riparian zones.

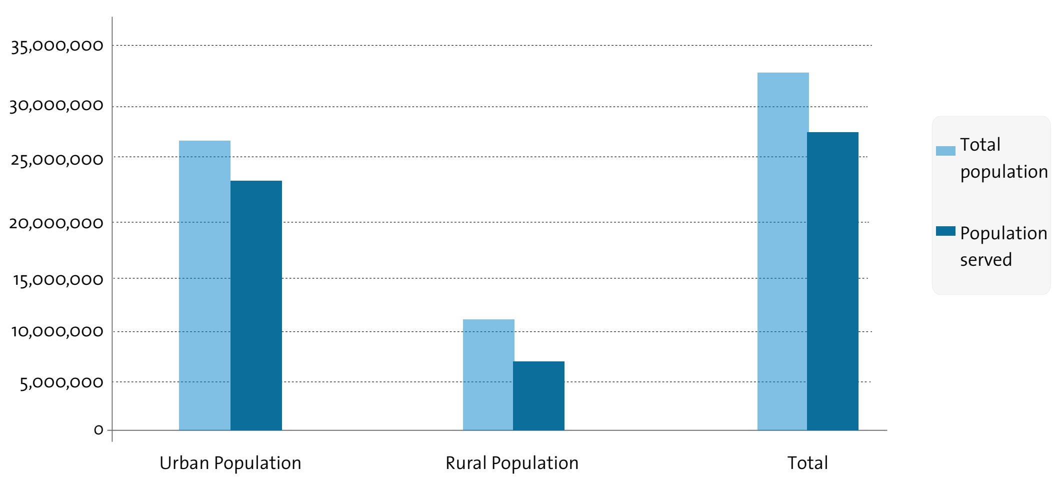
Despite these efforts focusing on Lima, it must be recognized that one of the main shortcomings of health services in Peru is the lack of treatment for most wastewater. Wastewater treatment methods are extremely varied in Peru due to the wide range of climates and geographical conditions. SUNASS (2008) has pointed out that potable water and sewerage treatment plants are not properly operated or given adequate maintenance. Very few projects can be considered successful. The main causes of the deficit in wastewater treatment and inefficient treatment plants are given below: (i) Insufficient research and technological development, (ii) Lack of coordination between institutions in the area of sanitation, (iii) Insufficient resources for the operation and maintenance of water treatment plants, and (iv) Lack of financing for wastewater treatment.

It was estimated that by 2007, total investment for achieving the MDGs by 2015 would be $4.042 billion USD. Annual investment would stand at approximately $550 million USD.

Figures 5 and 6 show water supply and sewerage coverage in Peru. Water coverage is higher in coastal cities, where a large sector of the population is concentrated. The Lima-Callao Metropolitan Region has the highest coverage. In general, the lowest water coverage occurs in parts of the Sierra and the rainforest.

Large inequalities in coverage between regions can be observed, together with significant gaps between rural and urban populations, as shown in Figure 7.

Figure 7. Urban-rural inequality in access to water, 2013



Source: Ministry of Housing, Construction and Sanitation, 2014.

Table 4. Volumes of wastewater: treated, untreated and total

Sewage produced by sanitation services	Volume per year (MMC/year)	Equivalent flow (m3/s)	% of treatment
With treatment	217.25	6.89	29.10
Without treatment	530.03	16.81	70.90
Total	**747.28**	**23.70**	**100.00**

Source: SUNASS, 2012.

Table 5. Potable water and sewerage coverage in major cities served by EPSs, 2013

Geographical Regions	CITY	EPS	Total urban population	Drinking water coverage (%)	Sewerage coverage (%)
COAST	Chiclayo and others	EPSEL S.A.	866,509	89.4%	80.8%
	Piura and others	EPS GRAU S.A.	1,049,547	89.3%	75.1%
	Trujillo and others	SEDALIB S.A.	943,942	85.3%	79.9%
	Tumbes	AGUAS DE TUMBES S.A.	202,250	80.2%	51.2%
	Chimbote and others	SEDACHIMBOTE S.A.	399,469	99.0%	96.4%
	Metropolitan Lima and Callao	SEDAPAL S.A.	9,354,380	96.3%	91.5%
	Ica and others	EMAPICA S.A.	204,496	91.0%	83.3%
	Tacna and others	EPS TACNA S.A.	271,448	97.1%	95.4%
SIERRA	Huancayo and others	SEDAM HUANCAYO S.A.	368,683	78.8%	72.6%
	Huánuco	SEDA HUANUCO S.A.	232,335	82.9%	77.5%
	Arequipa and others	SEDAPAR S.A.	1,046,867	93.4%	81.2%
	Cusco and others	SEDACUSCO S.A.	393,325	98.2%	96.0%
	Huamanga and others	EPSASA	224,340	93.4%	82.3%
	Juliaca	SEDAJULIACA S.A.	250,188	82.0%	83.2%
RAINFOREST	Iquitos	EPS SEDALORETO S.A.	476,041	93.0%	53.9%
	Pucallpa	EMAPACOP S.A.	221,805	61.3%	62.3%

Source: Compiled by the Ministry of Housing, Construction and Sanitation for this publication; regrouped by region by the author.

Table 6. Number of connections, wastewater treatment, micrometering and unbilled water in metropolitan areas, 2007

Metropolitan Area	Number of Connections	% of Wastewater treated	% of Micro-Metering	% of Unbilled Water	Services Provider Company (EPS)
Lima-Callao	1,194,879	13.3	70.1	37.5	SEDAPAL S.A.
Arequipa	201,144	16.1	64.2	35.9	SEDAPAR S.A.
Trujillo	135,883	80.1	37.7	45.7	SEDALIB
Chiclayo	133,767	89.2	9.3	41.6	EPSEL
Piura	163,824	50.6	19.9	55.9	EPS Grau
Iquitos	56,684	0.0	23.7	57.9	SEDALORETO S.A.
Cusco	57,497	75.4	78.2	46.0	SEDACUSCO S.A.

Source: SUNASS, 2013.

Table 7. Price of potable water and sewage service per m³ to 2011

Type of PW and S supplier	Price per m³ (S/./m³)	Price per m³ (US$ /m³)
SEDAPAL	2.41	0.87
Large	1.66	0.6
Medium	1.24	0.45
Small	1.03	0.37
Total	**2.01**	**0.73**

Source: SUNASS, 2011.

Table 8. Population growth in RML and Peru

Year	Lima		Peru	
	Population (in thousands)	Annual Growth Rate (%)	Population (in thousands)	Annual Growth Rate (%)
1940	645	-	6,208	-
1961	1,845	5.1	9,907	2.3
1972	3,303	5.4	13,538	2.9
1981	4,608	3.8	17,005	2.6
1993	6,345	2.7	22,048	2.2
2007	8,482	2.1	27,412	1.6

Source: INEI: 2007.

Water rates

The price per cubic meter of drinking water is given in Table 7, which shows the price of SEDAPAL and drinking water and sanitation providers in local currency and US dollars in 2011. An exchange rate of 2,76 soles to the dollar was used. In general, prices were kept low because wastewater treatment coverage remained low until 2011. Prices are higher in the Lima-Callao Metropolitan Region because water treatment is expensive due to the high burden of pollutants in the Rímac River .

Maintaining rates that do not include sustainability criteria constitutes a perverse incentive for users, as they will tend to use more water because of its low cost. Furthermore, the absence of rates that increase exponentially once they exceed basic household consumption encourages families to use disproportionately more water than that required to cover basic needs (Peruvian Society of Urban Planners, 2011).

3.2 Water and Sanitation in the Lima-Callao Metropolitan Region

The Lima-Callao Metropolitan Region (RMLC) comprises the Lima Metropolitan Region (RML) and the Callao Region (RC). The Lima Metropolitan Region comprises 43 mainly urban districts, with a total population of 8,48 million in 2012 (INEI, 2012). The RC, located in the west of Lima and adjacent to the Pacific Ocean, comprises six districts with a total population of 0.97 million. These two regions together contain 9.45 million inhabitants. The birth rate has significantly declined, with urban women having an average of two children. However, migration to the cities remains high, which greatly increases the growth rate of urban areas. Table 8 shows and compares the growth of RML and Peru between 1940 and 2007.

Three rivers cross the RMLC. From North to South, these are the Chillón, the Rímac and the Lurín (Figure 8). The main features of the three basins, together with the total area of the basin, the main channel length, maximum and minimum altitudes, average slope and discharges are presented in Table 9.

These three basins constitute the main water sources for the RMLC for surface and groundwater extraction, as well as the collection of fog water in certain poor urban neighborhoods. Seawater is not used.

The Rímac River is the main freshwater source for the RMLC. Water is taken from Rio Chillón at a rate of 2 m³/s during the rainy season and 1 m³/s in

Figure 8. Chillón, Rímac and Lurín rivers and RMLC

Source: Metropolitan Municipality of Lima, 2001.

Table 9. Main characteristics of rivers flowing through the RMLC

Cuenca	Area (km²)	Length (km)	Maximum Altitude (masl)	Minimum Altitude (masl)	Average slope (%)	Average flow (m³/s)
Chillón	2,353	126	4,850	0	3.85	8.74
Rímac	3,504	127	5,100	0	4.02	29.00
Lurín	1,670	109	5,300	0	4.86	4.27

Source: ANA, 2013.

the dry season. Water is not extracted from the Lurín River for Lima's drinking water service. Most of the water is used for agriculture purposes.

To complement the volume of water needed to cover the RMLC's demand, water is transferred from the Upper Mantaro River to the Pacific slope. The Marcapomacocha project involves storing water in existing lagoons on the Amazonian slope. Closure dams have been built in these lagoons to increase their storage capacity. Water is stored in lagoons during the rainy reason. A system of canals carries water to the dammed lagoons and then to the Pacific slope through the Transandean Tunnel, carrying water to the upper basin of the Rímac or Chillón rivers.

Groundwater extraction totaled approximately 3.6 m^3/s in the RMLC in 2011 (INEI, 2012). The extraction rate has significantly decreased due to the closure of wells caused by the pollution of groundwater resources. Filtration galleries are no longer used in Lima. The evolution of groundwater extraction in Lima in MMC per year and the equivalent discharge are presented below in Table 10. Together with 452 SEDAPAL wells, 284 of which are operational, there are over 1,100 wells operated by the state, industrial and agricultural sectors and countless informal wells (SEDAPAL, 2012).

Lima produces an annual average of 544 million m^3 of wastewater, i.e. approximately 17 m^3/s with peaks of 24 m^3/s (SEDAPAL, 2005 Vol.2: 49; DIGESA, 2008: 5), equivalent to an average of 170 liters (0.17m^3) per person/day. Drinking water production is 23.1 m^3/s, in other words, over 730 million m^3 annually (SEDAPAL, 2009: 15). Of this amount, 692 million m^3 are produced by SEDAPAL, and 38 million m^3 by alternative supply systems (wells, tanker trucks and so on). Average drinking water consumption per person per day is between 229 and 250 l., whereas in many European capitals it fluctuates between 150 and 190 l. (SEDAPAL, 2009: 4). This high water consumption means high wastewater production.

SEDAPAL studies indicate the gaps between the water consumption of wealthy social groups (between 330 and 460 l./Inhab./Day) and poor groups (between 103 and 145 l./Inhab./Day). Populations living in extreme poverty are not listed in the classification since they lack access to water. Consumption is usually less than 30 l./inhab./day.

The evolution of the index of access to networks (Figure 10) shows that during in the first phase (1981), the city center had been connected to the sewerage network (over 75%) for a long time, whereas low income neighborhoods had a rate of access of under 75%, of 50% at most.

The following phase (1993), described in the 1993 census, shows that the first peripheries are undergoing a process of consolidation. Finally,

Table 10. Extraction of groundwater in the RMLC, 2000- 2011

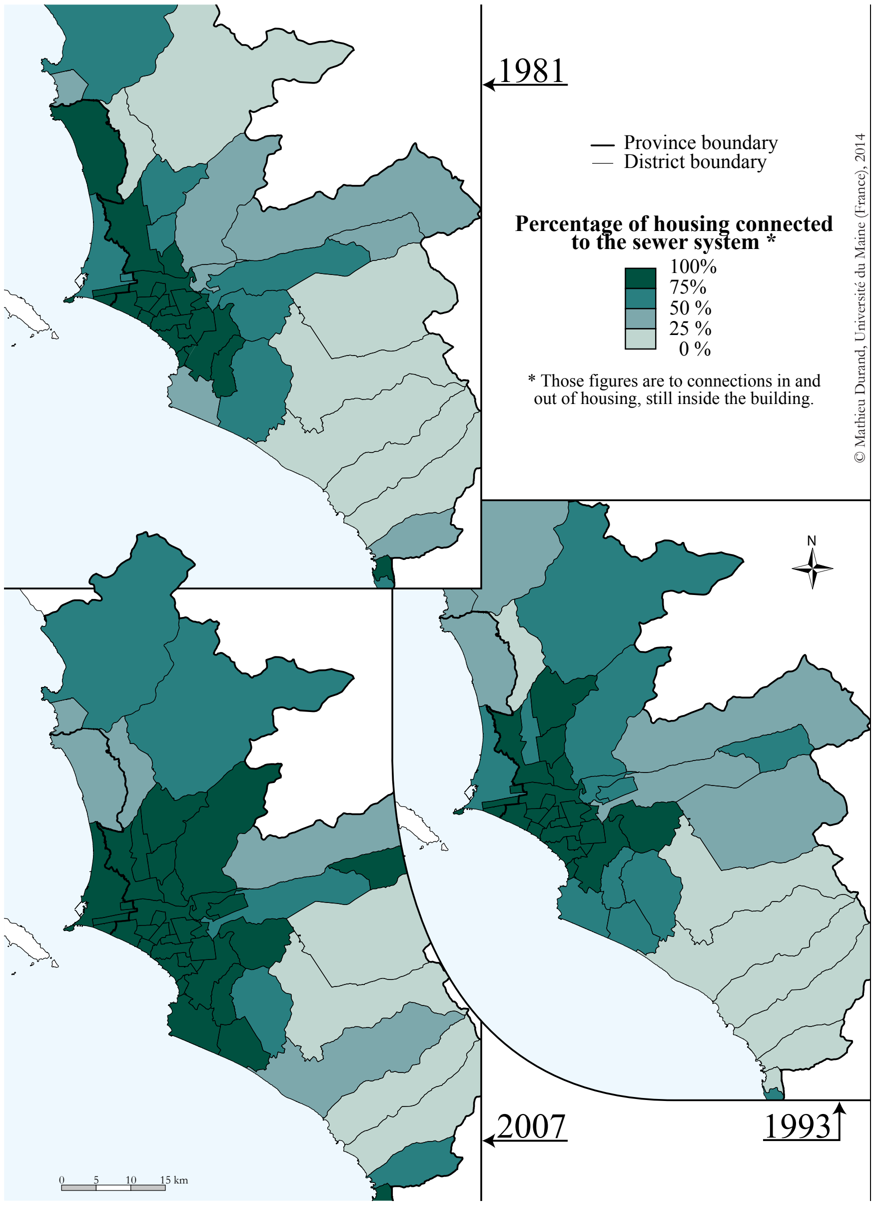
Year	Production (MMC)	Average flow (m^3/s)
2000	190.32	6.02
2001	176.61	5.58
2002	163.62	5.17
2003	127.37	4.03
2004	174.48	5.52
2005	151.34	4.79
2006	139.33	4.41
2007	105.56	3.34
2008	133.36	4.22
2009	108.44	3.43
2010	118.37	3.74
2011	115.80	3.66

Source: SEDAPAL, 2005, 2009 and 2012.

Figure 9. Channel discharging wastewater in areas not connected to the sewerage networks, Huachipa 2009

Photo: Mathieu Durand.

Figure 10. Figure 10. Rates of access to sanitation in RMLC in 1981, 1993 and 2007



Source: Durand, M., 2010.

during the last phase (past 12 years), large peripheries have gradually been incorporated, in other words, districts with informal urbanization, while the oldest suburbs such as El Callao, El Agustino and Chorrillos have continued to be consolidated.

The Lima Potable Water and Sewerage Service (SEDAPAL) is the company that provides potable water, sewerage and wastewater treatment services in the RMLC. This company belongs to the Ministry of Housing, Construction and Sanitation, which reports directly to the Central Government.

The La Atarjea water treatment plant is located on the left bank of the Rímac River. This plant began operating in 1956 with an initial capacity of 5 m^3/s. It was the treatment plant with the greatest capacity in the world at the time of completion of its construction (SEDAPAL, 2013). In 2010, SEDAPAL channeled between 15 and 19 m^3/s to the La Atarjea

Plant to supply water to Lima. During the dry season (May to November), the average annual flow is about 23.5 m^3/s. It has been estimated that the ecological flow is 1.5 m^3/s (Yepes, 2002). The La Atarjea water plant processes approximately 20 m^3/s and captures virtually all the flow available during the dry season. Water availability in the Rimac River basin is approximately 148.6 m^3/inhab./year whereas in the Rio Chillon it was approximately 202.2 m^3/inhab./year in 2005, well below the threshold of 1000 m^3/hab./year defining the state of water scarcity (Salazar, 2005). In 1876, stone masonry and concrete dams were built for energy and agricultural purposes and from the mid-20th century onwards to improve the drinking water supply in Greater Lima. In addition to Marca I, Marca II was expanded (through the construction of a 10 km tunnel, the expansion of the capacity of the Lower Huallacocha and Pomacocha dams), Marca III was built for storage and reserves (Santa Eulalia Lagoons, Yuracmayo and Antacoto dams), while Marca IV (Huascacocha-Rimac) was constructed to allow an average additional flow of 2.5 to 3 m^3/s.

In 2011, construction was completed of the new water treatment plant, Huachipa, upstream of the La Atarjea plant. This allows water to be transported by gravity to sectors that could not be supplied in the same way from La Atarjea. Total water treatment capacity is 10 m^3/s, although at present, it only captures 5 m^3/s. It is expected to operate at full capacity when the Marcapomacocha projects are completed. SEDAPAL has invested approximately $461 million USD in the project, which will provide potable water and sewerage services for 2.5 million inhabitants in the northern sector of the RMLC.

Consorcio Aqua Azul S.A., a private partnership between Peruvian and foreign investors, won a concession under the Build, Operate and Transfer (BOT) model to build a water treatment plant that will take approximately 2 m^3/s of water from the Chillón River during the wet season and 1 m^3/s during the dry season. This river is heavily polluted.

The Rímac River is one of the most highly polluted waterways in Peru. The sections are classified as Type II or Type III. The maximum permissible limits according to both Peru and the World Health Organization (WHO) are exceeded in several areas of the river. The basin contains old tailings dams, mines and processing plants that have contributed to the pollution from heavy metals, particularly arsenic, cadmium, copper and zinc (Méndez, 2005). The basin has also been polluted by domestic sewage, since there are several towns and small cities that discharge effluents into the river without any form of treatment. In the middle basin, towns and cities such as Surco (1,798 inhabitants), Matucana (4,508 inhab.) and Chosica (169,359 inhab.) discharge untreated sewage into the Rímac river. The district of Santa Eulalia, with a population of 10,591 inhabitants, discharges untreated sewage into the river of the same name, a tributary of the Rímac. Agricultural activities also contribute to pollution since fertilizers and pesticides are washed into the river when the land in this watershed is irrigated.

Table 11. Parameters measured at the intake of the La Atarjea Plant and reservoirs

Physico-Chemical Parameters	Rímac River			Water in Reservoir	General Water Act		
	Maximum (mg/l)	Minimum (mg/l)	Average (mg/l)	Maximum (mg/l)	Class II (mg/l)	Class III (mg/l)	WHO drinking water quality standards (mg/l)
Iron Fe+ 3	50.600	0.269	6.991	0.199	0.300	1.000	-
Manganese Mn+ 2	1.143	0.023	0.207	0.055	0.100	0.200	0.400
Lead Pb+ 2	0.379	0.009	0.089	0.016	0.050	0.100	0.010
Cadmium Cd+ 3	0.010	0.001	0.004	0.003	0.010	0.050	0.003
Aluminum Al+3	2.256	0.160	3.695	0.112	-	-	0.100
Arsenic As+3	1.101	0.035	0.392	0.048	0.100	0.200	0.010

Source: SEDAPAL, 2005.

Heavy metals, fecal coliform and other pollutants have been detected throughout the middle and lower sections of the river.

Table 11 shows the heavy metal concentrations in the La Atarjea intake. Maximum heavy metal concentrations exceed the maximums permissible for classes II and III of the watercourses in the General Water Act (D.L. N°17752).

The class II and III parameters can be compared with those of the WHO. The parameters were measured in 2002.

The illegal occupation of land exacerbates the problems of water supply and sanitation. The city of Lima has seen illegal land occupations since the 1950s. In the beginning, squatters occupied the hills surrounding Lima as shown in Figure 11. Years later, they began to occupy the periphery of the city, taking over agricultural fields and fallow land. There are legal problems due to the fact that if property is not registered in the public records, it is not possible to sign contracts with the occupants. In some cases, it is difficult and costly to deliver water to the marginalized human settlements located in the hills because it is necessary to pump water uphill. In addition to the high initial outlay, operating and maintenance costs are exorbitant. Approximately 984,727 inhabitants lacked access to safe drinking water in 2011.

The population of Lima is expected to continue to grow at a high rate due to migration within the country. Water availability per capita is therefore expected to continue to decline.

Freshwater resources are being depleted, meaning that new sources will be required to meet future demands. Transferring water from other basins and desalinating seawater have been considered, among other alternatives.

Problems have also been identified with the water distribution system. Unbilled water accounts for approximately 37.5% of that produced by SEDAPAL. Roughly 29.9% of the households that receive this service do not have meters. Additional measures must also be taken in order to be able to record and identify losses in the system and optimize the water supply processes required.

Numerous environmental and geomorphological changes are caused by anthropogenic activities in the urban section of the Rímac River. Martínez and Martínez (2004) and Kuroiwa et al. (2011) identify the causes that led to the formation of an urban canyon in Lima. The bed of the Rímac River was deepened approximately 20 m downstream of Puente del Ejército, built in 1936. The installation of a prefabricated metal bridge led to the narrowing of the channel. This caused the incision of the channel by increasing the stresses on the river bottom. Former floodplains were illegally occupied by people who live under the constant threat of landslides. Kuroiwa and Valle (2014) note that the formation of the urban canyon caused the disappearance of the Chryphios caementarius river shrimp (Molina, 1872). Several structures located downstream from Puente del Ejército, such as the Dueñas Bridge, were affected. Kuroiwa et al. (2004) describe a temporary solution that helped stabilize Puente Dueñas. However, this temporary solution has become permanent since erosion control has been satisfactorily achieved since the summer of 2002, and no definitive solutions have been proposed by the Metropolitan Municipality of Lima (MML).

Supplying the city of Lima and Callao, with more than 1.1 million water connections and an equal number of sewerage connections, forces SEDAPAL - a state monopoly water management company- to address numerous problems highlighted in Table 12, and solve them, while recovering its exploitation costs (operational), repositioning capital and expanding service (investment). A number of problems have yet to be addressed, such as the renovation of networks, better sewage treatment, enormous losses due to unbilled water (34.58% until 2011) and water loss from leaks in extremely old networks (Prialé, 2012).

In 2011-2012, the variety of problems led to a review of the management of the company and the implementation of a major investment program in the expansion, optimization of water and sewerage services, and the rehabilitation and improvement of networks (from 2013-2016) through 148 projects totaling 8,443,500 soles and benefiting 1.9 million residents. These projects were known as Expanding Coverage to 100% (Figure 13), Rehabilitation (Figure 14) and Diversification of Sources (Figure 15). As for the Projects to Expand Coverage to 100%, the challenge is to achieve universal access through 81 projects involving a total investment of S/. 5,631,732,00.

The 67 Rehabilitation Projects involve a total investment of S/. 2,812,000.

Finally, projects to diversify sources must ensure the supply of the country's largest metropolitan population, through the treatment and reuse of its water.

3.3 Water and Sanitation in the City of Cusco

Cusco is the capital of the Cusco Region and the former political center of the Inca Empire and the region where Peru's main attractions are located. The city of Cusco is located at an altitude of 3,399 masl. The current population is estimated at approximately 410,000 inhabitants. Studies of the Middle River and lower Huatanay indicate that 100% of the water supply for the populations of the South Valley of Cusco comes from groundwater, meaning that it is the only source of water, and requires artificial recharge to maintain and improve the production levels of springs. Likewise, although 98.19% of the population of South Valley have a water supply system, only 17.01% of the total have potable water, 82.99% have piped water and 1.81% no service, meaning that the Ministry of Health (MOH) should exert greater control over water quality in the supply systems. As regards the system of sewage disposal and sewerage, in the districts of San Jerónimo, Saylla, Oropesa and Lucre, this is directly administered by the district municipalities, and both the service and maintenance of the networks is poor (Bernex, 2005).

As pointed out by Bernex et al. (2005), the quality of the water in the Huatanay River has considerably declined in recent years, since it contains an increasingly large load of contaminants, making the water unfit for any use. The first sign of this condition is its dark color and the odor it gives off, particularly in the afternoon. Mendívil Riveros et al. (2002) states that the main problems of the Huatanay River were flooding due to narrowing of the channel at various points in the city and pollution caused by the dumping of untreated sewage, reflected in the high number of fecal coliforms, and refuse thrown into the river.

Cusco's main supply source is the Huatanay River Basin, which is highly polluted due to the direct discharge of industrial and domestic sewage. In the middle and lower basin of the Huatanay River, water quality is poor, meaning that it must not be used for any purpose (CEC Guaman Poma de Ayala, 2004).

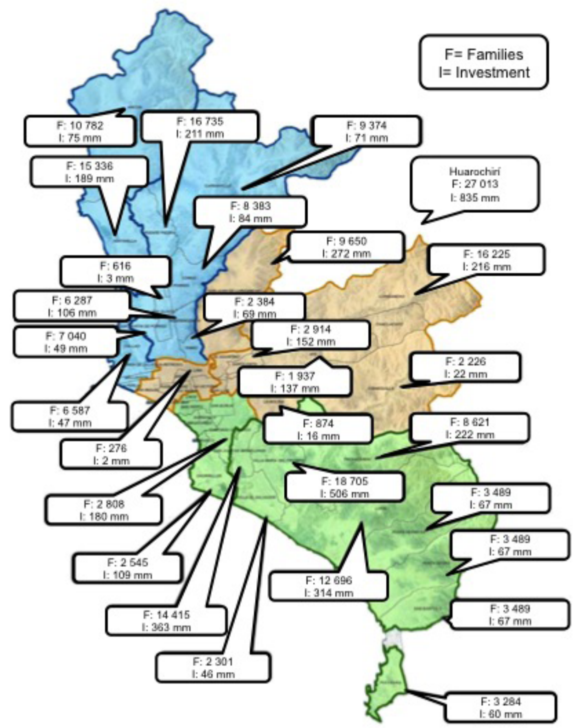
Figure 11. Water supply in a rural area on the outskirts of Lima (La Atarjea, 2012)

Photo: Julio Kuroiwa, 2013.

Figure 12. Urban Canyon formed by the degradation of the Rímac Riverbed downstream of Puente del Ejército

Source: Luis Castro Inga, 2010.

Figure 13. Projects to expand coverage to 100%



Source: Ismodes, 2013.

The company responsible for the water supply in the city of Cusco is SEDACUSCO, SA, whose board comprises the metropolitan mayor of the city of Cusco and district mayors. In February 2014, with a total investment of S/102 million, a modern Wastewater Treatment Plant (WWTP) was inaugurated to treat 80% of the waste produced by the Imperial City and the province of Cusco, benefiting 330,000 users. This plant will ensure the clean irrigation of vegetables and other crops. It was built using latest generation technology and includes a system for the total elimination of odors.

3.4 Potable Water and Sanitation in the City of Iquitos

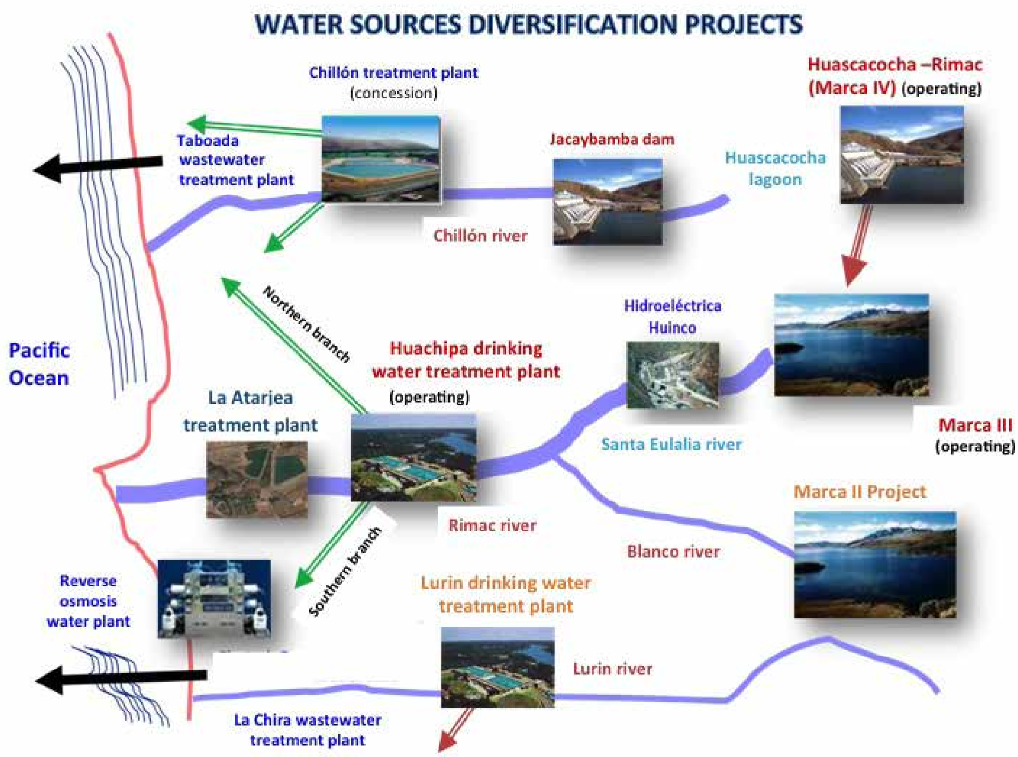
Iquitos, the Capital of the Peruvian Amazon, is located on the left bank of the Itaya River, a tributary of the Amazon River, at an altitude of 106 masl. It is a tropical area with an annual average rainfall of more than 2000 mm/year. Water for human consumption is captured in the Nanay River, a tributary of the Amazon River.

The local EPS is Sedaloreto, SA, which belongs to the municipality of Iquitos. Its functions include the acquisition, production and distribution of drinking water; sewage collection and disposal; and sanitary excreta disposal.

The district of Belén is located on the left bank of the Itaya River. Two-storey wooden houses have been built on wooden stilts above maximum flood levels. During the rainy season, the inhabitants of these houses only occupy the top level.

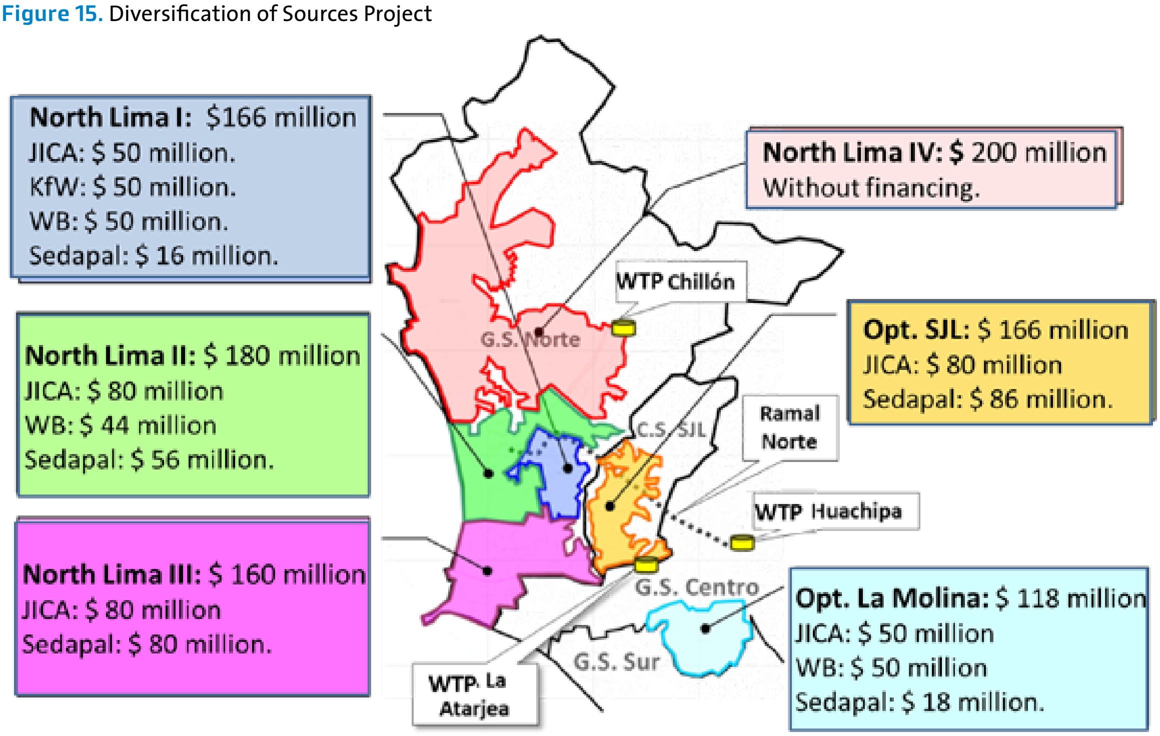
However, sewage disposal is complicated by the restrictions of the location. Domestic sewage is discharged untreated from every home into the Itaya River, which contaminates this important waterway. The sanitation deficit for a population of 41,000 inhabitants occupying 7,827 households was 73.8% in urban areas in 2007 (INEI, 2010).

Figure 14. Rehabilitation Projects



Source: Ismodes, 2013.

Figure 15. Diversification of Sources Project



Source: Ismodes, 2013.

Table 12. Major problems in SEDAPAL, 2013

- SEDAPAL
  - Regular activity
    - Water sources
      - Water storage: 300 MMC
      - Insufficiently managed aquifer
      - A heavy dependence in river Rimac
    - Waterpipes to WTPs
      - The Rimac River is treated as a drain
      - Inefficient irrigated Agriculture in the river bed
      - In summer water is lost at sea
    - Water treatment
      - Atarjea needs complete maintenance
      - Chillon WTP operates seasonally
      - Huachipa WTP is underused
    - Water distribution
      - Old water supply network
      - Brazen theft of water
      - Lack of sectorization and automation
      - Poor customer service
      - No payment of wells users
      - SIAC needs important improvements
      - Lack of control of SEDAPAL
    - Wastewater collection
      - Old sewage system
      - Silting of the sewage system
      - Illegal connections
      - Insufficient collection
      - Discharges without pretreatment
    - Water treatment in WWTPs
      - Plants in poor condition
      - Plants don't work efficiently
      - Insufficient plants
    - Water treated delivery in the environment
      - Water is treated in primary treatment
      - Water is sent to sea
      - Sludge and treated wastewater are not traded
  - Extension of coverage
    - New residential areas
      - Lack of coordination with the construction companies
    - Extension in areas with services
      - Disorder
      - Reactives Feasibility
    - Extension to population not served
      - Disorganization and disorder
      - Prioritization criteria have been political
      - Questionable high costs
      - Questionable adjudicatory procedures
      - Broken promises
      - Deceived residents blame to SEDAPAL
      - Manipulated settler
      - Leaders with varied interests
      - Superimposing leaders

Source: Ismodes, 2013.

The Japanese International Cooperation Agency (JICA) has helped improve sanitation services in Iquitos. In August 2010, work began on the "Expansion and Improvement of the Water System in the city of Iquitos" and "Improvement and Extension of the Sewerage System and Installation of Plant Wastewater Treatment for the City of Iquitos" projects. Expected investment totaled $210 million USD with an estimated 50,000 beneficiaries. The goal was for 80% of the population of Iquitos to have access to water for 20 hours a day with average consumption of 180 l/inhab/day (JICA, 2010).

3.5 Water Treatment and Reuse

Current information on municipal wastewater production at the national level corresponds to the production of domestic or municipal wastewater, reported by the EPSs. The average annual volume of domestic wastewater at the national level (2009-2011) is 798,539,655 m^3, of which only 260,916,866 m^3 are treated. Figure 18 details current wastewater management levels in RMLC.

In 2010, 428 million cubic meters of wastewater, equivalent to 80.4% of the total, were discharged untreated. Contaminated water flowed directly into the Pacific Ocean through two collectors or into the Rímac River, which eventually carried the effluents into the ocean, contaminating the coastline. Two collectors were used to transport wastewater to the sea: Costanera (2.26 mm^3/s) and La Chira (8 m^3/s). The Spanish company ACS Servicios, Comunicaciones y Energía recently completed construction of the Taboada Wastewater Treatment Plant, which is beginning to operate. The projected average capacity for this plant is about 14 m^3/s (equivalent to 442 MCM/yr) with peak flows of 20.3 m^3/s. This flow represents 72% of the total drainage flow. Moreover, construction of the La Chira Wastewater plant began in June 2013 (El Comercio, 2013). The projected average capacity of this plant is 6.3 m^3/s with a peak capacity of 11.3 m^3/s by the time construction is completed in January 2015. By early 2015, potable water, sewerage and wastewater treatment coverage is expected to reach 100% in RMLC.

Due to the low percentage of treated wastewater, the Ministry of Housing, Construction and Sanitation approved the "National Sanitation Plan 2006-2015," which envisages that 100% coverage for domestic effluents will be achieved by 2015. Moreover, Policy Guidelines are being implemented by a multisectoral committee to promote treatment for the re-use of domestic and municipal wastewater in the irrigation of urban and peri-urban green areas.

Despite this difficult situation, there have been success stories. Thus, in 1966, the Colegio de la Inmaculada, founded in 1878 and belonging to the Catholic religious congregation of the Society of Jesus, was forced to move, driven by the growth of Lima, to the south, to an arid, untilled area. In 1995, it was decided to develop the Ecological Project, which includes wastewater treatment with oxidation ponds to solve the problem of water for the irrigation of gardens and sports fields, and reduce maintenance costs for the 30 hectares of the school grounds.

Figure 16. Discharge of cuttings into the Huatanay (San Juan de Dios, San Jerónimo, Cusco)

Photo: Guamán Poma de Ayala Center, 2005.

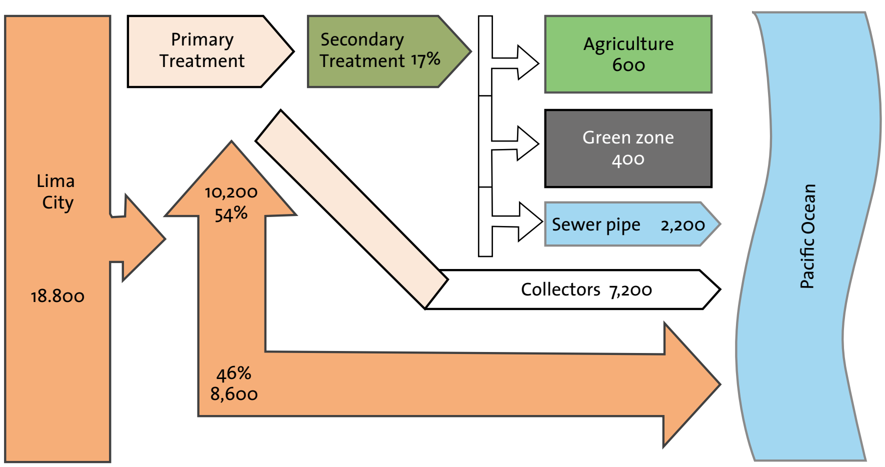
Figure 17. Iquitos, sewers in the neighborhood of Belén

Photo: Nicole Bernex, 2013.

The mechanism by which this recycling system operates is simple yet effective: wastewater is collected in the early morning hours from the Santiago de Surco drain; passed through a grid system that filters it, capturing solid waste; and subsequently transferred to the oxidation ponds built on the slope of the hill adjacent to the school. When they reach the ponds, bacteria (fungi, protozoa) from the wastewater interact with millions of microalgae, which produces oxygen (oxidation), which, when it dissolved in the water, activates the bacteria, breaking up all the organic matter. This disintegration produces carbon dioxide and inorganic matter, elements required for microalgae to produce carbohydrates. The cycle is thus completed through a series of transformations, where matter from the animal kingdom decomposes and enters the plant kingdom. This enables water of the required purity for use in the irrigation of the school's gardens and sports grounds to be released on a daily basis.

The main advantage is that students learn first-hand that it is possible to turn the desert into forest. In addition to saving the community potable water, the project helps reduce the amount of wastewater flowing into the sea. It also achieves significant monetary savings. As part of this project, there is also a zoo nursery, reforestation programs and worm farming complemented by solid waste management in the school and the sale of part of the agricultural production at a small vegetable store on the school grounds (cf. www.ci.edu.pe).

Figure 18. Current wastewater management in Metropolitan Lima (l/s)



Source: Julio Moscoso Cavallini, 2011.

Figures 19 and 20. Oxidation ponds and green areas irrigated with treated water from the Colegio de la Inmaculada, Lima

Photos: Fernando Roca, 2013.

4. Waterborne Diseases

The diseases caused by contaminated water not only affect public health, but are also associated with a loss of revenue due to lower productivity and absenteeism. Improvements in access to clean water and sanitation are cost effective. It is estimated that in developing regions, for every $1 USD invested in water and sanitation, between $5 and $46 USD are earned. Drinking water and sanitation are also related to the right to education. Being unable to exercise the "right of access to drinking water" may prevent children from going to school and force women to travel great distances, often several times a day, to fetch water for their families. The main diseases caused by the ingestion of water contaminated with human/animal waste containing pathogenic microorganisms or water contaminated with chemicals" are infectious, toxic and indirectly related (Table 13).

The National Institute of Statistics and Informatics of Peru (INEI) (2009) found a link between lack of potable water and sewerage and infant mortality rates. The infant mortality rate is 15.2 per thousand births in cases where households have water services provided by the public network, and 24.3 per thousand births when the source is different. Similar results were found when sewerage was analyzed. The mortality rate is 13.2 deaths per thousand births when the service is provided by the public network. Mortality increases to 24.3 per thousand births when there is no public network service (Table 14).

5. Water and Fire

Urban anthropogenic fires are common in all cities, particularly in Lima. They are caused mainly, "by faulty electrical installations, gas leaks, improper handling of flammable materials, lit candles and poorly maintained gas tank containers, among other factors." (INDECI, 2013).

Figure 21 shows a significant increase in the number of urban fires recorded nationwide by the Peruvian National Institute of Civil Defense (INDECI) from 1995 to 2002. The upward trend started in 2000, 2005 being the year with the highest number, with

Table 13. Classification of waterborne diseases

Photos: Fernando Roca, 2013.	Description	Examples
Water-borne	Fecal contamination	Cholera, typhoid bacillus and , enteric pathogens
Water-based	Organisms that spend a portion of their life cycles in water	Paragonimosis and Fasciolosis
Water-related	Vectors that reproduce in water	Malaria, Dengue fever
Water-washed	Associated with poor personal hygiene and contact with polluted water	Scabies, rickets
Water-dispersed	Organisms that proliferate inwater and enter via the respiratory tract	Legionella

Source: Cabezas, 2013.

Table 14. Relationship between infant mortality rate and type of service

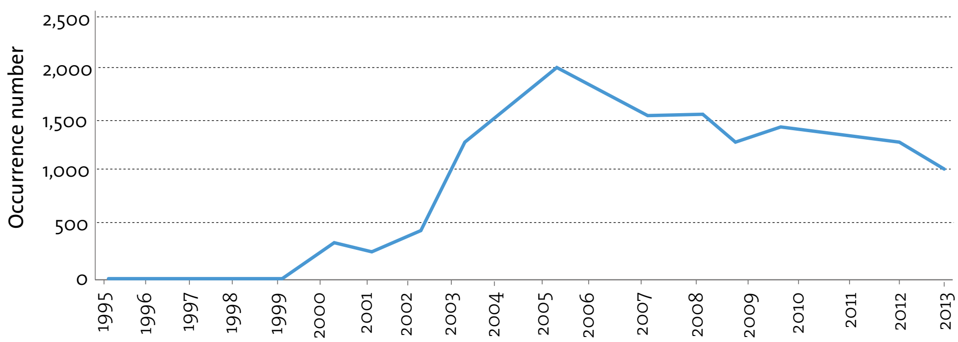
Parameter	Women of childbearing age	Percentage (%)	Infant mortality rate (perthousand)
Water supply			
Public network	5,159,230	68.2	15.2
Other	2,405,554	31.8	24.3
Sewerage			
Public network	4,893,925	64.7	13.2
Other	2,671,859	35.3	24.3

Source: INEI, 2009.

1,962 cases. The number of urban fires rose from 73 in 1995 to 1048 in 2013, an increase of 1,435%

A key factor in dealing with fires is the availability of water resources, which prevents fire from spreading to adjacent areas. To control everyday fires, firefighters face a number of difficulties, including the lack of hydrants, the distance from which they are located from the emergency area and in the event that hydrants exist, their inoperability (Espacio 360, 2013). In Lima and Callao there are 17, 010 hydrants, not enough to cover emergencies around the Lima area. The city has spread, occupying areas regarded as unsuitable for habitation, such as hillsides. Major changes in land use have occurred; while markets, commercial, industrial and service areas have multiplied. All these areas are vulnerable to accidents. It is important to recall the 29 people killed in a fire at the Utopia nightclub located in the elegant Jockey Plaza mall in 2001 and the 277 people killed and 180 missing in Mesa Redonda, an informal and precarious market in downtown Lima. In most cases, firemen's work is hampered by the lack of hydrants as well as difficulty of access due to overcrowding in the area. It is also important to underline the lack of operationality of existing hydrants, whose maintenance should be ensured by SEDAPAL. The Peruvian General Voluntary Firemen's Corp of Peru files a report whenever it detects a hydrant in disrepair. Despite firefighters' continuous reports, the state agency "does not keep a detailed record of how many hydrants have been reported as faulty or in poor condition." (Espacio 360, 2013).

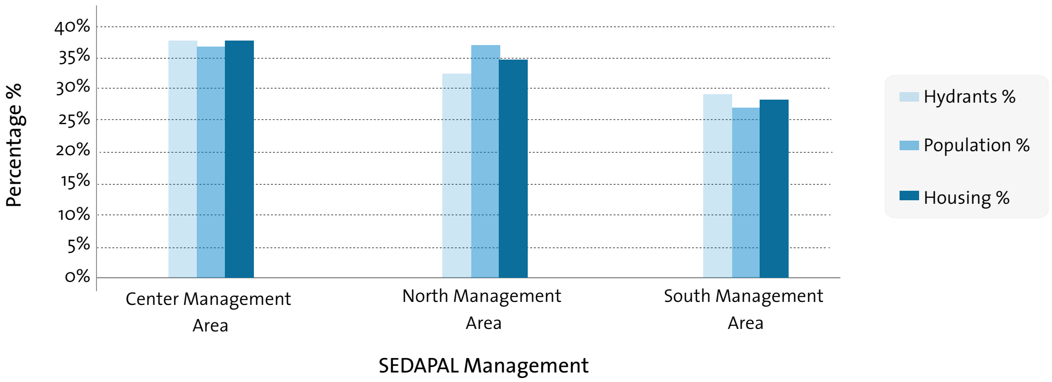
Figure 21. Time evolution in the occurrence of urban fires nationwide for the period from 1995 to 2013



*Preliminary figures

Sources: 1995–2002: INDECI, 2003, 265 pp.; 2003–2013: INDECI, Cuadros Estadísticos, Time series of national emergencies by phenomenon <http://www.indeci.gob.pe/objetos/secciones/MTM=/NTM=/lista/NDc0/201403041217091.pdf>

Figure 22. Comparison of percentages of hydrants, population and housing among the three SEDAPAL departments in Metropolitan Lima and Callao



Source: Compiled by the author.

In addition to technical problems, SEDAPAL and firefighters must address another problem related to hydrants, associated with social issues. Parts are stolen and sometimes misused. This is the most serious problem facing SEDAPAL, according to the company's Research and Development manager Juan Carlos Barandiarán Rojas. For example, "In the Cercado de Lima area alone, between January and December of last year [2012], they found 13 hydrants that had been tampered with by criminals and water thieves." This situation is repeated in districts such as Brena, Pueblo Libre, Magdalena, Ate and San Miguel (Correo 2013). This issue is more about responsibility and respect for firefighters' work as well as education and awareness about what hydrants represent in fire control.

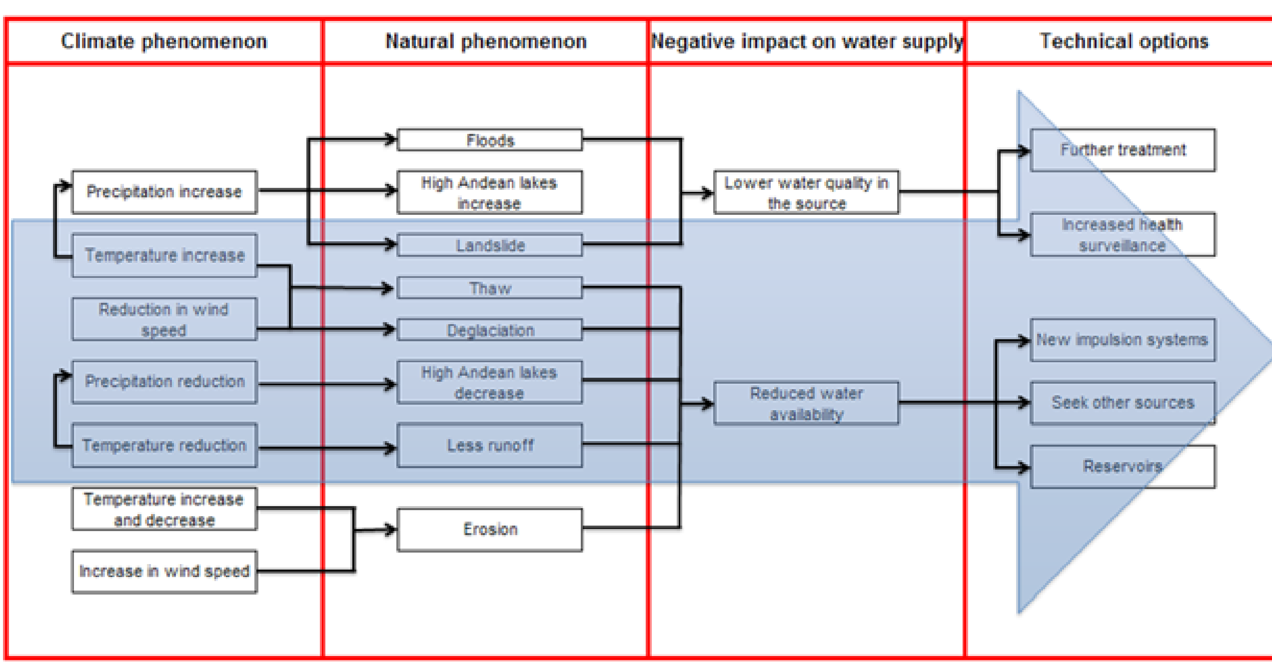
SEDAPAL attempts to meet these challenges and has therefore developed a mobile app for smartphone to reduce the time it takes for firemen's units to find the faucet closest to where a fire is taking place. This tool enables to find firefighters to quickly locate hydrants within a 500-meter radius in real time. The two institutions now also have better communication , allowing them to be simultaneously aware of a state of emergency (El Comercio, 2013) and to instruct SEDAPAL to open the main pipes (Mail, 2013). There is a recurring problem of fires in houses built from rustic materials such as wood, mats, plastic and straw, which are highly flammable. It is also common for parents going off to work to leave their children alone in these dwellings, with the door locked. In the event of a fire, some manage to survive, albeit with wounds and burns while others die. Firefighters often have to deal with fires in precarious human settlements, some of which do not have access roads, hampering the entry of fire units. Nor are there any water distribution services, essential for fire fighting.

Figure 22 shows the comparative advantages of the three departments in RMLC . The Southern Region (the oldest, best consolidated part of Lima) undoubtedly has more hydrants in relation to the others.

6. Climate Change and Urban Disaster Risks

Several studies mention global warming, which, due to the increase in greenhouse gases, is causing

Figure 23. Model of impact of climate change on water supply



Peru Urban Planners' Society, 2011.

the melting of glaciers in the tropical Andes and reducing the flow of rivers of glacial origin. This reduces the availability of fresh water, the main source for the consumption of the population, farming and hydropower generation, among other uses, and produces water scarcity. This shortage is exacerbated by rapid population growth, creating a social crisis (Lagos, 2013;. Magrin et al., 2007; MINAM, 2010; Sadoff et al., 2010).

The study on the vulnerability of cities to climate change as regards drinking water and sanitation, conducted by the Peruvian Society of Planners in 2011, pays particular attention to the vulnerability of Service Providing Companies (EPS), in a country with enormous contrasts and significant heterogeneity as regards the effects of climate change (Figure 23). The occurrence of natural phenomena has a negative impact on the water supply, reflected in i) Water of poorer quality at the source, and ii) Lower water availability.

According to SUNARP's analysis and weighting, the three EPSs most vulnerable to climate change in Peru are Chavin EPS, the EPSs of Utcubamba and Bagua Grande (EPSSMU SRL) and Chiclayo (EPSEL).

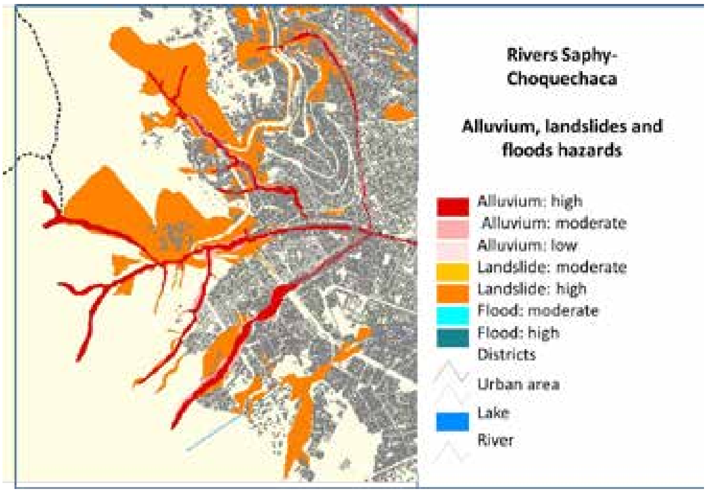
Ice in the Cordillera Blanca will probably disappear in the short term. That means that over the next three to 15 years, drastic climatic changes may take place that will endanger drinking water. Water networks are also vulnerable to extreme events, landslides and floods.

This is borne out by the following three examples. They involve the case of Cusco in response to exceptional rainfall, as in February 2010, when rains caused losses of 680 million soles and affected more than 35,000 residents; the case of Chicón, a dangerous glacier that threatens the resort town of Urubamba; and the case of Iquitos during the great flood of 2012.

6.1. Cusco, the City and its Risks

Located in the upper reaches of the River Huatanay in the southeastern Andes of Peru, 3,399 meters above sea level, the city of Cusco, the Archeological Capital of America, is the seventh largest city in the country with 420,137 inhabitants in 2014. Continuous migrations from the countryside has created a periphery of slums, many of which are located in areas of geological risk. Likewise,

Figure 24. Map of geotechnical risks in the Southwest Sector of Cusco



Source: Carlotto, Víctor et al., 2010.

riverbanks and streambeds were occupied, without considering the periods of maximum rainfall that might affect them. Consequently, rapid population growth and the consequent urban expansion have increased exposure to danger, resulting in annual disasters in the rainy season, especially in 2010, due to the heaviest rains in the past 50 years.

The city of Cusco and the valley of Huatanay are subject to a number of external geodynamic processes, where water plays a major role. This is compounded by other factors such as the existence of plains or terraces, steep slopes, and a varied lithological composition. These conditions coupled with urban explosion, show a city at risk of geodynamics, with floods, landslides and mudslides.

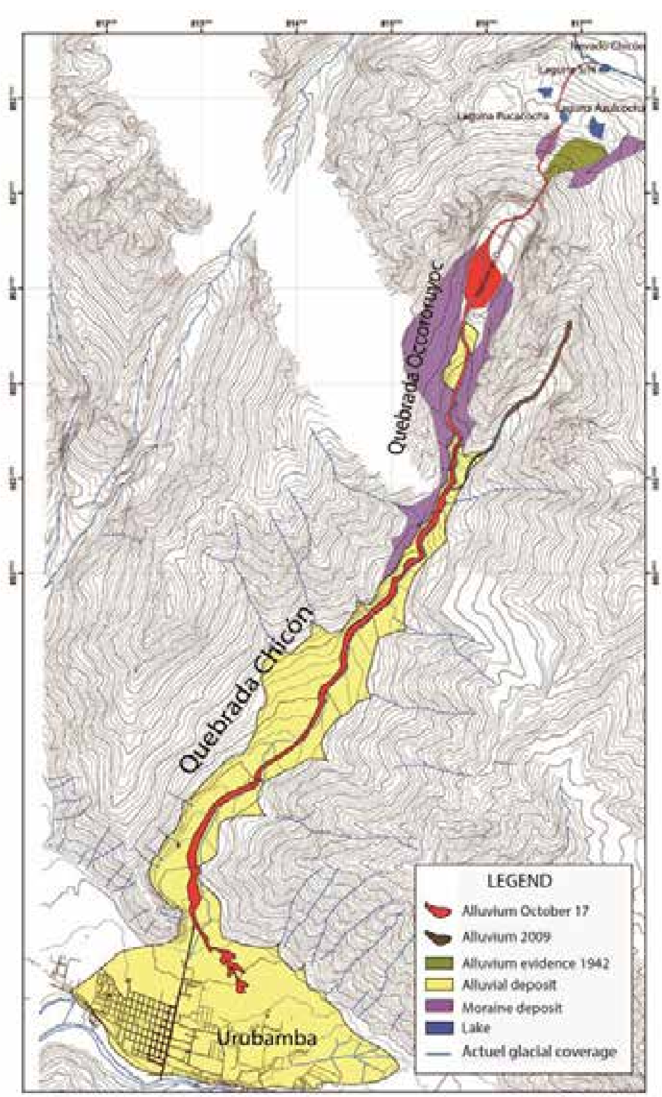
For example, due to heavy rains, landslides are reactivated or new ones are created, especially where land is of poor quality. These landslides may in turn result in the damming of stream beds and therefore silting, as happened in Huamancharpa, and the Saphy stream, which poses a great danger to the historic city center.

In response to an explosive urban sprawl, characterized by the occupation of areas with unstable slopes and ravines and river banks at risk of floods, mudslides and landslides, the Association of Municipalities and the Guamán Poma de Ayala Center developed a hazard map to improve risk management (Figure 24).

6.2 Dangerous Glaciers and Cities, the Case of the Nevado de Chicón and the City of Urubamba

At the heart of the Sacred Valley of the Incas, 2,900 masl, the city of Urubamba, with 10,741 inhabitants (2014), is located in the middle of several archaeological sites (Machu Picchu, Pisac, Moray, Cusco) and the snow-capped Chicón mountain. It enjoys an exceptional climate and landscapes, which, together with its location, makes it one of the most attractive cities in the country and a major tourist hub.

Figure 25. Alluvial events that affected the town of Urubamba (during the red mudslide of October 17, 2010)



Source: Carlotto, 2010.

The town of Urubamba is located on the right bank of the Vilcanota River, built on two alluvial cones of the Chicón and Pumahuanca streams. The Urubamba River valley separates the highlands to the south of the mountain range located in the north. The snow-capped mountain Chicón is located in this mountain range, with altitudes of over 5,300 meters. This mountain is the source of two major streams, the Chicón and the Pumahuanca, where there have been numerous landslides, while alluvial cones have been formed at the point where they flow into the Vilcanota River. Historical records shows that the Palace of Wayna Capac, encompassing the complex of the agricultural platforms of Quespihuanca, is built on these old alluvial deposits in the alluvial cone of Chicón. On the other hand, old alluvial deposits from the adjacent Pumahuanca stream cover the material that slid off Yahuarmaqui Hill, which dammed the Vilcanota River in 1678. In recent times, mudslides occurred in the Chicón gorge in 1942 and 2010.

The Chicón mountain is about five kilometers long in a NW-SE direction, with an average width of less than one kilometer. This mountain shows strong evidence of glacial retreat -at least since 1963- with an average of 20 to 25 m in 10 years, although in recent years this has been nearly 50 m. Glacial retreat is accompanied by the detachment of ice blocks from the edges of the mountain. When the blocks fall into nearby lagoons, they cause floods and mudslides such as the one that occurred in1942 and on October 17, 2010, which affected the city of Urubamba. Although the 1942 flood was large in comparison with the one in 2010, in both cases over 80% of the silt was trapped in a bucket or natural depression known as Occororuyoc Plain and only a minor part reached the city. In 2010, it affected approximately 300 dwellings, flooded farmland and affected over 1,200 people.

Driven by climate change, the retreat of the snow-capped mountain of Chicón produces overflows, leading in turn to mudslides. Due to the topography, they are cushioned downstream by the Occororuyoc depression, which traps the silt, prevents catastrophes and makes Urubamba a city with a low to medium risk of mudslides of glacial origin. However, a major earthquake could cause a large mass of ice to break off and produce more alluvium. Glaciers should therefore be monitored and early warning systems established as priority measures, while the Chicón River should be broadened in the section passing through the city (Figure 25).

6.3 Flooding in the City of Iquitos, 2012

The capital of the Peruvian Amazon, with 432,476 inhabitants (2014), Iquitos lies between the Nanay, Itaya and Amazon rivers and follows the rhythm of fluvial dynamics (Tuukki et al., 1996). On March 12, 2012 the level of the Amazon River exceeded 117 masl, and was declared a Hydrological Red Alert by the National Meteorology and Hydrology Service (SENAMHI). During the third week of March, floods in the city of Iquitos exceeded expected levels. On April 5, the Amazon River broke its previous record by 4 cm, reaching 118.62 masl. Substantial damage was caused by the exceptional rainfall and subsequent flooding.

The number of cases of acute respiratory infections, acute diarrheal diseases, febrile syndrome, parasitosis, leptospirosis increased, continuing even as the flood waters began to subside. Until the 36th epidemiological week, five deaths and 18,206 cases of the following diseases had been reported: 15,537 (85.34%) vivax, 2,666 (14.64%) falciparum, 1 (0.01%) malaria and 1 (0.01%) mixed. A total of 9,974 more cases were recorded than during the same period in 2011, equivalent to an increase of 121.2% (PAHO/WHO, 2013).

Figure 26. Iquitos underwater, April 2012

Source: http://cde.elcomercio.pe/66/ima/0/0/4/6/7/467607.jpg

Likewise, according to the April 24, 2012 report by the National Superintendence of Sanitation Services (SUNASS), the following was observed in the city of Iquitos:

- Water shortages in some of the districts of Punchana and San Juan Bautista.
- Floods due to the sharp rise in river levels in the city of Iquitos, which affected 45,262 inhabitants in Belén, San Juan and Punchana.
- Suspension of the water supply in peripheral areas affected by the floods to prevent contamination of the system in the rest of the city.
- 9,410 connections affected (15.81% of total).
- Collapse of 3,858 or 10.18% of domestic sewerage connections.
- Impact on water and sewerage network improvement works.

7. Conclusions and Recommendations

Although the institutional framework of the sector is fairly well established, since it clearly distinguishes between the importance of designing policies for service regulation and delivery,[1] it has yet to deal with the problem of weak coordination between the authorities at the central level, and between these and other levels of government as well as certain gaps (Marmanillo, 2006). Conventional water management in urban areas has failed to address the key challenges of RMLC and large, medium and small cities. Generally speaking, water supply, sanitation and stormwater management has not been undertaken in a coordinated manner. Neither town planning nor urban development have managed to integrate the various infrastructure components of urban water management (water supply, wastewater, dry sanitation, storm drain and solid waste systems) (Tucci, 2010).

Thus, an Integrated Urban Water Management System (GIAU) that encompasses all water sources within the urban catchment area (surface water, ground water, storm water, desalinated water, transferred water and virtual water) must be developed. The GIAU should include plans for matching water supplies of different qualities with water uses based upon the qualities needed serve those uses. In developing the plans it will be essential to treat the elements of storage, distribution, treatment, recycling and disposal in an integrated fashion and as part of the water cycle rather than as separate and independent elements. Plans should include measures to protect and conserve water at the source. Effective governance that includes meaningful stakeholder participation will also contribute to the sustainability of water management regimes and to water security. Integrated Urban Water Management has become an issue on the political agenda that can no longer be postpone. It requires institutional strengthening, continuity in processes, sectoral and transdisciplinary vision and well-trained human resources combined with responsible participation.

In this respect, a process of water culture must be implemented at schools, colleges and universities. These studies centers are places where one not only learns how to use, reuse and recycle water but also the benefits they entail for the community. Lastly, all cities, where peripheries of poverty grow and gaps are accentuated between those with and without access to services, and which thrive on ecosystems, fields and natural areas, urgently need to make their inhabitants aware of the new water culture, which requires building a new foundation based on a change in the scale of values, incorporating the value of the other and all the others, the value of otherness, of ecosystems and the value of life since the culture of water is the culture of life itself.

1. The first group are assigned to the Ministry of Housing, Construction and Sanitation (MVCS); the second to the (SUNASS) regulating body; and third to the EPS, municipalities and/or user boards.

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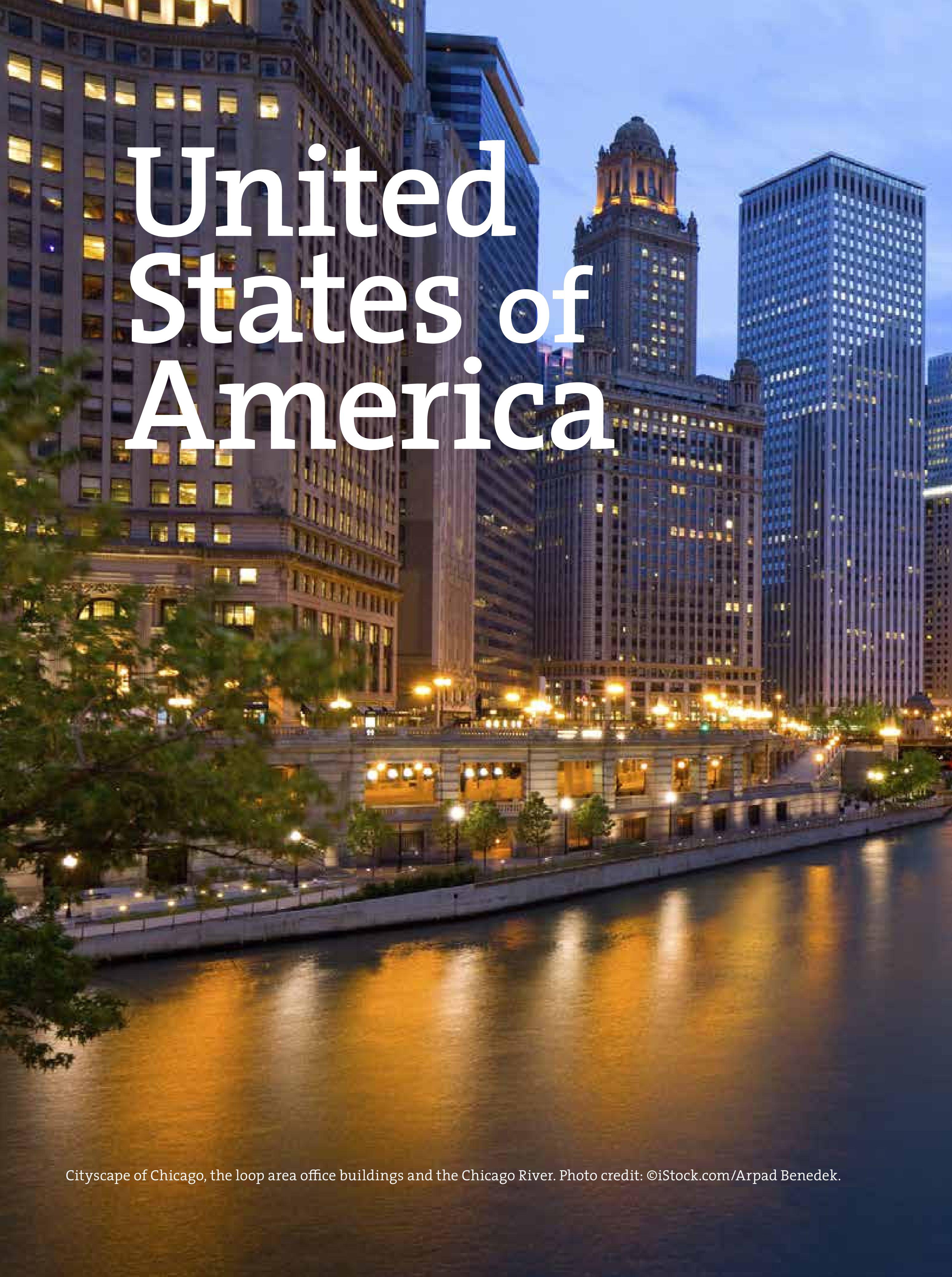
9. Acronyms

ANA:	National Water Authority
ANC:	National Academy of Sciences of Peru
BOT:	Build, Operation, Transfer
CIGA-PUCP:	Center for Research in Applied Geography at the Pontificia Universidad Católica del Perú
EPS:	Services Provider Company
GWP:	Global Water Partnership
IANAS:	InterAmerican Network of Academies of Sciences
IMP:	Metropolitan Planning Institute
INDECI:	National Institute of Civil Defense
INEI:	National Institute of Statistics and Informatics
INS:	National Institute of Health
JICA:	Japan International Cooperation Agency.
MINAM:	Ministry of Environment
MINSA:	Ministry of Health
MML:	Metropolitan Municipality of Lima
WHO:	World Health Organization
PAHO:	Pan American Health Organization
PTAR:	Wastewater Treatment Plant
RC:	Callao Region
RML:	Metropolitan Lima Region
RMLC:	Lima-Callao Metropolitan Region
SEDAPAL:	Lima Potable Water and Sewerage Service
SENAMHI:	National Meteorology and Hydrology Service
SUNARP:	National Public Records Superintendence
SUNASS:	National Sanitation Services Superintendence

United States of America



Cityscape of Chicago, the loop area office buildings and the Chicago River. Photo credit: ©iStock.com/Arpad Benedek.

"In the United States urban water supplies are adequate and water borne illness is rare. Yet, the problems of deferred maintenance, the need for future renewal, deteriorating water quality and intensifying water scarcity, if left unmanaged, will make additional water supplies hard to obtain and contribute to the deterioration of quality in existing supplies. These problems can be effectively addressed with a combination of demand management policies and the use of new and innovative technology. Wastewater recycling and desalination will like become more common. Solutions will be costly, however, and the political will to bear those costs will have to be developed through enlightened leadership"

An Overview of Urban Water Management and Ploblems in the U.S.A.

Henry Vaux, Jr.

Summary

The urban water problems of the United States are problems of maintenance and renewal of water systems, continuing deterioration of source water quality and water scarcity which impedes the development of new supplies to support urban growth. These problems are technological, institutional and political. There is a clear need to invest in the maintenance and upgrading of urban water facilities but the political will to bear the necessary costs of doing so is absent. Although current water supplies are largely adequate and waterborne illness is quite rare, the U.S. is a good example of the "water paradox of developed nations" because without substantial new, innovative and costly efforts its urban water supply systems will be in jeopardy. There are a number of ways in which the problems can be addressed. Demand management strategies include actions to manage water consumption more carefully, reduce wastage and maintain levels of reliability. Some of the elements of demand management strategies are water rationing, education, pricing and the development of water marketing arrangements thru which additional supplies might be acquired. Pricing reform will be particularly important because current pricing practices cover only a fraction of the true cost of the water which includes the scarcity value of water, treatment costs, and transport and disposal costs. The intensifying competition for public funds makes it unlikely that they would be as readily available as they were in the past to support these activities. Another general category of actions to address the problems of scarcity involves the use of technology and other supply augmentation strategies. Waste water recycling is attractive in certain situations where water quality regulations require that any wastewater discharged be treated to a high level of quality. However, the technology needed to upgrade qualitatively degraded water supplies is expensive and wastewater recycling is usually attractive only in instances where the costs of alternative sources

of supply are quite high. Desalination is another potentially attractive technology but the costs are quite high; the technology is energy intensive; and, it can lead to environmental problems which may themselves be costly to mitigate. Policy reforms to promote demand management strategies appear to be the least costly way to address urban water problems and induce water conservation which is demonstrably the cheapest way to augment supplies. Where demand management policies are insufficient the adoption of new technology and other supply augmenting strategies maybe helpful despite the fact that they are bound to be very costly.

1. Introduction

An overview of urban water management and the problems which urban water mangers face in the United States suggests that the general water picture could be characterized as "post modern." Virtually the entire urban population of the United States has access to generous supplies of healthful, clean water and access to good sanitation facilities. Although waterborne disease occurs occasionally, it is very much the exception. Yet, the problems faced by urban water managers throughout the country are in many ways as daunting as those faced by countries that must address problems of inadequate water supply and sanitation services. Although existing supplies for most urban areas in the U.S. are more than adequate the availability of new supplies to support urban growth is problematical in many regions as general water scarcity intensifies. The quality of urban water supplies is also threatened by the continuing emergence of new chemical contaminants and biological agents associated with the development of new industrial processes and products. Additional threats to the availability and quality of water supplies and sanitation services are posed by an aging water service infrastructure. Despite the age of the nation's water infrastructure, little investment or provision is being made to renew and update it.

The urban water situation of the United States thus stands in contrast to the situation in much of the rest of the Americas. The problems faced by the U.S. are problems of maintenance and renewal of water systems, continuing deterioration of source water quality and water scarcity which is particularly prevalent in regions where urban growth tends to be concentrated. These problems are both technological and institutional and if they are to be solved research, political will and public resources will need to be available in significant quantities. It is somewhat ironic that the problems fit into the same categories as those of developing countries: infrastructure, lack of government commitment, inadequate financial support, a need for effective institutions including regulatory institutions and the need for improved and updated technology.

The remainder of this chapter is organized in four sections. First, the general urban water supply situation in the U.S. is described. Second, the problems of water scarcity and the available solutions are described, discussed and evaluated. Third, potential solutions to the problems of maintaining and protecting urban water supplies and sanitation serves are reviewed and analyzed. The final sections contain some concluding remarks and recommendations for action.

2. Urban Water Supplies and Sanitation Services in the U.S.: an Overview

In 2005, the latest year for which comprehensive water statistics are available, withdrawals for urban water use totaled approximately 61.1 X 109 m^3/year in the United States. Of this total, two thirds came from surface water supplies with an additional one-third contributed by ground water. Urban water uses accounted for approximately 21.1% of withdrawals for consumptive uses in the U.S. in 2005. The comparable figure for 1950 was only 9.7%. The growth in urban uses after 1950 was accounted for by increases in population, which doubled, and increases in per capita use, which grew by a little less than 50%. Growth in per capita consumption was accounted for largely by increased water use for irrigation of landscaping, largely in the arid climates of the western U.S. (Kenny, et al., 2009). Despite the growth in population and in per capita rates of usage most urban areas have had generous supplies of high quality water for domestic purposes.

The explanation lies with the high levels of public and private investment in water storage and distribution facilities that prevailed during most of the twentieth century. Graf (1999) shows, for example, that reservoir storage capacity increased nearly one-hundred fold over the course of the century. Currently, very few water storage and supply projects are under construction and/or contemplated. There are several reasons for this. First, most of the good storage sites have already been developed and those that remain tend to be expensive and difficult to develop or remote from places of use. Second, water projects now have to compete with multitude of other public services for financing. This was not the case throughout much of the twentieth century. Third, the costs of public works have risen disproportionately faster than the costs of other goods and services. This increase in relative expense has made has made them less appealing on economic and financial grounds. Thus, although the recent history of urban water provision seems an unqualified success, there are reasons to suspect that future circumstances will be very different and the provision of adequate supplies will be more complicated than simply developing and operating additional water storage and conveyance facilities.

In addition to the physical and financial difficulties of augmenting surface water storage, there are a host of other reasons for believing that the problem of obtaining additional water supplies to support urban growth may be far more difficult in the future than in the past. The first of these is a locational reason. Scarcity of naturally occurring water supplies is more acute in the arid and semi arid American West than it is in other parts of the nation. Yet most of the population of this area of the country is concentrated in urban areas. Moreover, these urban areas which include Los Angeles, Las Vegas, Phoenix, Denver and Salt Lake City are among the fastest growing in terms of population. Linked to the demographic growth are significantly growing demands for additional urban water supplies. The problem is compounded by the fact that existing water supplies are already fully allocated among a variety of uses under the prevailing systems of water rights. Indeed, the growth of urban water demands comes on top of the fact that water is physically scarce and the competition for available supplies is especially acute. It should also be noted that shortages are also occurring in the more humid eastern regions of the country both because of population growth and because of the unreliability of accustomed supplies (Feldman, 2007; Feldman, 2008).

The implications of climate change for the availability of urban water supplies in the U.S. are unclear. Increases in temperature will increase the environmental demand for water resulting in additional consumptive losses from both increased evaporation and transpiration. Possible changes in the timing of available supplies may also serve to reduce supplies de facto. Many western urban areas rely on melt from snowpack to see them through the warm summer and early fall seasons. The possibility of higher snowlines and earlier spring snowmelt could change the pattern of supply both by reducing accustomed supplies absolutely and by altering the timing of availability of water. Climate change is likely to have different effects in different regions and it is difficult to draw firm conclusions about possible impacts on any specific region or on the country as a whole. The predicted increase in extreme weather events is likely to have adverse impacts on water quality as well as on the availability of supplies (Bates et al., 2008).

Added to all of this is a serious infrastructure problem. Infrastructure for both water supply and sanitation is aging. In 2013 the American Society of Civil Engineers (2013) reported that the drinking water systems in the United States face an annual shortfall of $USD 11 billion to replace aging facilities and comply with current and future federal water regulations. The report also noted that the costs of treating and delivering drinking water are in excess of the funds available to sustain such systems. This concern extends not just projects which can be federally underwritten but also to local utilities which continue to have operating deficits. The current unwillingness of elected politicians to appropriate funds to replace and sustain both drinking water and sanitation infrastructure seems destined to create a situation in which the reliability of such systems in protecting public health and delivering critical public services will be increasingly in jeopardy (American Society of Civil Engineers, 2013).

The picture with respect to water quality is very much the same. During the twentieth century the quality of urban water supplies in the U.S.

was the equal of the any place in the world. In the early years, the advent of disinfection and other improved sanitary practices sharply reduced the incidence of water borne diseases such as cholera and typhoid. In the last half of the century those diseases were virtually eliminated as were other waterborne diseases and threats to public health from inadequate sanitary facilities and wastewater management. In the latter half of the century new protections were added in the form of the 1972 Federal Water Pollution Control Act Amendments – known as the Clean Water Act (P.L. 92-500, 33 USC 1151 et seq) and Safe Drinking Water Act of 1974 (P.L. 93-523) as amended.

Broadly stated, the Clean Water Act afforded protection to the quality of the nation's surface waters by stipulating the minimum levels of ambient quality of those waters that must be achieved and regulating through discharge permits the point source pollutants entering those waters. The Clean Water Act also provided significant funding support for the construction of public wastewater treatment facilities. Such facilities ensure that wastewater is treated to the secondary level or higher. On the other hand, the Safe Drinking Water Act regulated the quality of drinking water by stipulating the establishment of National Drinking Water Standards which are legally enforceable and to which all public water systems must comply. Under the provisions of this act some 91 contaminants including, chemical, biological and radiological contaminants, are regulated. The Act also provides for processes through which additional contaminants can be added to that list. These laws have served the nation well in protecting drinking water quality and in cleaning up and protecting the quality of the nation's surface waterways. Nevertheless, there are signs that the protection of general water quality as well as of drinking water quality may also be jeopardized in the future.

New potential contaminants appear in the environment almost every day. These come from industry, agricultural, pharmaceutical chemicals, coal mining and natural gas extraction. Following the provisions of the Safe Drinking Water Act these potential contaminants are listed on Contaminant Candidate List. Furthermore, the Act mandates research to assess the health risks associated with each contaminant. The research is intended to serve as the basis for deciding whether the contaminant should be regulated and, if so, at what levels. The Act requires a decision to regulate or not be made on at least five contaminants in each five year period. Venkataraman (2013) documents the fact that the number of contaminants on the Contaminant Candidate List is growing faster than the capacity of the Environmental Protection Agency to evaluate them. Thus, without additional funding, the backlog of contaminants awaiting decisions about regulatory action will continue to grow.

The picture that emerges is one in which existing processes for identifying and evaluating new contaminants are inadequately scaled and funded. There is also no way to control for the number of new contaminants that may emerge since that is a function of economic growth and innovation, the details of which are largely unregulated. Despite this fact and the facts surrounding the available quantities of water supply the public appears to be relatively unaware of the threats that they pose. Venkataraman (2013) reports the results of a number of polls show sharp declines in public concerns about the quality and availability of water supplies. He attributes this lack of awareness to the fact that threats to the availability and healthfulness of water supply are largely hidden from view. In addition, he notes that prices paid by consumers of water supplies and wastewater treatment service in the U.S. are very small, averaging in the U.S. just 0.3% of disposable income, leading to an outcome in which user costs cover only a small proportion of what is required to treat and deliver a safe water supply.

The urban water supply and sanitation situation in the United States provides a good example of the "The Water Paradox in Developed Nations" (Venkataraman, 2013). Historically, plentiful amounts of high quality water have been available at low cost in virtually every urban area. Similarly, technologically advanced wastewater treatments facilities have helped to ensure that the nation enjoyed full sanitation services which were the equal of any in the world. The quantity and quality of these services is now very much in jeopardy. Fundamental water scarcity, an aging water supply infrastructure and inadequate plans to replace and maintain it, public apathy and an apparent unwillingness of users to pay a significant portion of the capital and operating costs of such systems threatens the future adequacy of urban water supplies in a very real way. The proliferation of new chemical and biological (and radiological) contaminants threatens the quality of urban water supplies in the future. This is because current processes are inadequately scaled and funded to handle the sheer numbers of contaminant candidates which are growing annually. In addition, the aging of wastewater treatment and sanitation facilities coupled with inadequate funding for renewal and maintenance poses a threat to the quality of urban water supplies in the future. (See box on The Big California Drought).

3. Addressing the Problems of Water Scarcity: Managing Water Demand

Urban water users have only recently begun to confront the reality of intensifying water scarcity. While existing water supplies appear to be adequate to serve existing levels of population in most instances the forces of economic and population growth fuel demands for additional water supplies to serve growing populations and regional economies. In the face of these growing demands, supplies in many areas remain static or are in decline. The supply situation is rendered uncertain by the specter of global climate change and the consequences of such change for water supplies across the regions of the nation. Although water scarcity is present to some extent throughout the country, it is most intense in the arid and semi-arid western regions of the country where the extent of urbanization and the rates of growth are the highest in the nation. Historically, urban water supplies were extensively developed in the face of population growth by constructing dams and canals to capture and store water and transport it to the urban areas in question. The strategy of developing new supplies in this manner is no longer viable both because the costs have risen and because available supplies in most basins are fully appropriated and unencumbered water is unavailable. There are nevertheless a number of means to address urban water scarcity. These involve both supply augmentation and demand management strategies. Demand management strategies which include rationing, education, pricing and the creation of water markets will be considered first.

Rationing: Rationing is most commonly practiced in developing countries and in places where water is extremely scarce. Thus, for example, water supplies are rationed in Amman, Jordan which has very limited rainfall and limited ground water. Weekly water deliveries can be augmented by purchasing additional water but the fact that supplies are delivered in fixed quantities once a week has the effect of limiting use (Zou'bi, 2011). Rationing tends to be most effective in limiting outdoor uses and it is particularly well suited to the management of drought situations. Where water is delivered through a distribution system that is constantly active the enforcement of rationing schemes can be problematical since indoor uses of water are particularly difficult to regulate. Yet, as the example suggests rationing can be tailored to a variety of circumstances. Thus, it can be made to work in the longer run where available water is stored at the site of usage and it is the quantity of storage that is rationed. In addition, as the Jordanian example shows, the tendency for rationing to beget black markets can be countered by creating legitimate markets through which users can augment available supplies through purchase. It is obviously undesirable to employ rationing in circumstances where basic needs for drinking, cooking and sanitation maybe jeopardized.

Education: There is clear evidence showing that water use tends to decline when consumers know where their water comes from and how much they use. Further, evidence suggests that the more consumers know about the origin, nature, treatment and costs of the water on which they depend, the more careful they are in economizing on use. Bruvold (1988) shows that metropolitan water consumers in California who are well informed about all aspects of their water supply will economize on its use. The Bruvold analysis was extended to major communities in the western United States by Michelsen, et al (1999) with similar results.

In major metropolitan areas, utilities sometimes attempt to educate people about where water comes from, the impacts of drought, the quality of water supplies and the impacts of treatment and disinfecting systems. Such efforts may be only partly

The Big California Drought, 2011...?

Box 8

Beginning in 2011, California which is the largest state in terms of both population and economic activity, has been beset by one of the most severe droughts of modern times. The calendar year 2013 was the driest year in recorded history and early in 2014 the Governor declared a drought emergency. By August, 2014, nearly 100% of the area of the state was in the grips of a severe drought with 80% of that area classified as experiencing extreme drought. Extreme drought is defined as entailing major crop losses and widespread water shortages and water use restrictions. Residents and business in the state's major urban areas were subject to mandatory water rationing (San Francisco) and other types of water use restrictions. All state residents and business were subject to steep fines for wasting water and violating drought management regulations. Agriculture has been particularly hard hit with 2014 economic losses estimated to be USD$2.2 billion and job losses expected to top 17,000 (Howitt, et. al., 2014). Many rural communities were similarly hard hit with water supplies projected to last only for a few short months and emergency measures in place. Although water supplies available to major urban areas have been sharply curtailed the entire water system appears flexible enough to forestall extreme hardship for the foreseeable future. In the meantime, restrictions and regulations will require curtailed water use. This will entail more than simply inconvenience as urban damages from less than accustomed levels of water availability continue to mount.

While the drought is currently more prominent in the public eye, it differs fundamentally from the longer term urban water security problems that are the focus of this chapter. The difference between longer term water security and drought is the same as the difference between scarcity and shortage. Scarcity is a persistent phenomenon that must be managed over the longer term. Drought is usually a much shorter term phenomenon which must be managed with flexible and adaptive techniques that may not be effective in the longer run. Thus, rationing is frequently employed to manage drought and it is effective because it is broadly understood to be a short term measure. When used as a tool to manage demand over the longer run rationing risks the development of black markets and almost always implies that water itself is not persistently scarce. Urban water management organizations customarily address drought in advance by developing supplies systems that have very high degrees of reliability so they have the capacity to deliver water even when the physical resource is scarce. This tends to avoid extreme hardship during drought though it really does not address the longer term problems that constitute the "Paradox of Developed Nations."

In August, 1914 two large and widely publicized breaks in water mains within the City of Los Angeles starkly illustrated the need to attend to longer term problems of water security. The breaks caused millions of liters of water to spill into the street and flood some adjacent buildings. That this was precious water dearly needed in a time of drought was only a part of the story. The water distribution system in the City of Los Angeles is over 100 years old and has come close to the end of its physical life. Estimates of the costs of rehabilitation are in excess of USD$1.0 billion. It is unclear where this money is to be found and there is no transparent planning effort underway to address a problem that does pose a threat to future urban water security in Los Angeles. For the moment the physical drought is serving as a distraction from the longer term problem which may well be a man-made drought brought about by the neglect to focus on the longer term issues of urban water security in a major metropolitan area.

successful, however. Thus, for example , traditional methods of reporting water consumption tend to make it difficult for consumers to understand exactly what their use levels are. Frequently, use levels are reported on utility bills in terms of unspecified and undefined "billing units" These provide most consumers with no understanding whatsoever of how much they are using. Alternatively, when consumption is reported in terms of gallons per day or some similar and familiar measure consumers have a better understanding of consumption levels and tend to use less than fellow consumers who lack this information. Educational programs such as these are low cost and simple. They often lead to early reductions in water consumption that are characteristic when people first learn about their levels of usage. They are also helpful in facilitating response to drought conditions. This is particularly true when special pricing or rate rules are imposed during drought periods in an effort to reduce consumption. Consumer education is one of the least costly means of inducing economizing in water use (Michelsen et al, 1999).

Public education may be very important in responding to the general problem of water scarcity. While there is evidence of a decline in public concern about urban water availability and quality there are several recent polls that indicate that pollution of drinking water remains one of the top public concerns over environmental issues. Thus, the Xylem Value of Water Survey (2012) found that 9 in 10 respondents considered water an important service while the Circle of Blue (2009) survey found that more than three quarters of the respondents across nations believed that it is important that all people have access to save, affordable drinking water. This latter survey also found that a majority believed that the public needed more information to protect their water supplies. These results suggest that there is substantial public concern about water issues and that there is also substantial public receptivity to efforts to further education the public about the current array of water problems and potential solutions to those problems.

Pricing: The price of water for urban areas is virtually always based upon the costs of impounding, treating and delivering it. Frequently, even these costs are not fully reflected in the price of water (Note: in some instances the price of water includes a sewerage charge to cover part or all of the costs of wastewater treatment services.) . More significantly, the price of water virtually never includes a component of scarcity value. That is, the water itself has an implicit scarcity price of zero. Such a price signals that the commodity in question – water in this case – is freely available. Yet, the scarcity of water is a fundamental problem and in the face of such circumstances policies that suggest that water is widely and freely available are perverse. Additionally, policies which require inclusion of a scarcity value in the price of water virtually always induce conserving or economizing behavior by consumers thereby making additional water available to serve new users or alternative uses.

The price responsiveness of the demand for water has been clearly established. As the price of water increases the quantity of water demanded or used will decrease. The measure of this response is referred to as the price elasticity of demand. Typically, the demand for urban water is relatively more price inelastic than the demand for agricultural water. Inelasticity means that the impact on the quantity taken in percentage terms is less than the percentage increase (or decrease) in price. The evidence suggests, however, that by assigning even a modest scarcity value or scarcity price to water will likely result in modest reductions in water use (Hanemann, 1997; Schoengold et al, 2006).

Water can be priced administratively or through the unfettered interaction of the market forces of supply and demand. In the United States, water prices are typically established administratively. It would be a relatively straightforward matter to include a scarcity value or a proxy scarcity value in an administered price. The scarcity value could be inferred or estimated and would be an approximation of the true value. Water utilities and other purveyors typically establish water rates to reflect the average costs of capturing, treating and distributing the water. This is done to ensure that the costs which the utility faces – not including the scarcity cost or value – can be fully defrayed with available revenues. Clearly, it would be straightforward just to include in this rate an average scarcity value.

Simultaneously, it should be recognized that the use of average cost pricing has at least two shortcomings. In many circumstances today, the incremental cost or value of water is much higher than the average value. Thus, for example, the desalinated water which the San Diego Country Water Authority will acquire and which will account for 10% of its supply when fully developed may cost as much as four or five time more than the average cost of current supplies. However, when the cost of this water is averaged in with the cost of the other 90% of the supply that are much lower the price increase of this new supply will be very much less than its relatively high incremental cost (NRC, 2008). This lower rate signals consumers that the water is much more plentiful than it is in fact. It also requires existing users (and uses) to subsidize new users (and uses) because historical users see their bills rise to help defray the costs of the expensive new supply that is only needed because of new users who then end up paying less than the full costs of the new supplies which they require. Incremental costs are sometimes difficult to estimate but increasing block rates, which are frequently employed by electric utilities, can approximate incremental costs and provide incentives for economizing behavior that are very similar to that which would occur if actual incremental costs were used. Incremental pricing for urban water supplies results in more efficient water use in the urban sector. Efficient allocation means that water is devoted to its highest valued uses within the sector in question.

The scholarly literature suggests that appropriate pricing of water probably needs to be at least a part of any strategy for managing water scarcity (see, for example: Baumol and Oates, 1979). Prices that are approximately accurate send important information to consumers about the relative scarcity of water and induce economizing. The pricing system does not always work perfectly and hence there may be circumstances where a mixed strategy that includes pricing may be more appropriate. Prices have the advantage of restraining excessive and wasteful use of resources and this is an essential part of any effort to manage water scarcity (Baumol and Oates, 1979). This fact together with the fact that current water prices rarely cover more than a small fraction of the amount expended and almost never reflect the scarcity value of water make a compelling case for the employment of more enlightened water pricing policies in managing water scarcity and in facilitating the efficient provision of sanitation services (Venkataraman, 2013).

Water Markets: Appropriate water pricing policies ensure that water is efficiently allocated within a single sector where they are used. Thus, appropriate pricing policies for urban water supplies can ensure – or help to ensure – that urban water is efficiently used. Water markets, by contrast, can ensure that water is efficiently allocated between various water using sectors, urban, industrial, agricultural and environmental. In addition, water prices generated by well-functioning markets almost invariably reflect the scarcity value of water. Markets work by facilitating the exchange of water from relatively low valued uses to relatively higher valued uses. It is important to recognize that market transactions are strictly voluntary and thus both buyer and seller are made better off from such exchanges. The buyer benefits by purchasing water that is cheaper than any alternative source and because the price of water acquired through markets is lower than the value which the buyer can obtained by putting it to the desired use. The seller benefits because the sales price exceeds the value which the seller could obtain by putting the water to its most valuable uses. All of these conditions are met when water is traded successfully in markets.

Market transfers in the water sector are not confined to the trading of water rights. Water can be sold in spot markets for one time transfers; it can be leased for specific periods of time; and, it can be made subject to contingent contracts where a potential buyer pays a potential seller a fee for the opportunity to purchase the water when needed. In this latter case, an additional price must be paid if and when the water is actually transferred. Thus, for example, the Metropolitan Water District of Southern California, a major supplier of urban water to the Los Angeles conurbation, has executed contingency contracts with several agricultural water districts that would help to ensure that urban supplies remain available during times of drought.

When water markets work well, the resulting allocation of water among the various use sectors is efficient. That is, there is no alternative allocation among sectors that would lead to a higher aggregate value of water in and between uses. Experience shows that most exchanges occur either within the agricultural sector or between the agricultural and urban sectors. In fact, agriculture is sometimes thought of as “the supplier of last resort”. In such exchanges the price that the agricultural seller receives plus the costs of transport and treatment are exactly equal to what the urban buyer pays. The existence of water markets helps to ensure that water can be transferred from low valued to high valued uses. Without markets many low valued uses can continue to be served even while water is unavailable to support higher valued uses (National Research Council, 1992).

Water markets are neither perfect nor a panacea. Without special arrangements, environmental uses of water, which are generally non-consumptive, cannot compete on the same bases as urban, industrial and agricultural uses which are consumptive. Environmental uses of water, which provide environmental services and environmental amenities, are appropriately viewed as public goods. That is, when one individual is provided with an environmental service it is not possible to withhold that service from others even if they refuse to pay. The result is underinvestment in the development of an environmental service because a purveyor is unable to capture the value cannot be captured from consumers who ride free. There are a variety of remedies that include: 1) special or designated funds, which might be publically appropriate, that can be used to buy water for environmental purposes; 2) a tax on the proceeds of other water transfers that can be used to purchase additional water for environmental purposes; and 3) special legislative protections or designations which protect environmental water from market facilitated transfers to serve other uses (National Research Council, 1992).

There are some additional problems that need to be addressed in the design of water markets. These include adverse impacts on people who are not parties to the transfer negotiation. For example, people downstream of a transfer who depend upon accustomed river flows for their own supplies may suffer from an upstream transfer to which they are not party because of a resulting reduction in flows. Market transfers could also have adverse effects on water quality because the dilution capacity of the stream is reduced. Markets then need to be designed and supervised to ensure that environmental uses are accommodated; that third party impacts are small or absent; and that there are not other unanticipated or unaccounted for impacts. Like prices, markets may be particularly effective when they are used as part of a mixed strategy for resolving scarcity. In the case of transfers to the urban sector from the agricultural sector the supplies of urban areas may be increased absolutely with associated increase in the total value of scarce water across the various uses.

4. Addressing the Problems of Water Scarcity: Technology and Supply Augmentation

The historic U.S. supply augmentation strategy of constructing storage and conveyance facilities is no longer a viable means of addressing scarcity. The lack of unallocated water, the absence of physically and economically desirable impoundment sites and the competition for funding reinforce this conclusion. However, modern technology coupled with the escalating costs of alternative sources of water mean that waters of impaired quality can be treated and upgraded to levels of quality suitable for most uses. Household (and industrial) wastewater that is discharged to centralized sewer systems can be recycled and reused depending upon the desired level of treatment and the costs of achieving it. In the United States relatively stringent surface water quality standards and discharge regulations (requiring a discharge permit) means that wastewater from sanitary (and in some cases, storm water) sewers must be treated to meet these standards. The costs of reuse are properly calculated as the costs of making the water suitable for reuse above and beyond the costs of meeting the discharge and receiving water quality standards. In some instances, treated wastewaters can be used for landscape irrigation and other non-potable uses in which little or no additional treatment is required beyond what discharge standards call for.

The importance of cost consideration is well illustrated by examining current trends in industrial water use. The quantities of water diverted for industrial purposes in the United States declined significantly following the enactment of national surface water quality standards and the associated controls on discharges. The explanation lies with the fact that once firms have treated wastewater to meet discharge standards, the additional costs of restoring the water to a quality where it can be reused are quite modest. The consequence was that many firms found it economical to reuse treated wastewater as feed water for industrial processes. In this way the advent of water quality protection and regulation provided incentives for industry to economize and reuse its water inputs.

Modern wastewater treatment technology is now advanced enough so that household and industrial wastewater can be treated so as to meet the standards for potable reuse. Thus, for example, the Orange County Water District in southern California produces significant quantities of water, from wastewater, which is recharged to local aquifers. The water is ultimately extracted to serve household needs. The unique circumstances of the Orange County Water District are discussed elsewhere (see Box). The District uses a number of technologies including membranes in reverse osmosis processes prior to injecting the water directly into the underlying aquifer. The more advanced of these technologies are costly and can be utilized economically only under certain conditions (Mills, 2010).

It is important to recognize that the ability to employ the sorts of advanced technologies discussed here is unlikely to be present everywhere. The technology itself is expensive both in terms of capital cost and the costs of operation and maintenance. Operation of the technology requires a relatively skilled workforce which also entails higher costs. And, perhaps most importantly, the performance of the technology must be constantly measured and monitored to ensure that it is performing at the promised level. In short the options discussed here are likely to be attractive only in circumstances in which alternative sources of supply are very expensive and there are ample resources and expertise available to build and employ technologically advanced wastewater treatment systems.

Wastewater Recycling: Approximately 35% of the municipal wastewater effluent discharged each day in the United States goes to an ocean or an estuary. Reusing these coastal discharges would augment available water resources by 6% of total U.S. supply or 27% of public supply (National Research Council, 2012). The absolute quantities discharged to coastal waters are significant, amounting to 45.4 million m^3/day. There may also be opportunities for reuse of inland effluent discharges but care must be taken to avoid harm to downstream users though flow reductions. Water reuse for non-potable uses is well established in the United States. Potable reuse is far less extensive and some of it is incidental and has not been quantified (National Research Council, 2012). Nevertheless, in arid and semi-arid coastal regions where water supplies are limited the opportunities for reuse are substantial as is the range of uses that could be served.

The vast majority of water reuse in the U.S. is for non-potable purposes. Thus, for example, landscape irrigation, irrigation of golf courses and freeway landscape irrigation are all purposes in which reclaimed water plays a significant role. Reclaimed water is also made available in some circumstances as industrial cooling water. Although circumstances will vary from location to location the likelihood is that non-potable will reuse will increase in coming years. This will be attributable both to the growing demand for water for non-potable uses and the fact the additional costs of rendering treated wastewater that meets discharge standards suitable for non-potable uses are frequently quite modest. The historic development of non-potable reuse has been helpful in exposing a sometimes skeptical public to the benefits of reuse. Those benefits include an augmented more reliable water supply which provides protection against drought for certain uses (National Research Council, 2012).

The current and future extent of potable reuse is hard to predict. This is because the extent of incidental reuse – also called de facto reuse – is not known and could grow significantly in the future. Incidental reuse occurs because some treated wastewater (which meets national standards) is discharged to surface waterways upstream of the water intakes. In the course of its journey in the stream this effluent is diluted and its quality is improved. Suchwater ultimately makes up some proportion of the downstream water supply which may be devoted to non-potable or potable use (reuse). The U.S. National Research Council (2012) reports that in many instances the degree of treatment of discharged effluent that becomes incidental reuse is less than that accorded to supplies that come from planned reuse projects. The fact that the extent of incidental reuse is unknown means that it is unclear how many people are exposed to the contaminants contained therein and the current concentrations of those contaminants. Clearly, it will be very important in the future to have better information on the extent of incidental reuse, on the locales where it occurs and on the risks that such reuse poses to water consumers.

It is important to compare the risks associated with potable reuse supplies with the counterpart risks associated with water supplies that are presently used. In some instances, the risks associated with planned potable reuse are less than those of conventional supplies. There are instances in which water consumers have rejected proposals for planned potable reuse even where it could be shown that the risks associated with potable reuse were demonstrably lower than risks associated with continued use of existing supplies. In addition, design objectives for reuse systems should include criteria of reliability and robustness. Redundancy typically enhances the reliability of contaminant removal while robustness has to do with the ability to respond effectively to a wide variety of contaminants. It does appear that the risks associated with planned potable reuse can be reduced to acceptable measures but the costs of doing so may be high. Again, the economic and financial feasibility of such projects will depend importantly on the costs of alternative sources of water.

The costs of water reuse are highly variable from site to site and situation to situation. The size of the facility, its location, and the quality of the feed water, the need for storage, energy costs, interest rates and the costs of complying with regulatory and permitting processes vary across a wide range of domains and make it quite difficult to generalize about likely costs. As a generalization, it appears that potable reuse costs are frequently higher than most water economizing options and lower than seawater desalination costs. In the case of reuse for nonpotable purposes, product costs can be quite modest given that treatment requirements over and above those needed to meet wastewater discharge standards may be quite modest. In these instances, the costs of distributing the water are likely to predominate. This may be particularly true where water for non-potable, outdoor household uses can be accommodated because dual plumbing systems will be required (National Research Council, 2012).

There are pricing problems with reuse water for both potable and non-potable purposes. As already noted, potable reuse costs may be quite high and not competitive with the costs of alternatives. The rates charged for non-potable reuse water frequently do not cover the total costs of acquiring the water; treatment, if any; and the capital and operating costs of the distribution system. Subsidies and other artificial means of lowering costs are sometimes employed to make reuse supplies attractive and financially competitive. However, as the demand for reclaimed water increases in the future it is likely that the costs of these supplies will rise. This fact serves to reemphasize the importance of pricing and the need to be realistic about costs and prices of water supplies of all sorts are to be managed efficiently and effectively (National Research Council, 2012).

Public acceptability is an important element in the successful prosecution of any potable reuse project. A number of otherwise justifiable potable reuse project proposals have failed because of public opposition. These include projects proposed for construction in Los Angeles and San Diego in which public opponents became arrayed against local water purveyors in circumstances where effective communication seemed all but impossible. Such opposition is frequently based on misinformation or lack of accurate information (Equinox Center, 2010; Ingram et al. 2006). There are nevertheless numerous examples of successful potable reuse projects and these seem to share characteristics of early public involvement and transparent communication of scientific and policy information on a continuing bases. These experiences underscore the importance of extensive and continuing public communication on water issues in urban areas. Public knowledge and understanding of water issues are now known to be increasingly important in the formulation of water supply and management alternatives in urban areas and in various decision making processes related to water (Ingram et al., 2006; National Research Council, 2012).

Desalination: Desalination processes typically treat seawater or brackish waters to produce a stream of freshwater and an associated stream of concentrate water that contains the salts that have been extracted from the freshwater. The fact that such a large portion of the Earth's water endowment is in seawater and the fact that brackish

Box 9

Orange County Water District, California

The Orange County Water District is located in the Santa Ana River watershed south of the City and County of Los Angeles and north of the City and County of San Diego in California. Its service area is coastal Orange County that, in the period following World War II, experienced explosive population growth which transformed it from an agricultural area into a densely settled urban and industrial area. Historically the area relied on ground water to a disproportional extent and ground water overdraft began to become significant in the first half of the 20th century. With population growth, overdraft became more severe and one serious consequence was the intrusion of seawater into the aquifer, threatening the quality and sustainability of the basic water supply. To address the problem the Orange County Water District devised a program and constructed the needed facilities to permit injection of water reclaimed from an advanced wastewater treatment facility known as Water Factory 21. The injection of reclaimed water began in 1976 and served the purposes of creating a seawater intrusion barrier and as an augmentation to the local potable supply.

In the first decade of the 21st century Water Factory 21 was replaced with a large Groundwater Replenishment System which consists of an advanced wastewater treatment facility, the seawater intrusion barrier and several spreading grounds. Current production is 200,000 m3/day with an ultimate capacity of 490,000 m3/day. The source water for the advanced treatment facility is secondary effluent from the Orange County Sanitation District Plant # 1. This plant is located immediately adjacent to the Water Districts' facilities. Half of the product water is injected directly into the seawater intrusion barrier after treatment with reverse osmosis. All of the treated water is accorded advanced oxidation and microfiltration. The half not directly injected is transported to the spreading grounds and undergoes soil/aquifer treatment as it is percolated to the underlying aquifer. Extraction wells are spatially removed from the spreading basins by over a mile and retention time underground prior to extraction is estimated to be in excess of six months. From a public health perspective the project has been unblemished for nearly 40 years.

The groundwater is supplemented by remote surface waters that are brought from northern California and from the Colorado River. These are expensive supplies, in part, because of the sizeable amounts of energy needed to pump and convey from remote locations. In this example, then. technologically sophisticated and large scale wastewater recycling and reuse is economically attractive because the costs of the least cost alternative supply are relatively high and because the Metropolitan Water District of Southern California, which imports the surface supplies offers subsidies to customers who develop alternative sources of supply to meet at least a portion of demand.

This case illustrates that potable reuse can be successful over the long-run if the resources and expertise needed to design, build and operate the facilities are available. It illustrates also the importance of the costs of alternative sources of supply in determining the economic attractiveness of the project. The technical sophistication, high costs and complicated financing arrangements make clear that projects with this level of expense and technical sophistication are unlikely to be attractive on a widespread basis though they can be highly successful given the appropriate circumstances.

Sources: Crook, 2007. Mills, 2010.

ground waters are found nearly everywhere in United States (Feth, 1965) makes desalination a potentially attractive technology for augmenting fresh water supplies. There are two distinct types of desalination technology sometimes characterized as distillation technologies and membrane technologies. Distillation technologies were among the earliest developed and rely on different processes which separate pure water dissolve solids though distillation. Such technologies tend to be very energy intensive and today are found almost exclusively in the countries of the Persian Gulf where energy is relatively inexpensive. Membrane technologies first appeared around 1970. These technologies entail the application of pressure to salty water to force it through a membrane which screens out and separates dissolved solids. These technologies tend to be less energy intensive and the costs of membranes have declined over recent years making such technologies economically and financially more attractive then the distillation technologies. Virtually, all of the recent desalination plants and those that are in the planning stage are of the membrane type and include electrodialysis, reverse osmosis, nanofiltration, ultrafiltration and microfiltration (National Research Council, 2008).

The advantages of these systems is that they permit new sources of freshwater supply to be developed from waters that tend to be plentifully available – depending upon location – but are qualitatively degraded. There are two principal disadvantages to such systems. First, the costs tend to be very high compared with the costs of many other modern sources of water including conservation and some reuse and reclamation schemes. Second, the environmental impacts of the concentrate stream are harmful and in many instances the need to mitigate or prevent them will increase costs even more. The two largest components of cost are the capital costs (annualized) and the energy costs. It has been estimated that for a seawater reverse osmosis plant with a capacity of 189,000 m^3/day each of these costs would account for one-third of the total. The fact that energy costs are disproportionately large is also a cause for concern because energy costs have exhibited significant instabilities from time to time.

The unit costs of producing freshwater from seawater are reported to range upward from \$0.64/m^3. Many estimates of unit cost tend to be understated because of a failure to account fully for all costs, because the role of subsidies is neglected or because other financial arrangements may involve forgiveness of some costs or hidden subsidies (Miller, 2003). Distortions in cost are frequently difficult to identify as irregularities in financing terms such as artificially low interest rates and perturbations in payback schedules are not uncommon and are far from transparent. Questions of cost are further confused by pricing practices that distort the true cost of the water in order to enhance affordability or for other reasons. One example is the case cited earlier in which the San Diego Water Authority intends to average the relatively high costs of desalinated seawater which, when the facilities are complete and operational, will contribute 10% of the total water supply. A hypothetical case illustrates what happens when average cost pricing practices are employed.

Suppose that the existing cost of water is \$0.20/m^3. Suppose further that the cost of the desalinated supply is four times that amount, \$0.80/m^3. The new water supply is composed of 90% of supply costing \$0.20/m^3 and 10% of the supply costing \$0.80/m^3. The average cost of the combined supplies is \$0.26/m^3. So, instead of charging users of the desalinated supply the cost of the supply (\$0.8/m^3) all users are charged the new average cost of \$0.26/m^3. In this example the addition of 10% to the supply, costing four times as much as the base supply and averaged over all users causes everybody's water cost to rise by \$0.06/m^3 or 30%. The implications of average cost pricing are mixed. This pricing practice ensures that water remains reasonably affordable and that the price increase is relatively modest when compared with the price increase of the additional increment. However, the practice of average cost pricing buffers consumers from the sharp price rise of the new supply and simultaneously conveys erroneous information about the scarcity value of the water. The underpricing of the water sends a signal to consumers that water is more plentiful than it is in reality and thereby provides an incentive to use more water than is warranted under the prevailing scarcity circumstances. This additional use is, by definition, wasteful. It is the result of perverse policies which encourage wasteful use of a scarce resource.

As indicated earlier the exact magnitude of cost depends upon local circumstances. It is known, however, that with membrane technologies the costs of desalting are sensitive to the salinity content of the water, meaning that brackish waters are almost always less costly to desalt than seawater. This means that both inland and coastal supplies of brackish ground waters may be more competitive sources of supply than seawater. It is also important to recognize that seawater desalination will almost always occur at sea level and the need to pump product water uphill to points of use will increase the cost, usually significantly. With inland desalting of brackish water conveyance costs can also be significant as can costs of extracting the brine from aquifers. Additionally, the second major shortcoming of the technology which is the cost of environmental impacts can also have adverse impacts on total costs.

The diversity and seriousness of environmental problems will vary locationally, technologically and with the scale of the specific desalination facility. Moreover, there is limited knowledge and thus substantial uncertainty about the environmental impacts of desalination. There are nevertheless three generic types of environmental problems that will have to be addressed in the planning, construction and operation of virtually any facility. They are impingement, entrainment and concentrate management. Impingement entails the pinning or entrapment of large organisms such as fish against the intake screens of the desalination facility. Entrainment occurs when relatively small organisms are taken in and killed by temperature or crushed against membranes. These problems can be attenuated to some extent by co-locating intakes with those of power plants. In some circumstances impingement and entrainment can be minimized by utilizing subsurface intakes or deep water intakes. With surface intakes fish handling systems and traveling screens can be used to minimize impingement. The need to address impingement and entrainment problems will increase both the capital and operating costs of a desalination plant (National Research Council, 2008).

The other generic environmental problem relates to the need to manage concentrate which is the waste product of desalination. The desalination process effectively partitions the feed water into a freshwater stream and a concentrate stream. The latter contains salt and residuals from the treatment process. The chemical constituents in concentrate pose complex problems. Thus, for example, it is thought that membrane cleaning chemicals should be disposed of separately rather than with the concentrate. Similarly, there are environmental hazards associated with the disposal of concentrates. Such hazards may be inimical to individual species or to entire classes of organisms. Disposal of contaminants falls under the provisions of the Clean Water Act and the Safe Drinking Water Act so that disposal processes and regimes must meet regulatory requirements. Inland desalination may exhibit different sorts of environmental problems. Ground water overdraft and associated subsidence is one example. Threats to the quality of existing surface waters are also a possibility.

The incremental costs of desalination are high even where environmental impacts are relatively modest. Those costs do not compare favorably with the costs of many of the available alternatives. It is clear that the least cost alternative source of water for urban areas in the United States is conservation (Equinox Center, 2010). It seems fair to assert that pricing policies that lead to marginal cost pricing of supplies from desalination and expensive reuse projects would themselves induce substantial quantities of conservation. It is ironic that in such an event the quantities of conservation would itself outstrip the quantities to be supplied by the new, high-cost technologies thus rendering them unneeded.

5. Conclusions

The picture of urban water management – current and future – that emerges for the United States is characterized by the water paradox of developed countries. Virtually the entire population of the country has access to healthful water supplies and fully adequate sanitation services. Yet, urban residents and water managers are faced with an array of future water management problems that appear to be just as daunting as those faced by countries which are not fully served. Water scarcity is intensifying, especially in the arid and semi-arid western parts of the country where urban growth is the highest. Water quality problems are also intensifying as new contaminants appear frequently and the institutional and policy apparatus for responding to them grows increasingly inadequate. Urban water supply and sanitation infrastructure is aging. The planning and financing needed to maintain and renew this infrastructure is inadequate and with time the inadequacy grows. The public appears apathetic to these problems largely because they are unaware of them.

Intensifying water scarcity is caused by a combination of factors. Growth in water demands is fueled by population growth in urban areas. This growth is occurring at a time when water supplies to serve it are static or shrinking. New quantities of supply from accustomed sources are not available since most river basins have been fully allocated and because supplies in some regions are not reliable. Future deterioration in water quality could shrink such supplies further. Water scarcity is made worse by the failure of political leadership to educate the public about the nature of the problem and garner support for addressing the various manifestations of it. Water pricing policies are focused on recovering the costs of supply and treatment and virtually never include or reflect the scarcity value of the water itself. Water prices which convey a scarcity value of zero to consumers signal that water is freely available. These pricing policies are perverse and contribute to public ignorance of the water scarcity problem.

While accustomed sources of new supply are largely unavailable modern technology can be employed to augment water supplies through water reclamation and reuse and with desalination technologies. The latter technologies produce freshwater from seawater or brackish waters which are thought to exist as ground water in much of the inland United States. The difficulty with these technologies is that they are very costly and especially so when compared with the cost of existing supplies. Current pricing policies mask this fact by averaging the high costs of the new supply in with the lower (frequently much lower) costs of the existing supply. This signals consumers falsely that the newer supplies are much less costly than they are in fact and leads to excessive –and wasteful – use of these supplies.

It is well documented that the cheapest source of additional water is conservation or economizing on the use of water. It is also well documented that the demand for water is price responsive. Higher prices induce consumers to economize and conserve. The failure to include the scarcity value of water in its price and the use of pricing gimmicks to mask the real cost of new supplies from reuse and desalination seem self-defeating. By underpricing water – on both counts – consumers are sent a signal that water is more plentiful than it is in actuality. That is, prevailing policies are aimed at understating or misstating the true extent of scarcity. Thus part of the response to the challenges confronting urban water managers is to fashion pricing and allocation policies and engage in programs of education which emphasize the reality of water scarcity rather than masking it. Such policies should also make provision for modern and adequate assessment of emerging contaminants in an effort to maintain or even enhance source water quality.

For situations where policy reform is insufficient to provide adequate quantities of water of appropriate quality water reuse schemes and, where feasible, desalination efforts can be considered important. Such supplies should be priced at approximately their marginal costs to signal consumers about scarcity and cost and to minimize or avoid altogether wastage of scarcity supplies. The experience of electric utilities with increasing block rate pricing structures has been very successful and provides a model which the "water industry" in the developed world should consider emulating. To some significant extent the problems of water scarcity faced by urban areas in the United States are self-inflicted. There is no reason why this should be so.

6. Recommendations

1. The three threats to urban water security in the United States – water scarcity, inadequate and aging water supply and sanitation infrastructure and a rapidly growing number of potential contaminants – should be ad-dressed in an integrated fashion. Addressing a single threat but not the others is unlikely to result in sustained states of water security. Moreover, different levels of government will be required to act in consonance if the issues are to be successfully resolved. The problems of contaminant identification, characterization and management are appropriately problems for the national government. Problems of water scarcity and inadequate infrastructure are best addressed at lower levels of government. Thus, the problems themselves need to be considered in an integrated fashion but effective responses will requirand collaboration between different levels of government – intergovernmental in-tegration.
2. Water pricing policies will need to be reformed to account for the scarcity value of water and to reflect the increasing costs of new supplies. Assigning water itself a scarcity value and reflecting that valuie in pricing strategies will result in water economizing and also has the potential for augmenting revenues that will be needed to finance rehabilitation, operation and maintenance of water and sanitation infrastructure. Such reforms in water policy will likely to be central to any effective strategy for protecting water security.
3. Purveyors and water supply and sanitation services should initiate and support robust programs of education and communication. The purposes of such programs should be the development of informed users groups and an informed public. Users and the public should develop solid understandings of the nature of water scarcity, the financial implications of an aging infrastructure and the problems of identifying and managing contaminants.
4. The national government needs to authorize and provide funding support for programs of evaluation and regulation of contaminants and potential contaminants. Failure to accomplish this task will adversely impact both the safety and reliability of the nation's urban water supplies in the future.
5. New technology and supply augmentation strategies should only be employed only after careful analysis of the costs of new supplies and services and a comparison of those costs with the costs of other options.

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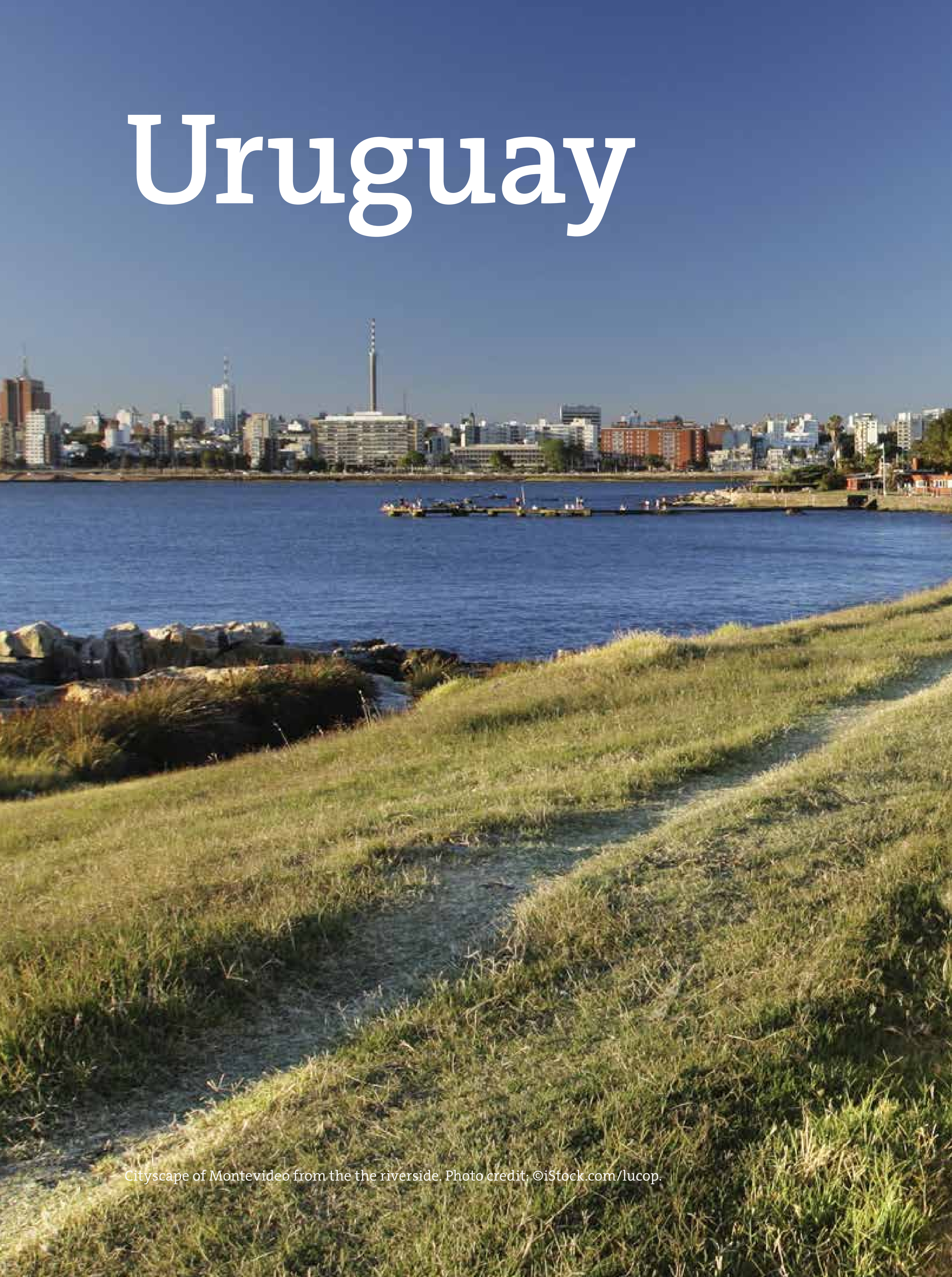
Uruguay



Cityscape of Montevideo from the the riverside. Photo credit: ©iStock.com/lucop.

"Uruguay has a very high urban population of 95% of the total with more than half living in the capital, Montevideo, and its surrounding metropolitan area. Uruguay is close to providing universal access to drinking water through its single water utility company. The management of rainwater in better designed urban drainage systems is one of the special challenges confronting management authorities"

Urban Water Supply in Uruguay: Progress Made and Challenges to Integrated Management

Adriana Piperno, Federico Quintans & Daniel Conde
Coordination and editing

Álvaro Capandeguy, Adriana Piperno, Federico Quintans, Pablo Sierra, Julieta Alonso, Christian Chreties, Alejandra Cuadrado, Andrea Gamarra, Pablo Guido, Juan Pablo Martínez, Néstor Mazzeo, María Mena, Nicolás Rezzano, Gabriela Sanguinet, Javier Taks, Guillermo Goyenola, Elizabeth González, Julieta López, Amancay Matos, Osvaldo Sabaño, Carlos Santos, Matilde Saravia, Luis Silveira, Rafael Arocena, and Luis Aubriot

Summary

Within the context of South America, Uruguay is a small country with gently undulating terrain and an evenly distributed water supply, with average precipitation of 1300 mm per year without a specific seasonality. The urban population comprises 95% of the total (3, 390,077 inhabitants), with more than half living in the capital, Montevideo, and its surrounding metropolitan area. Population growth is low, since the country has consolidated its urban transition (in 1963, the urban population accounted for 81% of the total).

The country's regulatory framework is advancing towards the integration of water, land and environment, as borne out by the amendment to Article 47 of the Constitution, which states that the protection of the environment is in the interest of all citizens and that access to drinking water and sanitation is a fundamental human right. However, the regulation and implementation of this regulatory framework is as yet incipient.

Uruguay is nearing the provision of universal access to drinking water through its single water utility company, OSE, Obras Sanitarias del Estado (State Sanitation Company). The challenge currently lies in protecting water resources, reaching small rural communities and reducing losses in distribution systems. And although sanitation coverage is high, the challenge is to expand sewerage

coverage, increase the amount of treatment for wastewater and household connections, and investigate alternative sewerage systems capable of providing service for inaccessible areas.

As for storm water management, problems in the drainage system affect the capitals of the departamentos or provinces into which the country is divided and small localities. Since over 60 urban centers are affected by drainage problems, with 70% of the cases classified as moderate to serious, the challenge is to improve and develop planning systems and incorporate more sustainable technology.

Floods are the main factor activating the National Emergency System. Since cities with flooding problems are distributed evenly around the country, the challenge is to incorporate risk maps into local plans, strengthen riverbanks and improve monitoring and warning systems.

A change is taking place in Uruguay, from sectoral visions to a more integrated vision of urban waters. This translates into a non-linear process of dynamic, multi-stakeholder transformations with enormous potential, although they are not free of difficulties. Increasing coverage and access to all water services, incorporating water into land planning, improving the quality of and access to the information required for effective decision making, adjusting the system of governance, strengthening technical capacities, encouraging an interdisciplinary approach and involvement of cross-cutting spheres are key issues for sustainable urban water management in Uruguay.

1. Introduction

This chapter proposes an interdisciplinary approach to identify and systematize the main problems affecting the urban water supply in Uruguay and determine how they affect the quality of life in cities; what their causes are and which processes, if not addressed, will exacerbate problems. Emphasis is also placed on identifying the engines of change towards sustainable models.

To this end, the Uruguay Academy of Science (by invitation of the IANAS (Inter-American Network of Academies of Sciences) Water Program and the Urban Water Supply Group of the International Hydrological Program for Latin America and the Caribbean at UNESCO (Spanish acronym PHI-LAC) brought together a wide-ranging group of specialists in an attempt to set a baseline to provide continuity for technical and scientific coordination and generate integral information.

1.1 Conceptual focus of the study

The quality of life in cities, where urbanization has significantly changed the natural characteristics of the water cycle, depends largely on their water management. Intensive water use, particularly because of the infrastructure required for its use and final disposal, has further complicated its dynamics and has generated particularities comprising the urban hydrological cycle (Marsalek et al., 2008).

Surface and groundwater, supply water (drinking water for the population and raw water for non-domestic use), wastewater, and storm water interact with each other, impact and are affected by the city. The historical lack of an integral understanding of urban water and its link with the territory has led to disconnected policies, works and structures, which has become one of the leading causes of the problems identified in Uruguay and elsewhere (Piperno and Sierra, 2013).

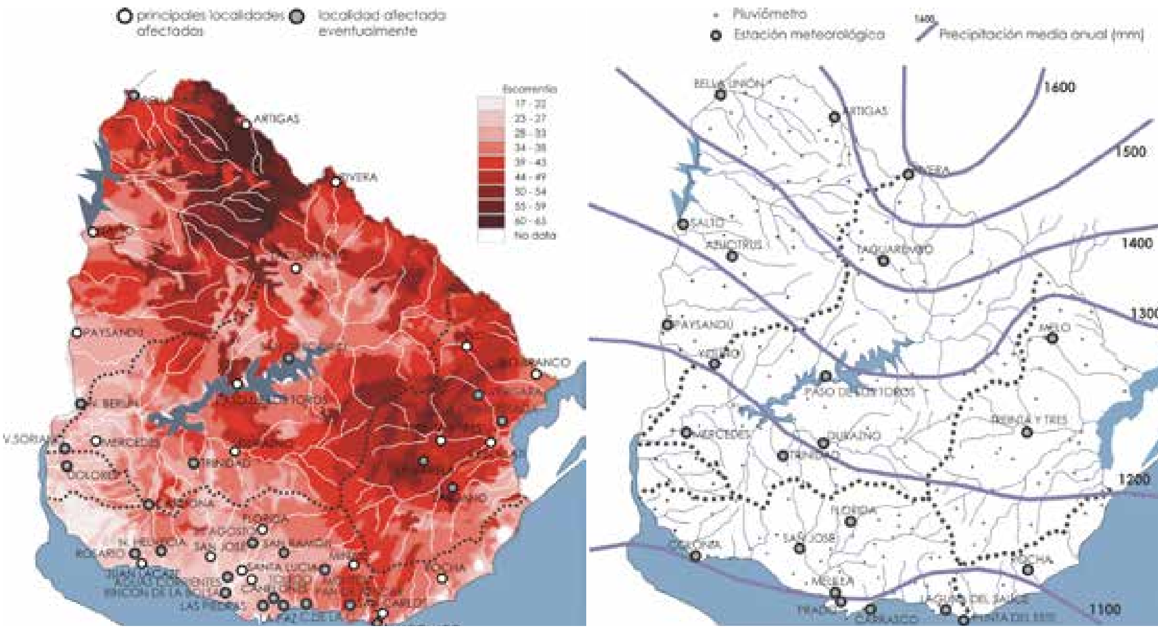
This chapter begins with an explanation of how the current situation arose, how each subsystem in the urban hydrological cycle developed and what its main challenges are. It then examines the framework of the urban water supply's system of governance in order to describe the country's main challenges.

1.2 General Characteristics of Uruguay

Uruguay's urban population[1] (3,390,077 inhabitants, National Institute of Statistics, 2011) accounts for 95% of the total with over half being concentrated in the metropolitan area of Montevideo, the capital. There are only three cities with approximately 100,000 inhabitants, the rest being medium-sized and small towns. The country has a low population

1. Urban population (according to the criteria used by the National Institute of Statistics (Spanish acronym INE) is a population that resides in all portions of land that, from the point of view of the census, are defined as blocks with at least 10 households.

Figure 1. Average run-off (mm/month) (left) and average annual rainfall in Uruguay (right)



Source: Urbanism Theory Institute, (Spanish acronym ITU) Architecture Faculty, based on date from the Institute of Fluid Mechanics and Environmental Engineering (Spanish acronym IMFIA) Faculty of Engineering and the National Office of Meteorology.

growth rate[2] (National Institute of Statistics, 2011) and has consolidated its urban transition (the urban population in 1963 was 81%)

Within the context of South America, Uruguay is a small country (176,000 square km) with gently undulating terrain and a dense, evenly distributed water network; average rainfall is 1300 mm per year with undefined seasonality (Figure 1).

The country's GDP is $49 billion USD (GDP/capita $13,500 USD), making it a high income country according to the World Bank. The last decade, after the severe economic crisis of 2002, was characterized by constant economic growth (an average of 5.5% over the past 10 years), which has affected employment levels (6% unemployment in 2013). Life expectancy at birth is 76 years, there are high levels of educational attainment (nearly 100% net enrolment in primary school and almost 70% in secondary school, according to the World Bank) while 62% of households are connected to the Internet (see: http://datos.bancomundial.org).

2. The growth rate is 0.19% per year (National Institute of Statistics Census, 2011).

2. Historical Development of Urban Water in Uruguay

Societies reproduce the structures they inherit, then make their mark on it, thereby determining future transformations. Thus, each era forms cities, which, in turn, affect the way of life in them. In order to understand the link between the city and the water supply, one has to understand the urban and environmental paradigms of each era and how they affect and influence a city, the needs of its inhabitants and the way the surroundings are understood.

Within this context, it is possible to point out certain singular events that characterize a city and its relationship with water. Firstly, cities in Latin America bear the stamp of Spain and Portugal, which set out "to make the American world (which they considered to be empty) a world of cities", like the European world (Romero, 2009). Water played a decisive role in the occupation of land since it was regarded as both a source (mainly freshwater) and a receptor where to deposit waste.

Most of the cities built on rivers “turned their backs” on the watercourse and focused more on services, equipment and the population, structured by the main streets and central plazas constituting symbolic places. Drinking water was stored in a system of reservoirs and wastewater was disposed of on the land or through individual systems of wells that eventually emptied their contents into the nearest riverbed.

The rapid industrialization, expansion and densification of cities at the beginning of the 18th century without considering sanitation transformed the polluted water into a source of disease that affected the quality of life of both the new salaried classes and the new bourgeoisie. In response to this, a school of thought arose in Europe called the “hygienist model” that associated health with urban development and developed a vision of healthy cities, associated with the construction of large-scale works. Montevideo, in particular, was not exempt from this problem and incorporated these “solutions” developed in Europe into both the building of the infrastructure and the design of parks and gardens. The second half of the 19th century saw the modernization of urban services. Cities began to be provided with sanitation, drinking water, electricity, railway and tram services. Montevideo was the first city in South America to have a sewage network (drains). Between 1854 and 1916, 211 km of sewers were build (Arteaga network), although private connections were not compulsory until 1913. In the provinces this development began later.

As far as potable water is concerned, the 1867 drought triggered the decision to provide permanent water service in Montevideo, with the Santa Lucía River being chosen as the main source. The service was run by licensees from 1871 to 1950, when the state took over. In 1952 the State Sanitation Company(Spanish acronym OSE) was established and since then, this organization has been responsible for the provision of drinking water, drainage and wastewater treatment services in the provinces, whereas in Montevideo, these services were provided by the Municipal Government. The hygienist model led to a reappraisal of urban parks with the water supply being the central factor. Cases in question include the development of the Prado Park in Montevideo that took into account the flow of the Miguelete River in its design and also the works carried out by the Cities and Town Improvement Department of the Ministry of Transport and Public Works.

The modern city gradually materialized and its water supply, small natural streams, sewer networks and storm water collection were supposed to take place invisibly, underground (Figure 2).

Urban expansion progressed during the 20th century with the creation of formal and informal residential developments, which ignored small water courses (Figure 3). The state was subsequently asked to provide the missing urban infrastructure. Depending on the physical characteristics of each city, the banks of large rivers either became an attractive urban residential area, or were

Figure 2. Miguelete River in Montevideo. Visit to the Arteaga Network c. 1900

Source: Photography Center (Montevideo City Hall)

Figure 3. Blocks in the city of Salto in 1892 (Agrim. T. Herrán). This shows the lack of knowledge about the natural course of the Sauzal Stream in the north of the city

Source: L. Vlaeminck

consolidated, as happens in many medium-sized Uruguayan cities, as another "poor" periphery where the poorest families settled on the flood plains.[3]

The crisis experienced by the country in the early 1960's (after several decades of growth) spawned new forms of territorial settlement, with irregular urban growth in sectors without services, occupying the riverbanks and flood plains of urban water courses. Public investment dropped sharply, leading to problems that highlighted the inadequacy of the existing infrastructure, difficulty in building new public works and the failure to incorporate water sources into the design of integrated urban solutions.

In the past decade, economic stability in Uruguay has achieved progress in services and infrastructure in cities. New approaches to urban water management have also gradually been adopted.

3. Drinking water supply in urban areas

A total of 98% of the population in Uruguay enjoys access to drinking water, with an average consumption of 130 liters/household/day (see: www.ose.gub.uy). With an almost universal supply of potable water to urban centers, the challenge lies in providing this service to small nuclei of rural dwellings. In order to achieve the Millennium Development Objectives, the OSE (the State Sanitation Company) plans to provide drinking water, collectively and individually, for an additional 28,000 inhabitants in rural townships across the whole country by 2015 (see: www.ose.gub.uy).

3.1 Drinking water coverage at the urban level

Drinking water coverage in urban areas in Uruguay is among the highest on the continent (Rojas, 2014) who used the main indicator as the availability of drinking water delivered to households by pipes. Over the past few years, Uruguay (like other countries) has used other indicators that fail to distinguish between water being provided inside or outside a home and which use the term "improved sources." Having a service with improved sources means that: 1) the source of the water is a general drinking water supply network or ii) a protected emerging well.

It is important to note that the high coverage rate of this service in the country is historical. In 1996, 83% of the urban population had access to drinking water through a public network connected to their homes. Currently, according to data from the 2011 Census, 96% of the urban population are connected to a general supply network and 99.4% have access to potable water through an improved source inside or outside their dwelling.

3.2 Drinking water service provision through networks

Potable water supplied through a network to a permanent population is mainly provided by the OSE (the State Sanitation Company) (with over 99.5% of the population being served by network). The service is provided in accordance with the

3. Although the Law of Population Centers (Nº 10,723, 1946) residential areas not be constructed in flood areas and that private constructors provide adequate services for effective urbanization, the inability to ensure compliance with this law has resulted in extended cities that lack services.

provisions of Article 47 of the Constitution and the Law for the Establishment of the State Sanitation Company, which was enacted for social rather than economic reasons. Information on the State Sanitation Company (OSE) is given in Table 1.

The State Sanitation Company fee structure allows the poorest, most marginalized communities as well as those that fulfill certain conditions to have access to drinking water. Subsidies are granted to those that consume between 10 and 15 cubic meters, depending on the individual case, and the company also has an action plan that allows for access to drinking water in irregular settlements (see: www.ose.com.uy).

There are also other organizations that make important contributions to the provision of potable water to low-income groups in cities: the Program for the Improvement of Neighborhoods, which regularizes settlements and improves the neighborhoods inhabited by these groups (Spanish acronym PMB-PIAI); the Juntos (Together) Plan which undertakes social works and the Housing Programs of the Ministry of Housing, Territorial Arrangement and Environment (MVOTMA) designed to improve the habitat of people living in extreme poverty and precarious housing (Rojas, 2014).

The State Sanitation Company's potable water service is not subsidized and or exempt from taxation; its investment in service improvement is therefore financed by the income obtained from its service provision. Since drinking water service is profitable, some of the earnings are invested in sanitation works, which are currently deficient.

3.3 Water sources

Availability

Article 47, Section C of the Constitution states that the National Water Policy is based on, "establishing priorities for the use of water by regions, basins (or parts of them), the main priority being the provision of potable water to the population".

Surface water. Uruguay has extensive surface water resources, and an average annual rainfall of about 1300 mm, uniformly distributed throughout the year and across the country. However, the availability of freshwater for conventional potabilization has certain constraints, including the fact that on the Atlantic shoreline, saltwater intrusion has been found in some of the water courses. There is also significant climate variability, with frequent periods of drought resulting in flows far below the monthly average. In several cases, this situation has required the construction of reservoirs (the State Sanitation Company has 22 reservoirs) and the undertaking of extensive pumping. This is the case of Montevideo, supplied by the Santa Lucía River located about 56 km from the city as well as by two reservoirs, measuring $70x10^6$ and $20x10^6$ m^3. Since the introduction of these reservoirs, apart from specific cases that have been addressed, problems have not arisen during extreme drought events.

Groundwater. Groundwater in Uruguay comes mainly from granular aquifers in sedimentary rocks and fissured aquifers in crystalline rocks. These and the less permeable granular rocks are located in 55% of the total area in the country, mainly in

Table 1. Information on drinking water service provided and managed by OSE in Uruguay (see: www.ose.gub.uy)

Localities served	More than 350
Service continuity	24 hours
Volume of water produced (annual)	348 million m^3 (Surface almost 91%; underground 9%)
Residential consumption rate (15 m^3 /month)	US $15.7/month (dollar exchange rate on April 30, 2014) equivalent to 0.85% of average household income
Micro-metering	90% of water connections with meters that work
Non-billed water/water provided	52.6% (in 2013)
Financing	With income by rates; does not receive subsidies
Operating margin	16.9% (operating income invoiced – operating costs)/invoiced operating income 2013
Planning	Strategic planning and yearly action plans
Investment in drinking water infrastructure (2010-2013)	US$165 million
Drinking water quality management	Progressive implementation of water safety plans 50,000 analyses per year

the south (the most populated area) and have low productivity, with flows of between 0.5 and 5 m^3/hour. One of the main granular aquifers is the Guaraní Aquifer, covering a significant area of the country (approximately 33%, basically in the North). However, most of it is found under basalt rocks at great depths and the water is extremely hot, with temperatures of up to 45 °C, making it difficult to use as drinking water. There are other aquifers with good yields, such as the Raigón Aquifer, occupying only 1.3% of the country. In short, groundwater as a source of supply has many quantitative constraints in several parts of the country.

3.4 Water quality

Surface Water Quality. In recent years, surface water in Uruguay, especially that used to supply potable water, has shown a significant increase in its nutrient levels. Phosphorous has been the most commonly reported nutrient, with levels in many sections of different river beds that exceed the level for being classified as eutrophic. This process is related to significant changes seen in recent years in the production matrix in agriculture and livestock farming. This has promoted the development of blooms of algae, cyanobacteria and aquatic plants under certain environmental conditions. This phenomenon has also been seen in the Uruguay and Plata Rivers, jurisdiction of which is shared with Argentina. Since this phenomenon affects water quality, the government has taken measures, such as formulating the Plan for the Protection of the Santa Lucía River Basin (see Box 10). It has increased its monitoring programs and set up Regional Water Resources Councils and Basin Committees whose members include representatives of civil society, as well as demanding that agriculturalists propose land use plans for certain activities.

The State Sanitation Company has also included surface water quality as a part of its strategic planning and has already approved action plans for 2014. Moreover, in terms of potable water production, several actions have been undertaken to improve the quality of potable water, such as improving hydrobiological monitoring and determining cyanotoxins with the introduction of warning protocols (including a preliminary protocol at the production level), introducing the use of activated carbon at existing drinking water production plants and incorporating these units into the construction of new plants.

Groundwater Quality. In general terms, groundwater quality is not a problem when used as a drinking water source, except in isolated cases. These isolated cases are derived from the hydrological characteristics of certain aquifers, salinization caused by over-exploitation, human contamination caused by agricultural activities or inadequate wastewater systems (e.g. a lack of sanitation networks). It is necessary to advance groundwater management, however, and knowledge of many of the aquifers is still limited (some, like the Raigón and Guaraní aquifers have been studied in depth). For example, there are very few vulnerability studies and little has been done to develop the perimeter of protection of the wells (which in any case have not yet been legally established). Another aspect to be considered is ensuring compliance with the laws.

3.5 Drinking water and communicable diseases

Among the diseases caused by lack of availability of drinking water, which must be reported by law in Uruguay, there are three major ones of worldwide importance. There have been no cases of typhoid fever or cholera reported in Uruguay (nor have there been cases of the cholera epidemic that ravaged Latin America in the 1990s). Hepatitis A has an incidence of 0.65/100,000 inhabitants, although it is important to point out that since 2008, there has been free, compulsory vaccination against Hepatitis A. In 2012, the infant mortality rate in Uruguay was 9.3/1000 live births (the post-neonatal mortality rate was 3.7/1000 live births). In the cases of deaths of infants under the age of one, 0.7% were caused by diarrhea and gastroenteritis. High drinking water coverage is an environmental condition that should be taken into account when considering these data (see: www.msp.gub.uy; www.higiene.edu.uy).

3.6 Challenges in drinking water provision

Below are some of the challenges related to drinking water provision at the urban level in Uruguay:

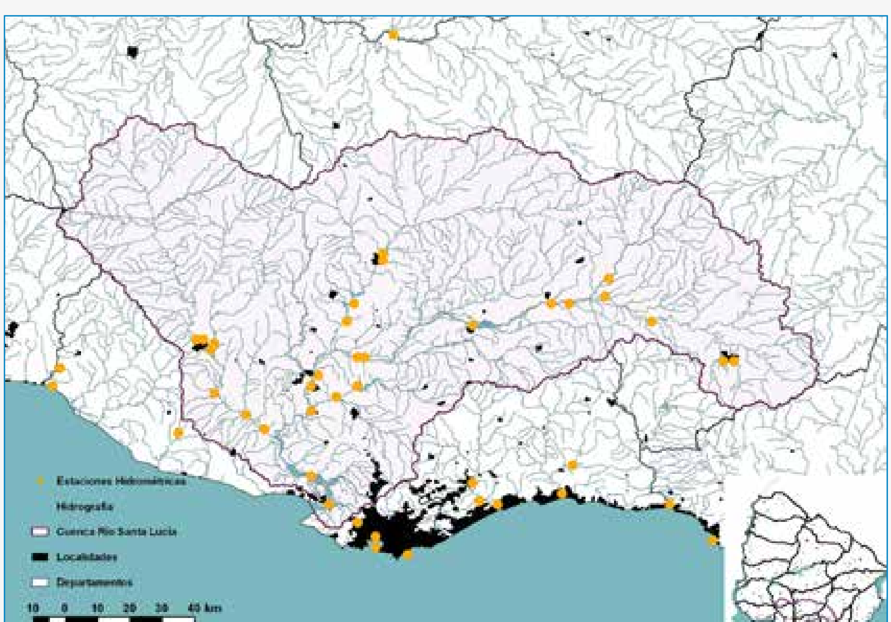
- Guarantee universal access to safe drinking water inside the home, since the lack of safe drinking water inside the home is regarded as

BOX 10

The Santa Lucía river basin, the main drinking water source in Uruguay

The Santa Lucía River supplies 60% of Uruguay's population with potable water. There are two reservoirs in the basin, (Paso Severino and Canelón Grande) and studies are underway for the construction of a new dam in order to ensure continued supply in the future. The basin covers 13,433 square km and nearly 32% of the total rural population lives there. It is one of the main food producing areas in the country, with significant industrial activity. This human activity has affected the quality of the water, accounting for 81% of the contaminants from different sources and 19% from point sources of pollution (industrial and domestic) (DINAMA-JICA 2011). Studies undertaken by researchers in the Department of Limnology of the Faculty of Science at the University of the Republic (UdelaR) concluded that most of the basin's tributaries are in poor ecological condition, with significant deterioration of the banks, the riparian vegetation and the canal. The physicochemical variables of the water demonstrated the effect of human activity on this environment, showing levels of phosphorous indicative of a eutrophic environment (Pacheco et al., 2012). This finding has worried politicians as well as the general population and resulted in the creation of an Action Plan designed to protect the quality of the water in the Santa Lucía River that features 10 emergency measures. At the same time, the Aguas Corrientes potabilization plant has been expanded and improved. As far as long-term measures are concerned, given the importance of the Santa Lucía River in the supply of freshwater to the metropolitan area, the Santa Lucía River Basin Commission (Executive Branch decree 106/2013 dated April 2, 2013) was created, which was regarded as a strategic maneuver by the Executive Branch.

Since its inception in 2013, the Basin Commission has served as a space for linking institutional and sectorial policy for water-related issues and its members (state, users and civil society) must agree on a contribution to the design and implementation of the Integrated Water Resource Management Plan for the Basin, in compliance with the principles established in the Constitution and regulated by the National Water Policy Law. It is the responsibility of this Committee to monitor the undertaking of the Action Plan.



a basic need that has not been met within the country. Just over 2.6% of the population still lacks access to drinking water supplied by a network inside the home, while approximately 1.3% of the population has access to drinking water inside the home supplied from protected wells, many of which, given the lack of quality control, cannot be considered sources of safe water. Most of the population without access to drinking water inside the home belongs to the most disadvantaged sectors, with a large percentage living in small localities. As already mentioned, the State Sanitation Company and other institutions are making efforts to improve this situation. The challenge is to set up and implement a national plan with objectives and goals.

- Improve the protection of surface water sources and recovery of surface water used for drinking water production and develop a better system for aquifer management and protection.
- Continue and reinforce the implementation of hydrobiological warning systems; improve the equipment in drinking water production plants and their management in order to address current and potential problems of water source eutrophication.
- Advance nutrient monitoring system in surface water, as well as the measures for controlling them.
- Continue developing Water Security Plans.
- Increase the invoiced water/used water ratio.
- Reduce potable water consumption by promoting the use of smaller cisterns, taps and showers with water volume control, washing machines that use less water; create legislation to this effect and step up the communications campaigns.

4. Wastewater

The sanitation sector in Uruguay has two situations: one in Montevideo and another in the rest of the country. There are several reasons for this: firstly, the capital city was the first urban center to have drain networks, much time before the provincial cities. Moreover, since sanitation in Montevideo was developed under just one system (storm water and wastewater were linked in the same network), it was run by the government while the rest of the country's sanitation was the responsibility of the State Sanitation Company (OSE). This issue must therefore be approached by bearing these two situations in mind.

4.1 Domestic Wastewater

Decree 78/010 defines sanitation as "systems that transport wastewater through a network of drains or in special trucks and dispose of them in a treatment plant, as well as systems that store and dispose of wastewater "in situ" in filtering wells and/or by infiltration into the ground". A cesspool or septic tank is defined as an impermeable deposit where wastewater is stored; when its capacity is reached, it has to be emptied by "barometric trucks" (in Uruguay this is the name given to sewage tankers with cisterns into which wastewater or silt is suctioned). However Decree 253/79 forbids that wastewater be filtered into the ground in urban areas.

Sanitation coverage reaches 94% of households nationwide. Of those, 54% have a sewerage network, while most of the rest have cesspools or septic tanks (Table 2).

Sanitation coverage of sewage sytems in the provinces is 43%, less than the national average (National Institute of Statistics, 2011), while Montevideo has the largest sewage network (more than twice the provincial average).

Montevideo

It is estimated that 90% of the urban population is connected to the sewage system, which covers 14,500 hectares and consists of 2,700 km of pipes and gutters. In Montevideo, there are two types of drains: the older ones are combined (transporting wastewater as well as storm water), which account for 60% of the total; while the remainder separate the two functions. Today, improvements and developments are only carried out on the latter system.

The objective of the sanitation and drainage system is to improve the quality of the urban environment. As already stated, the Sanitation Division of the City Council (IM) of Montevideo, unlike the rest of the country, not only operates the wastewater system but also the whole drainage system, including storm water drainage and in management of the watercourses. Thus, both systems are simultaneously planned, built and managed, thereby eliminating interference and interconnection problems; the City Council also manages the waterbodies into which these systems release their contents.

When the final stage of the Plan for Urban Sanitation IV (Spanish acronym PSUIV) is completed, the final deposition of wastewater will be released into the River Plata by means of two underwater ducts. Before it reaches the duct, wastewater will pass through a pre-treatment plant with gates, sieves and sand removal equipment. One plant on the east of the city has been in operation since the 1990s. This plant is fed by the combined system and operates even when there is no rainfall. The future duct will only receive wastewater (given that it is connected to the system that separates the two types of wastewaters) from the west side of the city.

According to the 2011 Census, 14.2% of households in the Department of Montevideo use an impermeable septic tank for their wastewater. The goal of the Sanitation Division of Montevideo City Hall is to expand the system to the entire urban population to reach the 130,000 inhabitants in the urban area who currently lack this service. To this end, the Montevideo Sanitation Master Plan has been implemented since the 1990s; the Master Sanitation and Urban Drainage Plan (Spanish acronym PDSDUM) whose planning horizon extends to 2050, is currently being updated (see Box 11).

Interior of the country

Approximately 42% of the urban population in the provinces has access to a sanitation network operated by the State Sanitation Company (OSE) with about 280,000 connections. This system is independent and only deals with wastewater, while stormwater drainage in the urban areas is the responsibility of each local government. Sewage coverage in the various urban areas is heterogeneous, exceeding 60% in some cities (with 30,000 to 70,000 inhabitants), though in some cases, it is less than 30%, and there are some areas (with over 20,000 inhabitants) in the metropolitan area that are still not connected to the network.

Although the State Sanitation Company is advancing in the construction of new sewage networks, particularly one in a major city in the metropolitan area (Ciudad de la Costa, with over 100,000 inhabitants) and major network extensions in several of the capital cities, there are still many towns with over 5,000 inhabitants (and even 10,000) that do not have a drainage network. Thus the proposed goals for sewage coverage through the sewage networks do not yet include the whole urban population.

On the other hand, 16% of the population that has a sanitary system in front of their dwelling is not connected to it. In order to increase the number of connections, the State Sanitation Company and the Ministry of Housing, Land Management and the Environment have created the National Sanitary System Connection Plan to provide financial support for low income homes for the purposes of improving

Table 2. Type of sanitation service in private households in rural and urban areas

	Total		Urban		Rural	
		%		%		%
Population (inhabitants)	3,286,314	100	3,110,701	100	175,613	100
Sanitation network		53.6		56.9		-
Septic tank		37.8		35.6		84.8
Pipes leading to a watercourse		0.6		0.5		1.6
Other system		0.3		0.2		1.1
Without sanitation services		1.6		1.5		3.3
Information not available (%)		>4		>1		>8

Source: INE, 2011 Census

their internal sanitary system so that they can be subsequently connected to the drainage system network (Rojas, 2014).

An important feature in Uruguay are the interferences and interconnections between the transport and evacuation of storm water and sewage waters in separate systems. This means that the network often works at overpressure, often causing a delay in the flow of water due to the connections, and overflowing into the streets (lifting up manhole covers), or channeling the flow into storm sewers or watercourses, with the corresponding negative effects.

Regarding sewage treatment, the State Sanitation Company's sanitation investment plan, begun in 1990, emphasizes the construction of treatment plants in urban centers with sewage networks. Twelve treatment plants have been built in several provincial capitals, while other cities have oxidation ditches and treatment lagoons. Thus, wastewater in approximately 80% of the homes connected to the sewage networks in the provinces is channeled into wastewater treatment plants. Cities located on the Uruguay, Negro or Plata Rivers only have pre-treatment plants, although plans are

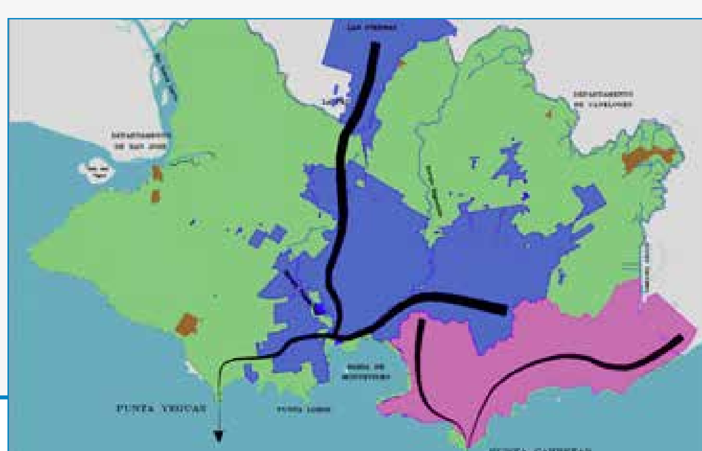
Box 11

Montevideo Master Sanitation and Urban Drainage Plan

The city of Montevideo has a continuous sanitation planning process. Between 1992 and 1995, the first version of the Montevideo Sanitation and Drainage Master Plan (Spanish acronym PDSM) was created. This is a strategic plan whose planning horizon is divided into three periods: two 10-year periods (1995-2005 and 2005-2015) and a final period of 20 years to 2035. During the first stage (Urban Sanitation Plan III, Spanish acronym PSU III), 570 km of networks and 10 pumping and syphoning stations were built on the Miguelete and Pantanoso Rivers. Sanitation and drainage was extended to 3,900 hectares of the city and to 11,000 persons. The existing sanitation and drainage system was restructured while networks built during the 19th century were refurbished. Measures to reinforce organization were also adopted, including the design of new structures and management tools.

During the second period (2006-2015), extensions to the networks were completed and the final disposal sites on the west side of Montevideo were built, together with four pumping stations, a pre-treatment plant and a new underwater duct. Total investment in these two periods amounted to \$440 million dollars (an average annual investment of \$22 million dollars).

Due to the changes in the environment, society, the economy and practices, the strategic planning process began to be updated in 2005 with the Montevideo Sanitation and Drainage Master Plan (Spanish acronym, PDSDUM) (see: www.montevideo.gub.uy). In the figure in this box, blue shows the final disposal system on the west side of the city (to the Punta Yeguas duct); violet indicates the final disposal system in the east, (Punta Carreta duct) while green denotes areas without sanitation services, mostly in rural areas.



in place to improve the quality of waste disposal. Likewise, there are residential complexes subsidized by state programs with independent treatment systems (individual septic tanks and lagoon systems) run by the State Sanitation Company. Table 3 shows the domestic sewage treatment plants managed by the State Sanitation Company nationwide.

Fifty-eight per cent of the urban population in the provinces lack a sewage system network although they do have septic tanks managed by their users. These tanks have an approximate volume of six cubic meters. Given that a typical four-person household consumes 18 cubic meters of water per month on average (130 liters/inhab./day), the impermeable tank must be emptied at least once every two weeks and its contents transported to the appropriate plants for their final treatment.

The service with barometric trucks are expensive for their users. Although theoretically impermeable, these systems often experience surface or underground losses, dumping their contents in the storm drains in the public thoroughfare or underground. A variation on this theme is the direct discharge of "gray water" (water used for washing and cooking) into the street to delay the filling of the septic tank. According to the 2011 Census, only 65% of homes with a septic tank use sewage tankers. According to an estimate by the Potable Water and Sanitation Division of the National Water and Sanitation Office, sewage tankers in cities in the provinces are able to handle just 16% of septic tank contents, assuming they were all totally impermeable. Moreover, there are not enough places for the sewage transported in these trucks to be dumped. As an example, only six departments have a suitable place for the disposal of these contents.

4.2 Non-Domestic Wastewater

Apart from domestic wastewater, there are several other types of wastewater in Uruguay.

Industrial wastewater: the authority in charge of regulating and controlling the disposal of industrial wastewater is the National Office of the Environment (Spanish acronym DINAMA) of the Ministry of Housing, Land Management and the Environment. Given that approximately 40% of industries that produce wastewater are located in Montevideo, Montevideo City Hall also controls and monitors these industries (National Office of the Environment, DINAMA, 2012). In 1996, a Plan for the Reduction of Industrial Contamination was launched, resulting in a significant reduction of the volume deposited which made it possible to achieve significant progress in the quality of industrial wastewater in Montevideo (Montevideo City Hall, 2012).

Table 3. Quantification of treatment systems managed by the State Sanitation Company (OSE, 2012)

Type of system	Quantity
Pre-treatment and discharge	3
Imhoff tank	1
Activated sluedge (extended aeration); nitrogen removal; UV disinfection	6
Transported in sewage transport truck	53
Treated in lagoons	229
Treatment of sewage by upward-flow anaerobic reactor (UASB)	2
Run-off plots	2
Imhoff tank with percolating filter	1
Activated sludge with conventional aeration	2
Activated sludge with extended aeration	11
Oxidation ditches-UV disinfection	1
Oxidation ditches	5
Dumping nearby system	38
Information not available	69
Total	**420**

Storm water and street cleaning: storm water carries solids, oil and other contaminants, but nationwide figures for this are as yet unavailable.

Water for businesses, shops and other services: some businesses (restaurants, laundries and dry cleaning, health centers, etc.) produce waste that constitute localized discharges of a significant volume and poor quality that are dumped into the sewage networks. These businesses need to undertake specific actions to improve the quality of their wastewater.

Leaching in final solid waste disposal: on a national basis, the broad majority of final Waste Disposal Sites (WDS) for solid waste are sites over which there is a widely varying degree of control, but which are not usually properly managed (Office of Budget Planning, Spanish acronym OPP, 2011). Of 23 WDS that receive more than 10 tons/day, only two have landfill characteristics and five have leachate recovery and treatment systems.

4.3 Sewage sector challenges

Below is a list of some of the main challenges facing the sanitation sector nationwide:

- Expand sanitation network coverage. Although construction of sanitation systems and treatment plants continues, ($220 million dollars were invested during the period from 2010 to 2013), several major urban areas still lack this service. This is the case of at least 14 cities and urban centers with over 5000 inhabitants (six localities with over 1000 and seven with over 5000 inhabitants for an approximate total of 168,000 inhabitants), as well as outlying areas in cities that already have networks.
- Increase the number of connections in areas covered by networks. Connecting up with networks can be expensive, especially for low-income families. However financing and subsidy projects such as the Fondo Rotatorio de Conexiones (Montevideo) (the Rotating Connections Fund) and the Plan Nacional de Conexión al Saneamiento (National Sanitation Connection Plan) have been developed, and are supported by social promotion activities in order to make connecting up with a sanitation network viable.
- Provide alternative decentralized sanitation solutions to the impermeable septic tank and improve quality standards. To this end, certain restrictions have to be overcome, such as the low technical capacities of municipal organizations; weaknesses in the legislation regulating the service (the existence of other systems that are not septic tanks is not contemplated), as well as users' lack of awareness of the system's shortcomings. Providing universal, affordable sanitation that is environmentally sustainable requires long-term planning that incorporates land-use management principles.
- Update the legislation for domestic and non-domestic wastewater. It is essential for the laws to introduce control criteria for disposal volumes; limits should be set not only on the basis of concentrations, but also of absolute volume.
- Investment to improve WDS management in the provinces. The improvements not only require an increase in funding but also in qualified human resources.
- Some areas that require immediate improvement in their operations have been identified: all aspects of control (control of discharge quality; monitoring waterbodies, etc.) and technical capacities in different parts of the country. Moreover, as in the potable water sector, institutional reinforcement is required for the departments involved in the planning and management of sewage services.

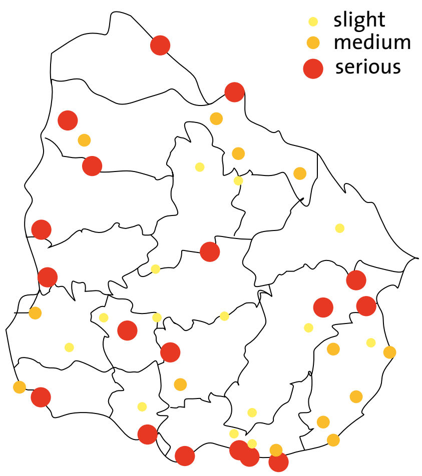
5. Stormwater

Stormwater provides several benefits for cities (use for irrigation and green areas, among others). However, from the traditional hygienist point of view, its management focuses on conflict resolution, which conceals its potential. This section presents the country's main problems affecting rainwater drainage as well as recent initiatives that are successfully addressing these problems and changing the approach adopted, in order to move towards a system of sustainable rainwater drainage management.

5.1 Principal problems

In Uruguay, storm drainage problems affect both capital cities and small localities. More than

Figure 4. Cities with drainage problems and type of drainage problem arranged by percentage of localities with problems



Sanitation and sewage connected to rainwater or streets	79%
Glens within private properties	68%
poor maintenance of the gutters	00%
Tube problems	55%
Works or developments upstream	53%
Storm sewers connected to sanitation	53%
pedestrian / vehicular entries inadequate size	49%
Poor maintenance of the network	46%
Poor designed gutters	40%
Pipes knowing the size of watershed and downstream effects	38%
Insufficient crossings	32%
Lack of capacity for gutters or collectors	32%
Lack of capacity for gutters or collectors	25%
Storm drains clogged by solid waste	16%
Others	18%

Source: MVOTMA/DINAGUA, 2011

60 urban centers are affected by storm drainage problems, with 70% considered to be moderately serious or serious (National Water and Sanitation Office, Ministry of Housing, Land Management and the Environment, 2011) (Figure 4).

The most frequent problems are caused by the conflicting interaction between subsystems: intrusion of stormwater into the sanitation system, reduction of drainage capacity due to interference from other piping systems; little or no consideration of water resources in city land planning (streams on private plots of land), upstream works or urban development, an increase in natural runoff, etc.), or cultural factors (poor management of gutters and storm drainage systems; sewage systems connected to storm water or vice versa, etc.)

Although stormwater drainage problems are similar between localities, local capacities to address them differ (Figure 5). The differences between provincial cities and Montevideo are significant, as evidenced by the fact that Montevideo has had a Master Plan for public works since 1994.

Montevideo has several sorts of flooding problems. In the consolidated urban area, the lack of drains causes flooding in the streets and homes. This is due, among other factors, to the design criteria applied to the construction of some of the networks (before 1950). Moreover, an increase in the impermeability of watersheds has caused an increase in the water flow. Other types of flooding occur along riverbanks, and where dwellings have been built in areas liable to flooding. There is also a third type of flooding caused by high water levels of the River Plata, which can cause flooding even in times of drought. These occurrences, if they coincide with precipitation, cause the greatest impact in cities.

According to an analysis undertaken by the National Water and Sanitation Office, technicians in local governments believe that the problem is caused by lack of planning and human resources dedicated to planning processes. The absence of drainage system planning makes it impossible to analyze storm water drainage problems on a national basis, thus making it difficult to quantify the amount of investment required.

Nevertheless there is information from various sources that allows an estimate for the current situation to be made. The Urban Environment Census[4] (The National Institute of Statistics 2011, Spanish acronym INE) yielded several items of interest: types of road surface, location of pipe infrastructure (gutters, drains, curbs), collection systems, (storm drains), as well as the existence of landfills. Although the information is very general,

4. Together with the Population Census, the INE undertook the first Urban Environment Census that classifies street sections according to their features and different types of infrastructure.

it does have the advantage of being national. The Urban Flooding and Drains Team of the National Water and Sanitation Office has identified problem areas related to water in cities using a participatory methodology with technicians and information on cities. The information was used to create conflict perception maps that identify storm water problems, interaction with other subsystems, proposals and complementary information (Figure 6).

Montevideo City Hall has a Geographic Information System that publishes land registry information on the drainage and sanitation system. The information describes the geometric and altimetric features of drainage networks and their special structures. There is also a general analysis and an estimate of what is required to solve existing problems and to develop and expand the city.

5.2 Advances and challenges in rainwater management

Within the framework of creating an effective public sector planning system, progress has been made in the following areas:

- Coordination with local Land-use Planning Teams, especially as regards to the designation of areas for city expansion, proposals for parks built on rivers, limits on the impermeability factor for soils, etc.
- Integration with other infrastructure projects in order to identify possible synergies among the different subsectors is beginning to be common. For example, the implementation of projects that combine storm water drainage with sanitation, roadways or park planning works.

Figure 5. Rainwater drainage problems in various cities in the country

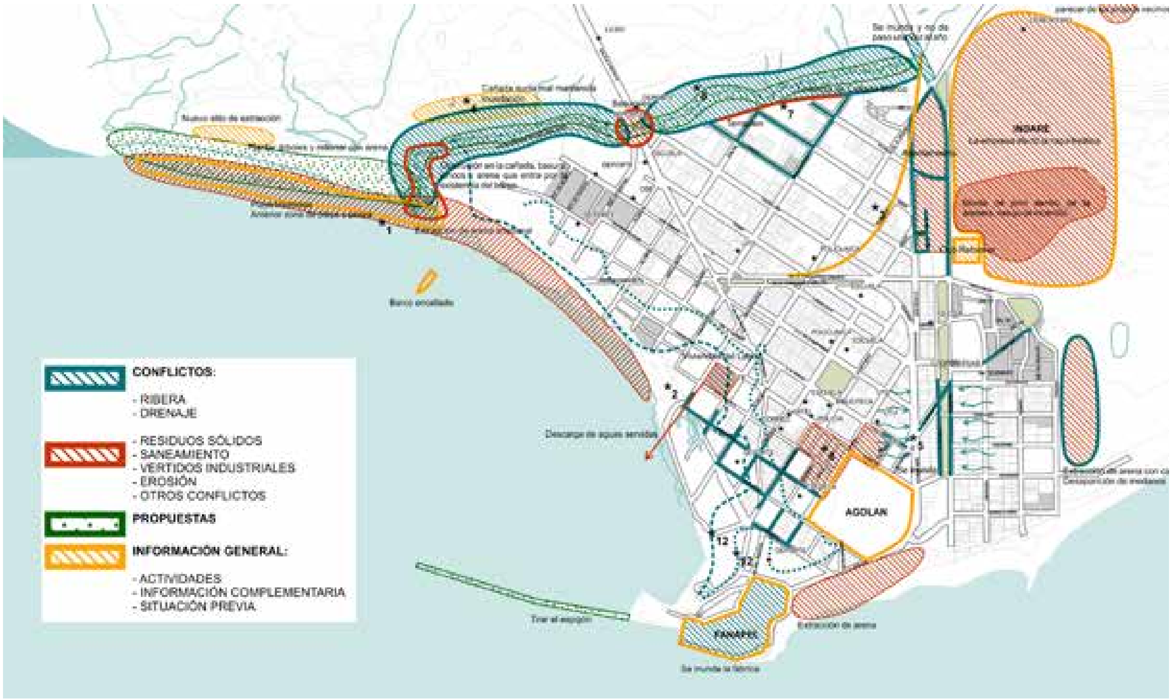
Source: MVOTMA/DINAGUA, 2011.

- Experience of control at source, both in Montevideo and more recently in other cities, has enabled the legislation to define measures limiting ground impermeability and buffering capacity within set standards. As a result, studies have been carried out in Montevideo on more than 20 residential buffer lagoons in large impermeable areas. Another interesting experience involved Ciudad de la Costa, where buffer ditches have been built to protect the water supply, thereby reducing its contact with the beach (Figure 7).
- Buffer pools in public spaces; for example, the construction of retention ponds has reduced the impact of flooding in several areas in Montevideo and in the provinces, and in many cases they have been able to be used by the public. In recent years more than six buffer areas or flood zones have been built, and a flood zone and four underground buffer tanks are currently in operation in Montevideo.
- Experience in the sharing of responsibilities and benefits by permitting exceptions in building laws, has meant that private constructors have built a number of storm water works (as in the case of the Diamantis Plaza building).
- Joint planning. The experience of planning and coordinated works has shown the need to undertake integral water management plans. Urban Water Supply Plans related to groundwater supplies, flooding, water for industrial and residential use, storm water drainage, industrial effluents and sanitation, and their link with solid waste and land-use planning are underway in the cities of Salto, Young and Ciudad del Plata.
- Updating the Master Sanitation and Drainage Plan (Spanish acronym PDSDUM). Montevideo has a Master Plan that defined infrastructure works over the past 20 years. At present, the bidding process has begun to update this plan, whose projection horizon extends to 2050.

6. Urban Riverbanks

Riverbanks are a fundamental part of city life, but at the same time they are a problem (basically due to flooding) as well as providing an opportunity for recreation and tourism.

Figure 6. Juan Lacaze conflict maps



Source: DINAGUA/IDU, 2012

Urban floods

Most of the rivers and streams in Uruguay lie on slightly sloping alluvial plains, with long, slow swelling as opposed to the sudden, short swelling typical of mountain rivers and streams that flow quickly down steep slopes. Flooding severely affects local economies and cities, though loss of human lives or injuries to people are rare

6.1 Situation in cities

Since 2000, 73% of the events recorded by the National Emergencies System were hydro-meteorological (floods, drought, storms, hailstorms, tornadoes) and 63% were floods. According to that database, more than 30 population centers located in 18 of the 19 provinces in the country have been affected. The population of 25 of these centers, of which 14 are capitals of their provinces, amounts to over 10,000.

Nationwide, more than 67,000 persons have been affected since 2000, with the situation being considered critical in the city of Río Branco, where more than 20% of the population were affected by the worst flood ever recorded (2002), Durazno (6,966 evacuated in 2007), Artigas (5069 in 2001), Paysandú (4,355 in 2009), Salto (3,230 in 2009) and Ciudad de la Costa and Costa de Oro in the 2014 floods (Figure 8).

The reasons behind the scope and persistence of the problem are varied and complex. Hydro-climactic factors (such as an increase in the magnitude and frequency of flooding causes, such as rain and/or sea level) can be critical, but do not fully explain the impact caused, since the risk of flooding is a process of social construction of threats and vulnerability (Blaikie et al., 1996), which complicates the search for long-term solutions.

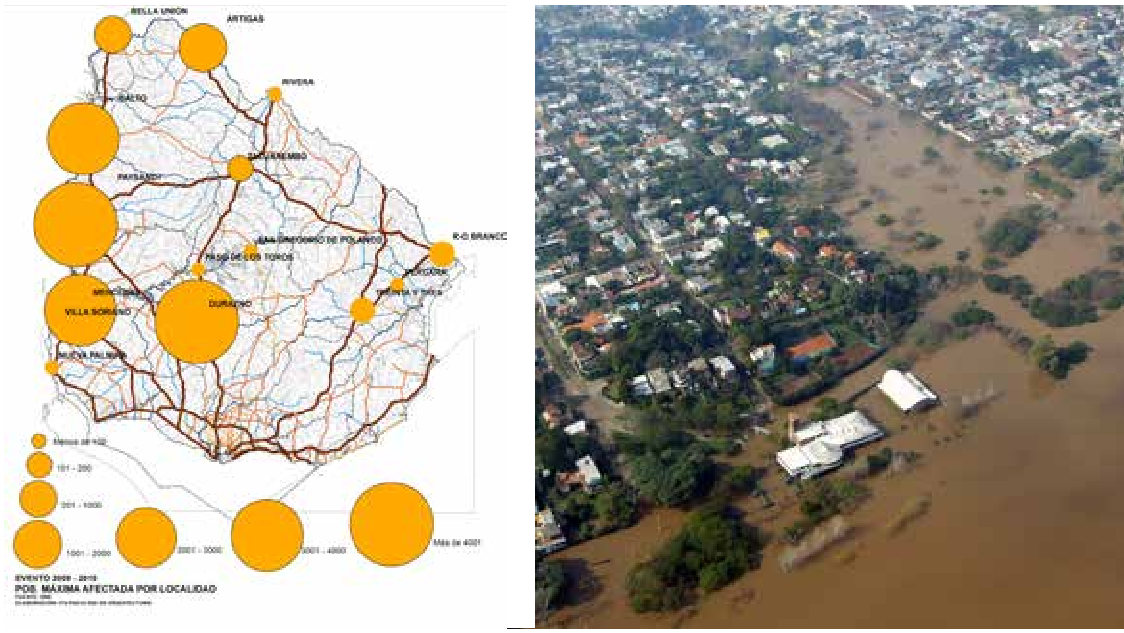
6.2 Advances and challenges regarding floods

For a number of years now, integrated flood measures have begun to be implemented (Integrated Risk Management, Integrated Flood Management). A process exists for the coordination of structural

Figure 7. Storm drains in Ciudad de la Costa: buffer ditches (left); area with project not implemented (right)

February 2014 flood; Source: www.lr21.com.uy

Figure 8. Evacuees in the 2009-2010 floods (left) Salto flood 2014 (right)



Source: Piperno et al., 2009; Photo: Salto City Hall.

measures (civil works) and non-structural measures (regulatory measures, training, coordination and participation) and for risk management through prevention and mitigation as well as warning and response. Below are some of the measures in which Uruguay is currently advancing:

- Inter-institutional coordination: The Law of the National Emergencies System (Law 18621) promotes risk management through a national network, incorporating key national and provincial organisms. Though still very new, it is slowly being implemented.
- Advances in knowledge: in recent years the country has capitalized on the improved knowledge on hydrological processes in river basins, the hydrodynamics of rivers and fluvial ecosystems, and the concept of threat and vulnerability. Progress has been made in the analysis and evaluation of solutions and with in-depth studies that help management. The developments in the cities of Artigas, Salto, Tacuarembó, San Carlos, Treinta y Tres, Melo and Durazno are good examples of this, particularly the solutions proposed by the populations affected (San Carlos, Salto and Melo), and by the University of the Republic (UdelaR Spanish acronym) (Institute of Fluid Mechanics and Environmental Engineering, the Institute of Theory and Urbanism, Faculty of Science, among others).
- Advances in professional training: there are experienced professionals who are trained to deal with flooding problems from the point of view of fluvial engineering, fluvial ecosystems, social and economic factors and land planning; training programs also exist that promote interdisciplinary action. However, the numbers and the nationwide distribution of these suggest that improvement in local training is required. The decentralization of the University of the Republic in 2009 and interdisciplinary options such as the bachelor's degree in Environmental Management, Applied Water Sciences and the master's degree in Integrated Coastal Management are some examples of this.
- Improve emergencies warning and management systems, particularly the Hydrological Warning System and the Emergency Action Plan (Spanish acronym PADE) at the Salto Grande hydropower dam and the Negro River dams managed by the National Administration of Power Plants and Electricity Transmission (Spanish acronym, UTE), as well as the Early Warning Sys-

tem (Spanish acronym SAT) currently in operation in Durazno and soon to be implemented in Artigas as part of an interinstitutional project supported by the National Innovation and Research Agency (Spanish acronym, ANII).

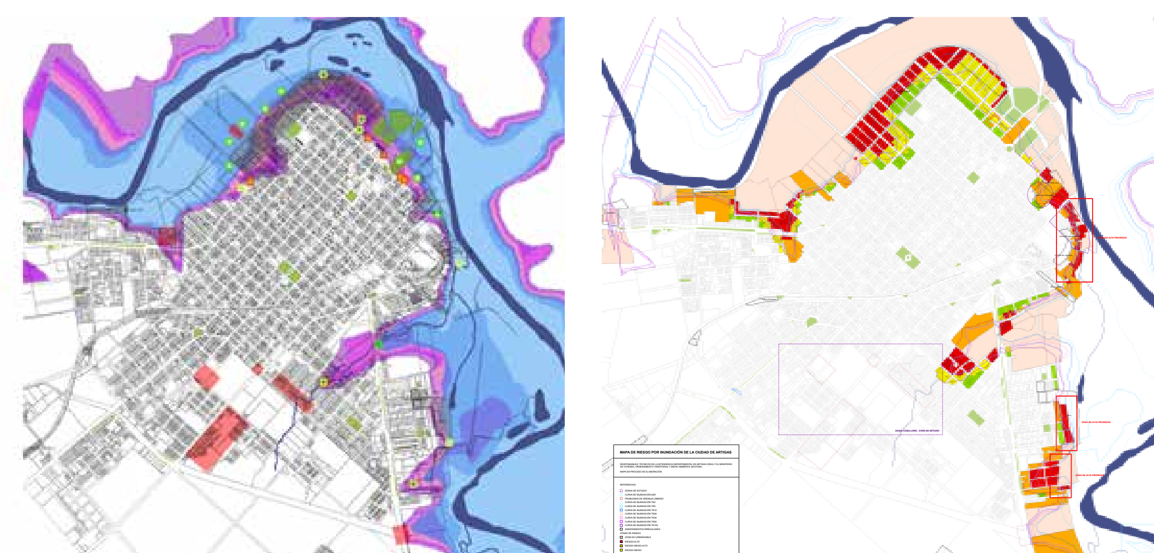
- Hydrometric networks with telemetric transmission are very useful for alerting, monitoring and operating emergencies in the event of hydrometeorological extremes. Although the main objective of the telemetric stations in the Yí River basin (National Administration of Power Plants and Electrical Transmissions, Spanish acronym UTE) is to quantify the contribution of central hydroelectric plants to the reservoirs, they are also used as an Early Warning System in Durazno, a concept that could be adapted to at least six localities in the Negro River basin (see Box 12).
- The incorporation of risk maps into local land-use planning in order to be able to define transformation areas (high-risk) and mitigation areas (medium and low risk). Flooding, vulnerability and risk maps have been created for the main cities with this problem (Artigas, Durazno, Salto, Treinta y Tres and Melo) (Figure 9).
- Flood risk is a high priority item in the implementation of public housing policies (Relocation Plans; acquisition of a new land portfolio, etc.).

6.3 Ecosystemic services of urban river systems

Urban populations have historically depended on a group of services provided by water ecosystems, several of which are essential to human well-being. Ecosystemic services include all the goods and services human societies obtain from natural systems (supplies, support, regulation, culture). The interaction between ecosystems, related ecosystemic services and the key factors in human well-being create extremely complex entities, now known as socio-ecological systems.

In Uruguay, ecosystemic services have not been historically identified or properly appreciated by the population or by those directly or indirectly involved in the management of the environment. This lack of knowledge, among other issues, has caused legislation, urban residential development and infrastructure works to ignore natural systems, thus jeopardizing sustainability as well as numerous services. At the urban level, although fluvial systems or rivers have historically been used for discharging wastewater and their banks for recreation, rivers are seldom regarded by society in an integrated manner while recognition of the importance of ecosystemic services in public policy is still incipient. Moreover, the increase in pressure caused by the need to make productive use of these resources promotes the

Figure 9. Flood risk and threat in the city of Artigas



Source: DINAGUA, Artigas City Hall

The early warning system in the city of Durazno

BOX 12

Throughout its history, the city of Durazno, located on the Yí River, has been liable to heavy flooding. Its most famous flood was said to have occurred in 1959, until the events of 2007 and 2010, which far exceeded it in terms of water levels and numbers of persons affected. Within the framework of the agreement between the World Meteorological Organization and the Julio Ricaldoni Foundation-Uruguay, improvements in flood management in Durazno were sought by means of a flood warning system. The result was the Durazno Early Warning system (Spanish acronym SAT), a locally operated system on the occurrence of drainage levels and their estimated permanence, which guarantees the required accuracy and reliability.

This system includes three modules: the first reads the data entered into the system from multiple sources (the telemetric network's rainfall records, other rainfall records and weather forecasts), the second module (Silveira et al., 2012) simulates the course of the Yí River Basin in order to obtain predictions for increased water levels in the city of Durazno (hydrological-hydrodynamic model) while the third module produces and prints out the results, including maps of the urban areas that will be affected by the predicted flood. The main advantage of the new systems lies in its ability to accurately predict between 48 and 72 hours in advance the date and time of the oncoming flood's highest water level and the permanence in time of levels above critical parameters, to enable emergency measures to be adopted. This system has greatly improved the flood emergency management service, run by the Durazno Emergency Coordinating Center (Spanish acronym CECOED).

perception that they are not finite and shifts the subject of the value of natural ecosystems into the sphere of management.

Although a systematic record of studies and practices that incorporate this perspective has not been undertaken in Uruguay, they are identifiable given the importance of the problem and of certain associated practices in particular cases. One case is the Maldonado River in the city of Maldonado, which has incorporated into its Local Planning project soil categories and an Eco-Park project, based on hydrological and biological studies carried out by the University of the Republic (Spanish acronym UdelaR). Another interesting case involves the Carrasco Stream located in the metropolitan area of Montevideo, seeking to emerge from a historical problem of deterioration. The first urban-rural land-use plan is currently being prepared with the purpose of ensuring the sustainability of an ecosystemic service (potable water supply) in the basin of the Laguna del Sauce (Lagoon) and evaluating the economic benefits of several environmental services.

More than 300,000 persons (45,000 in precarious settlements) currently live in the Carrasco River Basin and the introduction of industries over the course of time in the upper part of the basin has been a permanent source of contamination since earlier times. Major canals began to be built in the wetlands near the Carrasco River in 1975 in order to dry them out and to take advantage of "fallow land." However, these works eliminated an important component in the buffering and filtration of the wastewater provided by the ecosystem,[5] affecting the activities of groups of wealthier social sectors downstream. This made the problem visible and its recognition led to a series of actions, including the Integrated Strategic Management Plan for the Carrasco River basin (Spanish acronym PECAC) in 2007.

5. Monitoring campaigns by Montevideo City Hall have registered total phosphorous and nitrogen levels that far exceed the maximum levels established by national and international legislation. http://www.montevideo.gub.uy/ciudadania/desarrollo-ambiental/cursos-de-agua/programa-de-monitoreo

6.4 Challenges to an ecosystemic vision

Uruguay must change the way it systematically incorporates ecosystems, particularly water ecosystems, into the management of its cities, given that:

- In order to protect and/or restore ecosystemic services, a multiplicity of processes and related scales must be taken into account. Future action on urban watercourses must not focus exclusively on what takes place inside the city and must instead contemplate longitudinal (up and downstream), lateral (e.g. flood plains) and vertical (groundwater) interactions.
- The response of ecosystems' to human use is neither linear, predictable, nor controllable, while the ways natural processes work has a number of counter-intuitive characteristics that create a discrepancy between human perception and actual functioning. This will require the understanding and appropriation of the scientific knowledge currently available in management spheres.
- Urban planning must systematically incorporate the idea that the various uses of water resources in the urban environment can be conflicting and cause the loss of one or more services.

7. Governance of the urban water supply

Governance is the process of interaction between public and private stakeholders at different levels and their rules of the game, both informal and formal, on the basis of which a society determines its behavior and makes and implements decisions. Below are three dimensions related to this concept: public institutions that plan and manage the urban water supply, the regulatory framework and forms of participation of organizations and the general public in decision making.

7.1 Institutions responsible for planning and managing water resources

As regards the planning and management of water resources, there are several institutions acting at various levels. In Uruguay, the Executive Branch is the national authority responsible for water management and related policies. It operates through the National Water and Sanitation Office, (Spanish acronym DINAGUA), which reports to the Ministry of Housing, Land Management and the Environment (Spanish acronym MVOTMA). This organization is responsible for drafting the National Water Resources Plan and the National Drinking Water and Sanitation Plan. Likewise, MVOTMA, through the National Office of the Environment (Spanish acronym DINAMA), is responsible for policies regulating the quality of the environment, watercourses, and discharges.

The State Sanitation Company is responsible for the provision of drinking water service nationwide and of sewage to provincial cities. It is a decentralized service administered by MVOTMA. Although it enjoys budgetary autonomy and receives no national government subsidy, its rates require approval from the Executive Branch and its plans must be consistent with the guidelines set by the National Water and Sanitation Office (Spanish acronym DINAGUA).

Local governments across the country are responsible for urban drainage systems and establishing rules for the occupation and use of flood areas. They also regulate the indoor sanitation facilities of households and construct individual sanitation systems. They provide sewage tankers and are responsible for the final disposal of silts and solids and sometimes deliver this service themselves. Montevideo City Hall is also responsible for the Sanitation Service of the entire province.

The Ministry of Public Health is responsible for sanitation and the supply of potable water in the country in cases where human health is at risk; it also sets environmental health control standards (National Food Technology Regulation) (Reglamento Bromatológico Nacional).

The Water and Power Services Control Unit (Spanish acronym URSEA) is a decentralized organ of the Executive Branch that enjoys technical autonomy and is connected to it through the Ministry of Industry, Energy and Mining. It is responsible for activities "…. related to the adduction and distribution of drinking water through networks when it is destined partially or completely for third parties, and drinking water production, understood as the collection and treatment of raw water and its subsequent storage, when it is intended for distribution at a later date."

The Office of Budget Planning (Spanish acronym OPP) was created to help the Executive Branch design development plans and programs, and plan the decentralization policies to be implemented.

The Advisory Commission on Water Resources and Sanitation (Spanish acronym COASAS), established in the Law of National Water Resource Policy, allows for the participation of the three sectors: government, water consumers and civil society.

At the same time, the University of the Republic, a public institution, conducts significant research and training activities on water resources in general and on the urban water supply in particular.

There are also housing improvement and access policies such as the Neighborhood Improvement Program (Spanish acronym PMB), which includes, among other financeable works, the refurbishment, expansion and/or construction of sewage systems, household connections, connections to urban networks and the construction of individual or collective solutions for wastewater treatment, pumping stations, pumping lines, effluent treatment plants and the like (see http://pmb.mvotma.gub.uy). Likewise, the Movement for the Eradication of Unhealthy Rural Dwellings (Spanish acronym MEVIR) constructs housing with built-in sanitation.

7.2 Principal normative instruments

The introduction of the Land-use and Sustainable Development Law No. 18.308 (2008) (Spanish acronym LOTDS) and the Law on the National Water Resource Policy, Law No. 18.610 (2009), led to the start of a paradigm change regarding water resources that advanced the idea of integrated water, environmental and land-use planning. Although the legal framework for flood management and urban drainage systems has yet to be consolidated, progress has been made in institutional organization. Below is the most relevant legislation on the subject (see www.parlamento.gub.uy and Box 13 on water as a human right in Uruguay, according to Article 47 of the Constitution):

- The Land-use and Sustainable Development Law (Spanish initials LOTDS) states that "land-use instruments should direct future urban development towards areas not affected by floods identified by the state entity responsible for water resource legislation".
- Law No. 18.610 (Law on National Water Resources) based on land-use, conservation and protection of the environment, includes the preservation of the hydrological cycle and sustainable management of water resources, the setting of priorities for water use by region, basin or parts of them, giving priority to the providing of potable water and sanitation services over other demands, and also provides for the establishment of Regional Councils.
- The Land-use and Sustainable Development Law (Spanish acronym LOTDS) states that "land-use instruments should direct future urban development towards areas not liable to flooding identified by the state entity responsible for water resource use."
- Law No. 18.610 (Law on National Water Resources) based on land-use and environmental conservation and protection, includes the preservation of the water cycle and sustainable water resource management, the setting of priorities for water use by region, basin or parts of the latter, giving priority to the delivery of drinking water and sanitation services over other demands, and also provides for the establishment of Regional Councils.
- Law No. 18.621, which establishes the National Emergencies System (Spanish acronym SINAE) states that "the public institutions responsible for formulating and/or implementing development plans, sectoral strategic plans and/or land-use plans are obliged to incorporate planning, analysis and risk zoning so that the policies resulting from this process contain the necessary provisions to reduce the risks identified and address the emergencies and disasters they may cause."
- Law No. 18.840 states that connections to existing public sanitation networks and their construction in the future are of general interest.
- Executive Branch decree No 78/010 defines sanitation as systems that transport wastewater through drains or sewage tankers for final dis-

Box 13

The human right to water in Uruguay

Taken from Article 47 of the Constitution (reform approved by 65% of eligible voters through a referendum conducted October 31, 2004)

- Protection of the environment is in the public's general interest.
- Water is a natural resource essential to human life.
- Access to drinking water and access to sanitation systems are basic human rights.
- Sustainable water management that takes future generations into account and the preservation of the hydrological cycle are both in the public's general interest.
- Users and civil society will take part in all planning, management and control of water resources, with river basins being established as basic units.
- Setting priorities for the use of water by region or basin (or parts of them), the first priority being the supply of potable water to the population.
- Drinking water and sanitation service delivery should be provided for social rather than economic reasons.
- Water is a unitary resource, subject to general interest, which forms part of the public state domain, as public water domina.
- The supply of potable water for human consumption and sanitation system services to the public at large will be carried out exclusively and directly by state legal entities.

posal in a treatment plant, as well as storage and final disposal "in situ" with filtering wells and/or by filtering into the ground.

7.3 Citizen participation in the urban water supply

Recent legislation reflects the state's interest in involving citizens, whether or not they are organized, in development processes related to water, land, the environment and local political representation.[6] Since the mid-20th century, citizen participation has evolved from demanding public services for providing information and consultation and to a very incipient joint management between the state, consumers and/or civil society (Garcés, 2013).

Participation in filing complaints

The State Sanitation Company (Spanish acronym OSE) and local government have a system for receiving complaints with stages of development. In particular, Montevideo City Hall offers a Customer Service Center, while the Residents' Defender's Office has existed since 2007.

Budgets and financing

Departmental committees (local government legislative bodies elected by citizens) are responsible for the five-year budget, external financing and urban legislation. The Montevideo Departmental committee is responsible for monitoring the sanitation policy designed and implemented by the Sanitation Division of the Department of Environmental Development.

Citizen involvement in programs

The micro-financing program for indoor work in dwellings and for connecting them to the sanitation networks requires citizen involvement in planning the system; which ends when the debt is settled. Likewise, active lobbying by grass-roots organizations for urban housing and for official approval of non-conventional sanitation systems increases the portfolio of land suitable for urbanization.

6. The Law for the Evaluation of the Environmental Impact (Law No. 16.466 and its regulation Decree 349/005; Land-use and Sustainable Development Law (LOTDS) (Law No. 13.308) Law on National Water Resources (Law No. 18.610) and the Law of Decentralization and Citizen Participation (Law No. 18.644).

Information and citizen consultations

Uruguayan law requires that citizens be provided with information and consultation on environmental matters for projects with potentially negative effects on the environment, as defined by the National Office of the Environment (Spanish acronym DINAMA) (Decree349/005). There are also provisions in the Water Code (Art. 177) for works associated with public water concessions and in the Land-use and Sustainable Development Law (Spanish acronym LOTDS) for Local and Special Plans (Chapter V, Art. No. 25). These often include risk mapping and land-use and land occupation categories.

Co-management

Members of the Water Resource and Sanitation Advisory Service (Spanish acronym COASAS) actively participated in the drafting of the Water Resources Law, completed in 2010. Since then, their participation in the sector's activities has been minimal.

As of 2011, the Regional Basin Councils and the Basin and Aquifer Commissions, as provided for in Law No. 18.610, have been responsible for promoting the organic participation of government representatives, consumers (i.e. water users) and civil society (NGOs, unions, universities, and grass-roots social organizations). Their advisory nature, lack of funding and the small number of public servants in the technical ministry have, however, limited their ability to bring about change. To date, urban issues have been largely ignored.

Beyond formal participation

At the civil society level, there are social and environmental organizations –mostly local– whose educational, ecological and political activities are centered around water. The National Commission for the Defense of Water and Life (Spanish acronym CNDAV) played an active role in the promotion of the Water Referendum (Figure 10).

7.4 Challenges in urban water governance

- Uncertainty and the large number of uncontrollable variables demand constant evaluation and a continuous, creative, participatory redesign of strategies.
- Although the new legal framework is advancing, integrated water, environmental and land-use planning, state organizations are far from being prepared for the flexible management processes required by an integrated focus. Moreover, citizen participation structures must be updated to include more creative participation from the various sectors.

Figure 10. Mural painted during the 2004 referendum

Photo: Gonzalo Gómez

- It is also necessary to reinforce the institutions responsible for urban water policies, especially those that improve coordination between organizations with different roles in national policy design (the organization governing public health, the public drinking water supply and sanitation provider; those responsible for regulating and auditing public services and protecting users of the latter).
- The small size of the country provides a comparative advantage and allows for interpersonal exchanges between national and local authorities. At the same time, the scale of the cities makes it possible to design strategies involving a high degree of participation by the population, thus mitigating the problem.
- The knowledge production network is generally associated with management, which enables innovation to be incorporated into it.
- Although there are conflicts of interest, the large number of technicians in political spheres facilitates dialogue in the definition of priorities.
- It is essential to shift from command and control to adaptive structures. In this respect, the recently established Basin Committee liaises between the various stakeholders to overcome these difficulties, and its performance must be evaluated in the near future.

8. Challenges to integrated urban water management in Uruguay

In Uruguay, evaluation in various spheres of the historical conflicts regarding cities and their water supply, coupled with an examination of the many associated practices and experiences is achieving a shift from the current sectoral approach to a more integrative one. This translates into a non-linear process of multi-stakeholder, dynamic transformations with enormous potential, although they are not entirely free of problems.

A series of critical problems have been identified in this process. Some are already being addressed, while others are more complex. There are also other major potential problems that have yet to be evaluated. Several good practices have been developed from which lessons can be drawn, while gaps or weaknesses in the knowledge of certain subjects have been identified. This all falls within the context of conflicts of interest, financial restrictions, and the need to address priorities in other sectors.

Uruguay possesses a series of basic characteristics that could encourage the development of the traditional water management towards integrated water management (GIRH). Key aspects include a well distributed water network, average rainfall of 1,300 mm; population centers with good physical and telecommunications connectivity; a relatively small country; sustained economic growth; confidence in the country's institutions, low corruption levels and slow population growth.

In order to understand the complex process of urban water management in Uruguay, a number of

Integrating issues and the main challenges are described below.

8.1 Water in urban planning

Water supply is an essential component of cities and should therefore be incorporated into their planning. Building a city with a water supply poses a challenge on various levels (town council, neighborhood, metropolitan). The construction of urban landscapes that include storm drainage systems, or restoring small internal watercourses or the integral design of riverfronts not only reduces impacts, the cost of infrastructure and the risk of flooding but also creates spaces for public recreational use, turning threats into a resource. In this regard, there are good national practices that are gaining ground over the outdated yet still dominant model that promoted the construction of channels and the expulsion of wastewater as quickly as possible. Fortunately, good national and international practices, aided by the institutions' hiring of young technicians, are driving this transformation (Figure 11).

Taking water into account in provincial and urban land-use planning has been a slow but steady process, which has included the incorporation of flood risk maps into the use and occupation categories. Flood risk mapping provides technical support for the process of flood zone transformation and management based on the needs of the city's population and the vulnerability of river ecosystems, which, in turn, increases a city's resilience and gives rivers value in residents' collective imaginary.

All the issues related to the interaction between the nature and quality of urban life require in-depth study. Knowing what can be transformed without compromising nature implies bringing together the scattered knowledge on ecosystems, urban projects, land-use planning and social education.

8.2 Drinking water: a key human right and the intensification of productive uses

Supplying potable water for the population is the first priority of river basins, as stated in the country's Constitution (Art. 47). However the intensification of agricultural uses and its implications for the quality of the resource is increasingly affecting raw water (both surface and groundwater), requiring greater monitoring from the organizations responsible for managing the resource and increasing the cost of producing drinking water. This warning led –albeit insufficiently– to coordinated measures being adopted between the institutions involved in drinking water production and the environment to encourage more integrated public policies. Within this context, the territorial dimensions of basins associated with funds from the urban sector (whose budget allocation is particularly relevant) must be taken into consideration in a cross-scale, inter-institutional management strategy.

8.3 A system of governance appropriate to the new paradigm

Waster system management in urban areas is so complex that it can only be addressed by using an interdisciplinary, multi-sectoral approach. One of the main problems observed in Uruguay is the need to change single-sector analyses (based mainly on the command and control paradigm) into integral approaches with the capacity to promote adaptive schemes and incorporate effective monitoring and learning mechanisms to understand the causes of both successful and unsuccessful decisions made in the past.

During the past decade, Uruguay has made great strides in legislation and the organization of institutions directly involved in land and water resource management. However, real interaction between the different disciplines involved is still limited, as is fluid interaction between different levels of government. Under the current governance

Figure 11. Holding pond in the Diamantis Plaza building in Montevideo. Experience in sharing responsibilities and benefits, undertaken with financing for maximum use

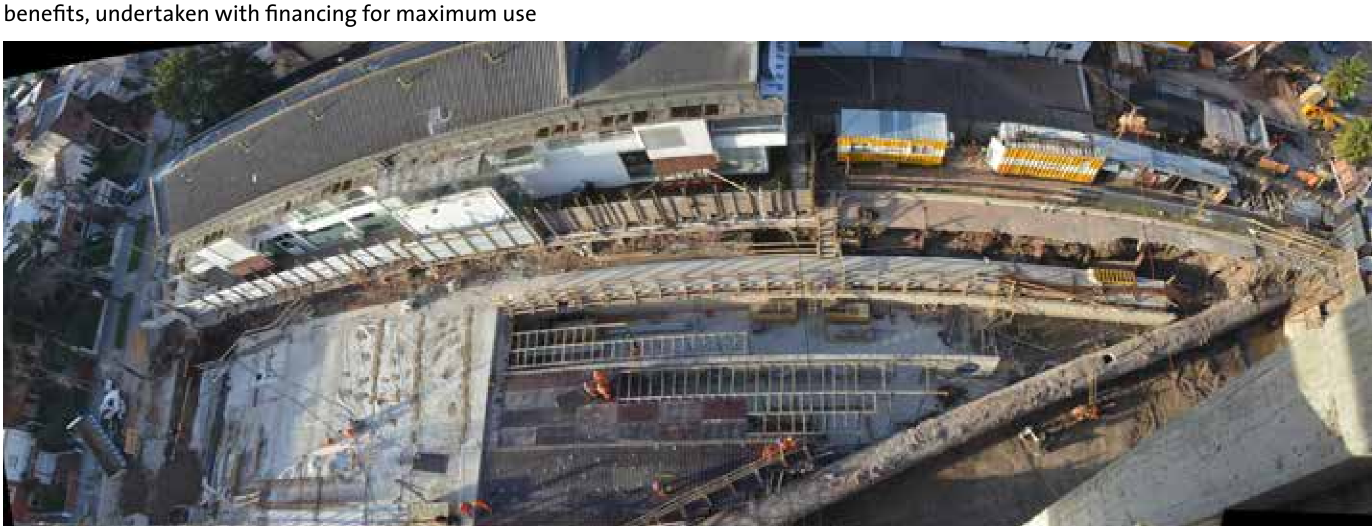


Photo: Montevideo City Hall

scheme, recently created cross-cutting organizations such as the Regional Councils and the River Basin Commissions, the National Emergencies System network and the Land-Use Committee, are groups that should be considered and strengthened.

8.4 Information and monitoring in areas of uncertainty

Urban water planning and management in a changing environment (climate variability, economic, social and cultural change) requires access to the best possible information for decision making.

Information in Uruguay varies according to the different subsectors. As an example, while large amounts of data exist on the amount of water available, information on its quality is recent and incomplete, as is the data on aquifers and rainwater. In general, the information available on water resources is insufficient for managing them properly. There is often a problem of lack of coordination of initiatives, frequently due to unawareness or proper planning (e.g. duplicate collections), leading to unnecessary expenditure. This same lack of coordination between the agencies gathering the information sometimes prevents efficient cross-evaluation. Moreover, some of the information is difficult to access (in some cases, because it is filed on paper) and/or its interpretation is extremely laborious.

Improving monitoring systems and adapting them to the urban reality would allow trends and possible modifications to be identified, which could be useful for reformulating strategies. This would also provide for transparent management and participation, based on quality information, which is essential for decision making.

Another major challenge is the need to adjust academic research projects in order to make them more useful for water management. Although this aspect has significantly improved in the last decade, there is room for improving the understanding between science and managemen.

8.5 Drinking water, sanitation and quality drainage services coverage and accessibility

Access to potable water, sanitation and quality drainage services by the entire population is one of the country's current challenges. Urban areas that currently do not enjoy these services are generally located in high-risk areas (areas not included in town planning) and/or low income areas. These population sectors tend not to be connected to formal drainage systems due to their inability to invest in remodeling their indoor sanitation systems. Moreover, these areas have a low population density, which increases the per capita cost of investment in networks.

In this respect, the expansion of the sanitation service faces the major challenge of having to adjust its strategy to specific urban characteristics due to the fact that not all the zones currently lacking sanitation networks are able to receive them. Consequently, other types of more economical networks must be found and other types of sanitation technology that treat wastewater "in situ" implemented.

Addressing this lack of services implies a challenge that not only involves building networks, but also a multidisciplinary and inter-institutional effort with short-, medium-, and long- term measures in which the population's participation is vital. Moreover, apart from needing to ensure that the expansion of sanitation services into potential town development zones is carried out in accordance with the city's urban plans, plans and projects must incorporate sanitation, storm drains and the design of associated public spaces (streets, plazas, squares, etc.). Likewise, related non-structural measures such as organizational adjustments and training the population and local technicians to use and give maintenance to the new system must be implemented.

One of the most pressing issues in solving this problem is the pressure on public housing programs to comply with the Land-use and Sustainable Development Law (Spanish acronym LOTDS), which requires that dwellings be developed and built in areas with basic services.

One issues requiring special attention is the need to implement plans to eliminate septic tanks, or reduce their impact on both the environment and human health. This widespread form of contamination, along with poor solid waste management, pollutes groundwater resources, ditches and small watercourses and is one of the main problems in the peripheries of Uruguayan cities. Given the living conditions of the population, users' economic and financial conditions must be taken into account in order to ensure the sustainability of sanitation services.

9. Final Considerations

Promoting the value of water, responsibility and innovation in its use, both consumptive and non-consumptive (recreational and educational), should not be complementary or secondary tasks, but rather a central axis of an integrated urban water management strategy, combined with the improvement of mechanisms for the population's access to information, opinion and control. This investment in the empowerment of the population, together with building the capacities of the human resources that form part of the management system and implementing changes in the structures of the service providers towards decentralization, will lead directly to a flexible, adaptive management system that will contribute to the sustainability of water within the context of integrated management.

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11. Acronyms

ANII - Agencia Nacional de Innovación e Investigación (National Innovation and Research Agency)

CECOED - Centro Coordinador de Emergencia Departamental de Durazno (The Durazno Emergency Coordinating Center)

CNDAV - Comisión Nacional en Defensa del Agua y la Vida (National Commission for the Defense of Water and Life)

COASAS - Asesora en Aguas y Saneamiento (Water Resouce and Sanitation Advisory Service)

CSIC – Comisión Sectorial de Investigación Científica (Sectorial Scientific Research Commission UdelaR)

DINAGUA - Dirección Nacional de Aguas y Saneamiento (National Water and Sanitation Office)

DINAMA - Dirección Nacional de Medio Ambiente (National Office of the Environment)

IANAS - Interamerican Network of Academies of Sciences

IDU - Equipo de Inundaciones y Drenaje Urbano de DINAGUA (Urban Flooding and Drains Team)

IM - Intendencia de Montevideo (Montevideo City Hall)

INE –Instituto Nacional de Estadística (The National Institute of Statistics)

LOTDS - Ley de Ordenamiento Territorial y Desarrollo Sostenible Land-use and Sustainable Development Law

MEVIR - Movimiento para la Erradicación de la Vivienda Rural Insalubre (Movement for the Eradication of Insalubrious Rural Housing)

MVOTMA - Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (Ministry of Housing, Land Management and the Environment)

OMM - Organización Meteorológica Mundial (World Meteorological Organization)

ONG – Organización No Gubernamental (Non-governmental organization)

OPP - Oficina de Planeamiento y Presupuesto (Office of Budget Planning)

OSE - Obras Sanitarias del Estado (State Sanitation Company)

PADE - Plan de Acción Durante Emergencias (Emergencies Action Plan)

PDSDUM - Plan Director de Saneamiento y Drenaje Urbano (Sanitation and Drainage Master Plan)

PECAC - Plan Estratégico de Gestión Integrada de la Cuenca del Arroyo Carrasco (Integrated Strategic Management Plan for the Carrasco River basin)

PEDECIBA – Programa de Desarrollo de la Ciencias Básicas de Uruguay (Program for the Development of Basic Sciences of Uruguay)

PHI-LAC -Programa Hidrológico Internacional para América Latina y el Caribe, UNESCO (The International Hydrological Program for Latin America and the Caribbean at UNESCO)

PMB-PIAI - Programa de Mejoramiento de Barrios, Programa de Integración de Asentamientos Irregulares (Program for the Improvement of Neighborhoods, the Program for the Integration of Irregular Settlements)

PSU - Plan de Saneamiento Urbano (Urban Sanitation Plan)

SAT - Sistema de Alerta Temprana (Early Warning System)

SDF - Sitios de Disposición Final Final (Waste Deposit Sites)

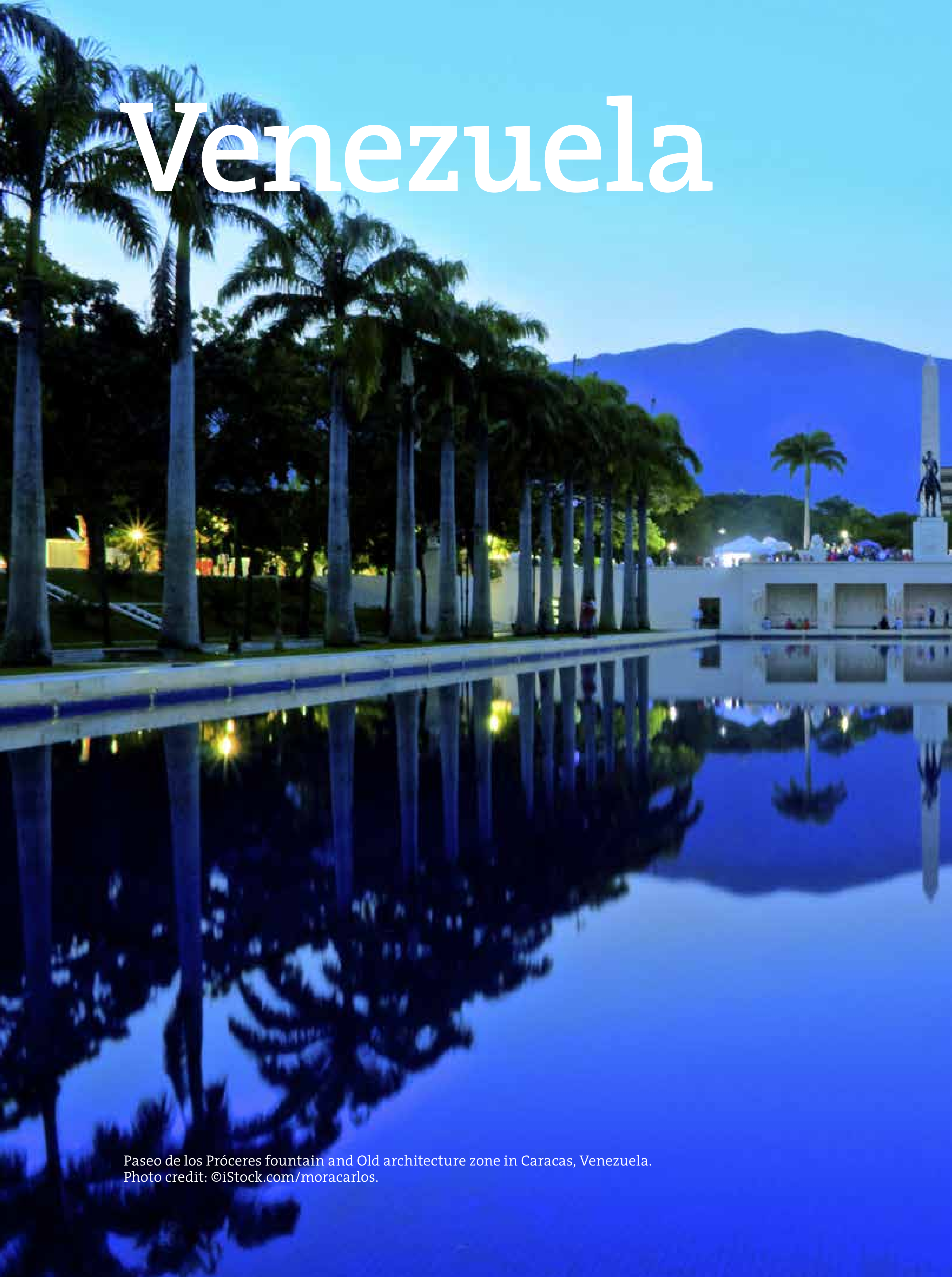
SINAE - Sistema Nacional de Emergencias (National Emergencies System)

UdelaR - Universidad de la República (University of the Republic)

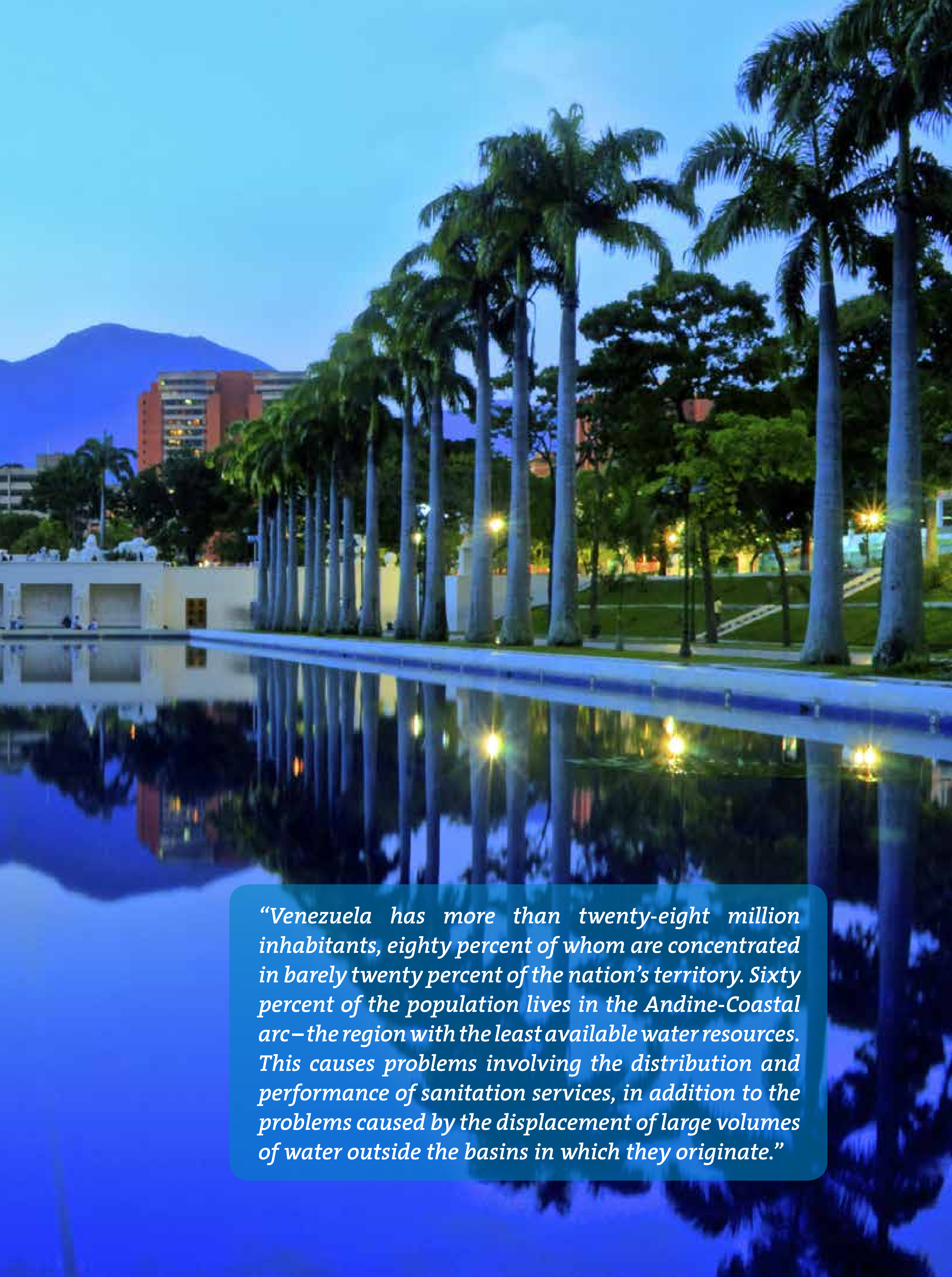
URSEA - Unidad Reguladora de Servicios de Energía y Agua (Water and Power Services Control Unit)

UTE - Administración Nacional de Usinas y Trasmisiones Eléctricas National (Administration of Power Plants and of Electrical Transmissions)

Venezuela



Paseo de los Próceres fountain and Old architecture zone in Caracas, Venezuela.
Photo credit: ©iStock.com/moracarlos.



“Venezuela has more than twenty-eight million inhabitants, eighty percent of whom are concentrated in barely twenty percent of the nation’s territory. Sixty percent of the population lives in the Andine-Coastal arc–the region with the least available water resources. This causes problems involving the distribution and performance of sanitation services, in addition to the problems caused by the displacement of large volumes of water outside the basins in which they originate.”

Urban Water Venezuela

Ernesto José González, María Leny Matos,
Eduardo Buroz, José Ochoa-Iturbe,
Antonio Machado-Allison, Róger Martínez,
and Ramón Montero

Summary

Venezuela has more than twenty-eight million inhabitants, eighty percent of whom are concentrated in barely twenty percent of the nation's territory. Sixty percent of the population lives in the Andine-Coastal arc – the region with the least available water resources. This causes problems involving the distribution and performance of sanitation services, in addition to the problems caused by the displacement of large volumes of water outside the basins in which they originate. There are nine (9) regional hydrological companies and eight (8) decentralized companies nationwide that offer drinking water and sanitation services. The supply of drinking water in the largest cities depends mainly on surface water (reservoirs), which cover over ninety percent of the urban population and more than eighty percent of the sewage collection, but with less than fifty percent of these waters being treated. At present, several sanitation and sewage treatment projects are underway. Regarding the relationship between available urban water and health, in Venezuela there have been many cases of waterborne diseases. Prominent among these are diarrhea, amoebas, malaria and dengue, with the highest rates occurring among the poorest strata of the population. This chapter also offers an approach to environmental health from the space inside housing projects and homes, with observations about indications and indices aimed at gauging the interaction between water and environmental health. There are also observations concerning the high vulnerability of the nation's water regime. Accordingly, it is of vital importance to monitor the effect of climate change on the sundry water supply sources, since most of the adverse effects are tied to the availability of water. There have occurred such phenomena as extreme drought and flooding in the country's largest cities, all of them with negative effects on the urban population. Therefore, there is emphasis on the importance of timely population planning (master plans) in order to

prevent future personal and property damage. Also prominently mentioned are the structural and non-structural measures intended to mitigate the effects of flooding on the cities. The conclusion is that plans must be implemented for water resources management, which are the result of a well-planned and conceived interaction among the available technology, society, the economy and –given the occurrence of extreme water related events– the existing institutions, with a view to balancing the supply and demand of this resource. Furthermore, the plans for managing water resources and the mitigation of problems linked with the water availability cycle in urban areas must involve the participation of organized communities.

1. Introduction

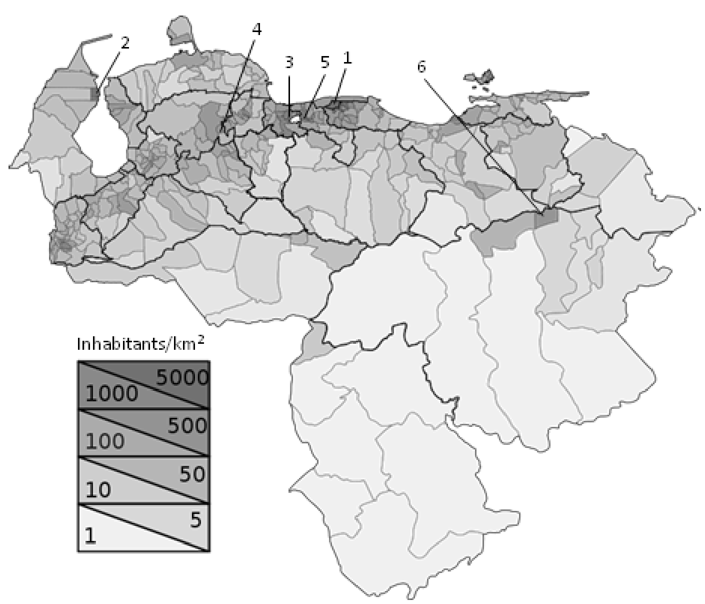
Venezuela has approximately twenty-eight million inhabitants, spread over 916,445 square kilometers of territory. According to the 2011 National Census, the population density is 29.6 inhabitants per square kilometer, with more than eighty-seven percent of the population living in urban areas, and about twelve percent in rural areas (INE, 2013).

Eighty percent of Venezuela's population is concentrated in twenty percent of the nation's territory. Of this, more than sixty percent live in the Andine-Coastal arc –specifically in forty percent of the country's largest cities, such as Caracas, Maracaibo, Valencia, Barquisimeto, Maracay and Ciudad Guayana, which have the greatest water availability (Figure 1).

Considering that the largest percentage of the population lives in the area with the greatest water supply, it is evident that problems may arise in its distribution and in the performance of services requiring water, such as sanitation, and others caused by the displacement of large volumes of water outside their original basins. All of this requires the characterization of the urban water cycle in order to guarantee drinking water and sanitation services, and to address the different problems in securing proposals looking toward their mitigation.

This chapter will present a summary of the main aspects concerning water in Venezuela's urban areas, especially in the country's largest cities –such as the supply of drinking water and sanitation services, water treatment, the health aspects and subjects related to their possible effects on climate change.

Figure 1. Population concentration in Venezuela.
Cities: 1) Caracas, 2) Maracaibo, 3) Valencia, 4) Barquisimeto, 5) Maracay and 6) Ciudad Guayana.



Source: Modified from INE (2013).

2. Drinking water service in urban areas

The supply of water in Venezuela comes, in large part, from surface sources. According to González Landazábal (2001), the space distribution of surface water runoff in Venezuela is characterized by the following aspects:

- The average annual rain-generated water runoff in Venezuela, excluding Guayana Esequiba, is estimated at seven-hundred and five million cubic meters.
- The river basins in the states of Amazonas and Bolívar, which are tributaries on the right bank of the Orinoco River, produce about eighty-two percent of the aforementioned volume.
- The part of the country to the north of the Orinoco River produces the remaining eighteen percent. Of this, nine percent is contributed by the tributaries, on the West Central Lowlands, with another nine percent from Lake Maracaibo, the slope of the Caribbean, the Lake Valencia basin and the Gulf of Paria.

Beginning in 1990, Venezuela began restructuring the organisms responsible for providing drinking water and sanitation services, with the purpose of moving from a centralized supply scheme to a model which would take into account the principles of joint responsibility and the participation of every inhabitant of Venezuela, as guaranteed in Articles 60, 70 and 184 of the Constitution of Venezuela as a point of departure from which to incorporate them legally into the design of the water and sanitation policies, plans and projects related with their community and environment, thus contributing to People's Power and an interchange of know-how, among other skills. To this end, HIDROVEN was created as a main office for the drinking water and sanitation sector, with steering and supervisory functions, with ten (currently nine) affiliated regional hydrological companies, with the purpose of preventing the privatization of the water supply industry and the decentralization of its administration, thus achieving the operation of the affiliated companies with their own income and resources from the cancellation of the rate payable, in addition to contributions from the national government through economic subsidies.

The federal government will continue to own the shares of the Regional Hydrological Systems, since its only stockholder is HIDROVEN, which serves as the main office for these companies and in turn, the People's Ministry of the Environment (MINAMB). This latter owns ninety-five percent of HIDROVEN's shares. The remaining five percent is also owned by another governmental agency. In the case of the states of Amazonas and Delta Amacuro, which belong to the Guayana region, this service is also furnished by a governmental agency, which is the Venezuelan Corporation of Guayana (CVG).

The distribution of the Regional Water Companies (see Figure 2) is as follows (HIDROVEN, 2008):

- HIDROCAPITAL: The Metropolitan Aqueduct of Caracas and the Vargas and Miranda States.
- HIDROCENTRO: Aragua, Carabobo and Cojedes States.
- HIDROLAGO: Zulia State.
- HIDROFALCÓN: Falcón State.
- HIDROSUROESTE: Táchira State and the Ezequiel Zamora District of Barinas State.
- HIDROANDES: Trujillo and Barinas States (except the Ezequiel Zamora District).
- HIDROPÁEZ: Guárico State.
- HIDROCARIBE: Sucre, Nueva Esparta and Anzoátegui States.
- HIDROLLANOS: Apure State.

There is also a series of Decentralized Companies which provide drinking water and sanitation services with the participation of the federal and municipal governments and that of the Venezuelan Corporation of Guayana (CVG), which oversees the Sanitation Services and Water Management (GOSH) for Amazon and Delta Amacuro states.

The Steering Committee is elected by the Shareholders' Assembly and is independent of the Federal Government. Its members are usually from the state sphere and are concerned with the management and operation of drinking water and sanitation services. At present, the following decentralized companies are operating in the country:

- HIDROLARA: Lara State.
- AGUAS DE MONAGAS: Monagas State.
- AGUAS DE MÉRIDA: Mérida State.

- HIDROS PORTUGUESA: Portuguesa State.
- AGUAS DE YARACUY: Yaracuy State.
- HIDROBOLÍVAR: Bolívar State.
- CVG-GOSH: Amazonas and Delta Amacuro States.
- AGUAS DE EJIDO: Ejido District, Mérida State.

The sources of water for supply in the nation's largest cities come from reservoirs built for this purpose (Table 1).

According to HIDROVEN (2008), the supply of drinking water for the urban population has been increasing in recent years, attaining a coverage of ninety-one percent (Table 2), while the rural population coverage has reached seventy-nine percent. In addition, wastewater recovery has reached 82.41%. However, only 25.91% of wastewaters are treated (through secondary treatment).

Figure 2. Distribution of Regional Water Companies in Venezuela

Source: HIDROVEN.

Table 1. Reservoirs furnishing water to the main cities of Venezuela

City	Reservoirs	Total Volume M³
Caracas	Camatagua, La Mariposa, La Pereza, Taguaza, Taguacita, Lagartijo, Quebrada Seca, Macarao, Cuira (under construction)	1,975.6 x10^6
Maracaibo	Tulé, Socuy, Tres Ríos	659.4 x10^6
Valencia	Pao-Cachinche, Guataparo, Pao-La Balsa	615.7 x10^6
Barquisimeto	Dos Cerritos, Dos Bocas (under construction)	127.4 x10^6
Maracay	Pao-Cachinche, Pao-La Balsa	196.7 x10^6
Ciudad Guayana	Guri, Macagua (I, II and III)	111,467 x10^6

In-house document based on data from Castillo et al., (1973).

Table 2. Progress in the supply of drinking water supply and in wastewater recovery

Year	Drinking water supply (% of population)	Wastewater recovery (% of population)
1998	81.57	63.77
1999	83.66	64.38
2000	85.15	66.96
2001	86.37	68.15
2002	87.65	71,27
2003	89.27	71.69
2007	91.70	82.41

Sources: Arconada, 2005; HIDROVEN, 2008).

2.1 Groundwater in the Cities

Freshwater from rivers and lakes is the natural resource most extensively used by society since time immemorial. However, in recent decades the use of groundwater has increased as the result of the gradual deterioration of the sources of surface water. In many cases, groundwater is the main source of water for human consumption and for agricultural, livestock and industrial activities. Large quantities of water are also required as a secondary demand in gardening and recreational activities (Demirel and Güler, 2006).

Groundwater is the product of the seepage of rainwater through rock formations with such favorable physical characteristics as porosity and permeability, which facilitate its transportation, storage and use, whether natural or artificial, through the construction of wells using pumps or by manual extraction. In this sense, the factors affecting the availability, accumulation and type of groundwater are climate, lithology, bedrock geomorphology and time (the age of the water). Meanwhile, the geological environment within these factors includes strategic relationships and geological structures, the direction and variability of the flow of the groundwater, the location of the water recharge and discharge areas and its composition. These factors have been thoroughly documented and studied by Hem (1985), Domenico and Schwartz (1990), Custodio (1996), Ettazarini (2004), Rajmohan and Elango (2004), Van der Hoven et al., (2005) and Rao (2006).

Another factor which controls the accumulation and composition of groundwater is tectonic activity (Hendry and Schwartz, 1990; Van der Hoven et al., 2005). Its importance lies in the fact that during periods of orogeny there occur not only the creation of large mountain ranges but also the formation of sedimentary basins which can later serve as major hydrocarbon and water reservoirs in the intramountain regions (Hidalgo and Cruz-Sanjulián, 2001).

Likewise, human activities carried out in urban areas have a major impact on the final condition of the water. Thus, solutes may be incorporated directly into the groundwater through domestic wastewater, industrial waste, sanitary landfills, agricultural and cattle-raising activities, oil spills, gasoline leaks from storage tanks and the overworking of wells (Hem, 1985; Navarro et al., 1988; Domenico and Schwartz, 1990; Custodio, 1996; Magrinho et al., 2006).

Venezuela's geological history was characterized by a high degree of dynamics associated with the most important orogenic activity both worldwide and regional (Villamil, 1999). This had as a consequence that, throughout Venezuela, there are conditions that lend themselves to the accumulation of large volumes of water, associated with a wide variety of geological structures, especially in large and small sedimentary basins which contain quaternary rock formations. Decarli (2009) points out that nearly fifty-five percent of the surface of the country is covered by poorly consolidated or unconsolidated sediment and consolidated rocks with characteristics favorable to the formation of aquifer units. The seepage of rainwater and its migration through these aquifers produced significant variations in the chemical composition of their waters, due to the chemical weathering processes during the water-rock interaction.

In Venezuela, the zones with the highest groundwater and aquifer availability are mainly in the Central Region, in the South and the Lake Maracaibo plains, the Andine foothills region of the Central and Western Lowlands, on the Guanipa Plateau, in the central part of Anzoátegui state and in some sections of the coastal aquifers. Figure 3 shows the relative location of Venezuela's main aquifers.

During the development of the large cities, the potential recharging areas located at the foothills of the mountainous regions surrounding them are vulnerable or eliminated. This is the result of the construction of large urban developments and the clearing of major forests. In addition, the construction and paving of access roads and highways can lead to a limitation of the local recharging of groundwater. This, in turn, as regards the water balance, means that the only consequence is a deep infiltration, produced by the regional flow regimen. This means that, as far as this equilibrium is concerned, there is a water deficit. Thus, during rainy periods, large volumes of water appear as surface runoffs, while the underground runoffs are less dominant.

In this sense it is supposed that, given the increasing population and economic growth, the groundwaters have been subjected to a continuous waning in their availability and quality –especially to the urban areas in the northern and central regions of the country, and in those zones with significant economic activity, such as cattle-raising, agriculture, mining and hydrocarbon exploration and operations. The country's renewable groundwater reserves are spread over twenty-two billion, three-hundred and twelve million cubic meters. It is estimated that about fifty percent of this is used for drinking, industry and irrigation over a network of waterworks comprising one-hundred thousand wells (FUNDAMBIENTE, 2006; Decarli, 2009; Durán, 2011).

An example of the use of groundwater in cities is the Caracas Valley –a major region in northern Venezuela with an area of seventy-six square kilometers, measuring fourteen kilometers east-to-west between the residential area known as Propatria and Parroquia de Petare, widening by four kilometers from the San Bernardino residential complex to the El Paraíso complex. This valley comprises water-saturated sediments from the quaternary period, comprising layers of sand and gravel capable of providing a useful supply of water, enabling the construction of prominent aquifer units.

During the last forty years little attention has been paid to Caracas' groundwater. Among the most prominent hydrogeological studies, one can mention those of Delaware (1950), Gomes (1997, 1999) and TAHAL (2002). This latter carried out a study for the placement of new wells throughout the entire valley. Freile (1960), for his part, carried out a hydro-geochemical classification of Caracas' groundwater. Singer (1977a, 1977b), Rocabado (2000) and Kantak (2001) studied the soil cover of the Caracas Valley.

Of all the drinking water consumed in the city of Caracas, over eighty percent comes from the Tuy I, Tuy II and Tuy III aqueducts, which are fed from the watershed basins of the Tuy and Camatagua rivers. These basins have been undermined in recent years by long droughts, combined with short rainy seasons and a greater demand for water supply due to the increased population of the nation's capital.

The available data (Decarli, 2009), indicate that the city of Caracas consumes about eighteen thousand liters per second (lps). Of this, about twelve-hundred liters come from the more than five-hundred groundwater extraction wells in existence. While the sum total of groundwater at the different aquifers in the Caracas Valley is incapable of meeting the requirements of the entire population, it can serve as an alternate source of supply for the zones that require it. It is, therefore, important to evaluate it in terms of the characteristics of its aquifers, flows, direction of flow, of the identification of recharge areas, composition and types of water available, to conduct an inventory and determine the location of the most productive wells.

In this regard, the use of the aquifer was recently estimated in approximately 1.5 m^3/second. The principal pumping centers are in such sectors as El Paraíso, the entrance to El Valle and Miranda state. The most abundant flows are found in the El Paraíso sector, with wells offering from 20 lps to over 40 lps (Gomes, 1997). The piezometric maps prepared by the Ministry of the Environment (MINAMB) show that the flow in the valley follows the mountains (lateral recharge zones), to the main pumping centers and on to the Guaire River (discharges from the aquifer system).

According to MINAMB, the transmissivities (or measures of the distance that water can be transmitted horizontally through a unit under

Figure 3. Location of Venezuela's aquifers. 1) Río Motatán Basin, 2) Río Guárico irrigation system, 3) Caracas Valley, 4) Guanipa Plateau, 5) Quíbor Valley, 6) Eastern Lowlands, 7) Coro aquifer, 8) Western Lowlands, 9) the Barlovento aquifer, and 10) the Paraguaná aquifer.

Source: Modified from Rojas and Serrano (2007).

the influence of a hydraulic gradient), varies from sixty to one-hundred and twenty square meters per day, averaging ninety square meters per day. The average permeability obtained by dividing the transmissivity into the saturated thickness varies from 2.6 meters per day (the geometrical average) to 7.0 (the arithmetical average), while the horizontal water conductivity varies between one and forty meters per day.

The recharge zone of the Caracas Valley aquifer comes from the mountains, mainly through the main ravines which empty into it. In addition, another major water inlet to this aquifer comes from the losses sustained by the HIDROCAPITAL drinking water system which according to Seiler (1996), are on the order of one to two m^3/second.

Another example which should be mentioned is the project aimed at combining the operation of groundwater with that of surface water in western central Venezuela in order to transfer water resources from the Río Yacambú basin (in Lara state), with the following objectives: (a) increasing the agricultural area under irrigation in the Quibor Valley, which is a highly productive area, (b) through the joint use of surface water and groundwater, restoring the Quibor Valley aquifer (the area identified as Number 5 in Figure 3), the availability and quality of whose water have deteriorated considerably due to overuse, and (c) offering an additional, massive water supply to HIDROLARA, the region's public drinking water and sanitation service company (Garduño and Nanni, 2003). According to these authors, the experience with this project made possible the recommendation to include aquifers in the definition of "basin" in the Water Law passed in 2007, among other recommendations.

Groundwater represents a specific alternative to boost the supply in some sectors supplying water to cities. According to Escalona et al., (2009), in view of the high degree of chemical treatment the treatment of surface water is more costly than the treatment of groundwater. Groundwater is cheaper to produce, since by passing through the different subsoil strata or configurations it receives natural filtration. This reduces residues and obviates chemical treatment since only chlorine is used in its disinfection. It is, however, wont to contain, generally, high concentrations of such metals as iron and manganese, and a high degree of hardness, which can complicate and increase multifold the cost of its treatment. It is, therefore, important to evaluate it in terms of the characteristics of its aquifers, flows, the direction of flow, the identification of the recharge areas, the composition and types of water present, and to conduct an inventory of and to locate the most productive wells.

Box 14

Drinking water and sanitary services for the city of Caracas

The present situation and prospects for the management of drinking water and sanitation services for the Caracas Metropolitan Area.

The drinking water supply for the Caracas Metropolitan Area (AMC) was established in 1950 as a regional system. This implied the collection and transfer of large volumes of water from the Tuy and Guárico river basins, and the incorporation of small contributions from the Rio Guaire basin. After different incorporations and adjustments, the Caracas Metropolitan Region (RMC) was established, comprising five systems which in 2011 produced and distributed nearly twenty-six thousand liters per second (lps) over all. These are the Metropolitan, Litoral, Fajardo, Losada-Ocumarito and Pan-American systems (Martínez, 2012). A sixth system, Barlovento, supplies the region of the same name and completes the group of systems managed by the Hydrological Company HIDROCAPITAL. For the AMC, the production of drinking water for the Metropolitan System is 17.7 m^3/second, offering an average supply loosely calculated at 470 liters per person per day (Martínez, 2012).

The fact that half the population lives in unplanned neighborhoods, with high altitude service sources, limited water storage, pumping and distribution systems implies that the supply of 470 lpd

Box 14

does not benefit all the inhabitants residents uniformly (IMUTC, 2012). There are no known recent, overall studies to ascertain the actual drinking water supply in the AMC's informal neighborhoods. However, partial studies carried out in a number of neighborhoods show rationing that lasts for several days, and a supply less than that recommended by the health standards (Martínez, 2012). Another weakness of the distribution network, which is increasingly evident, consists in broken pipes and the difficulty in replacing them. A large part of the distribution system is over fifty years old. Therefore, its useful life has expired, making it necessary to replace them completely. The losses from leaks in the distribution system total 5.4 m^3/second. Individual readings reached only fourteen percent of the subscribers (IMUTC, 2012) while the amount of uninvoiced water has been at sixty percent for several years (HIDROCAPITAL, 2002).

With regard to the sanitation sewage system, from the technical standpoint, the system should collect wastewater and rainwater separately, discharging them in collectors running along the banks of the ravines that flow to the Guaire River. Their left bank and right bank collectors should collect all the wastewater. At times of excess flow due to the influx of rainwater to the sewers, relief ducts, installed at the junction between the collectors on the banks of the ravines and those of the Guaire River, should evacuate the excess, now highly diluted, to the Guaire River. Although before 1930, under the Public Works Ministry's Overall Sewage Duct Plan, it had been contemplated that the Guaire River would not receive wastewater and that it would be purged prior to discharge, ninety years later this still has not been achieved (Martínez, 2012).

At the end of the 'fifties, new riverbank collectors were designed which, over all, are capable of handling a flow of up to 60 m^3/second – more than three times the current average flow of the aqueduct (Pérez Lecuna, 2005). Despite the fact that these riverbank collectors have been completed since the 'seventies, they do not work properly due to lack of maintenance of the system, to urban sprawl and weaknesses in following up on collection and treatment plans, including the more recent Rio Guaire Sanitation Project. With regard to the collectors in outlying, unplanned neighborhoods, these have been built thanks mainly to the participation of the communities themselves, without observing the technical standards. Accordingly, they work poorly and lead to seepage into the soil and discharges into the natural drainage structure.

The social and environmental conditions of poor drinking water and sanitation management in the AMC. Future prospects

As the result of the current management of drinking water and sanitation systems, there still persist some social, economic and environmental problems. With regard to the social problems, the morbidity statistics for 2012 (Martínez, 2013) indicate the greatest incidence of water-transmitted diseases in those parishes of the Libertador District which lack water and sanitation systems and where the poorest population is concentrated.

With regard to the economic problems, it may be said that the limited access to drinking water and sanitation has a negative impact on the family income of the population with the least economic resources, who have to buy water at the highest price from private tank truck operators who are not subject to proper supervision and do not guarantee the supply of "safe" drinking water (Jouravlev, 2004). Another economic consequence of the lack of sanitation networks which has major repercussions on vital statistics, concerns the increased vulnerability of the informal neighborhoods. The deficiency of the existing water and sewage networks generally leads to seepage into the ground, weakening its ability to support buildings, causing massive landslides and increased vulnerability in the event of earthquakes. According to Civil Protection reports, massive landslides in the Capital

Box 14

District account for seventy two percent of the total occurrences, while the remaining twenty-eight percent are due to collapses, flooding, earth settling and other phenomena (Grases, 2006).

Finally, from the environmental impact standpoint, the construction of unplanned sewage networks implies the discharge of untreated wastewaters into the ravines. However, even if the problem of collecting all the effluents in their riverbank collectors along the Guaire were resolved, neither has overall treatment been achieved. This means that raw wastewater is still discharged into that river and, consequently into the Tuy River and the Caribbean Ocean, causing serious eutrophication and contamination problems. In addition, the nonexistence of a water rate policy that promotes saving implies a lack of rationalization in drinking water consumption. This leads to excessive use of water from fresh water bodies, which has irreversible environmental effects.

If in the next two decades there emerge no measures tending to rationalize water consumption and recycle wastewater, then water consumption in the AMC for the year 2031 could reach 21.3 m^3/second, while in the RMC it could reach 34.2 m^3/second. This will require the use of the Tuy I to IV systems, with no possibility of relieving the operation of the water supply systems (Martínez et al., 2013). With regard to the generation of wastewater, if measures are not taken to rationalize their usage to separate rainwater and to recycle wastewater, the production for the AMC by the year 2031 could reach 34.5 m^3/second, while for the RMC it could reach 57.5 m^3/second. In addition, if the treatment problem is not resolved, the contamination of natural water streams will continue, with harmful and irreparable effects on the underground ecosystems affected by the discharge of the Tuy River, whose basin is that which has the most serious harmful impact on the Caribbean Sea (Martínez et al., 2013).

The proposed policy

A desirable evolution of water management would have to bring together the participation of the institutional players at the different levels of government (federal, regional and local), preserving the incorporation of the organized communities, which is an international trend (WSP, 2008), but within a scheme that does not relieve the government of its responsibilities. According to the analyses carried out for the different supply systems which today comprise HIDROCAPITAL, there will apparently be, worldwide, enough water from the current sources – with the imminent incorporation of the Tuy IV System – to sustain the growth of the entire Metropolitan Region. It is, however, necessary to rationalize consumption in order to reduce the per capita provision. This is a task which necessarily implies joining forces with the districts (Martínez et al., 2013). The replacement of distribution pipes in order to prevent leaks, the regularization of clandestine taps, the micromeasurement and collection for services performed, tending toward a reasonable consumption that facilitates financial balance for the performance of services, is a task which could well be undertaken by local entities.

A new institutional arrangement must be adopted, in which the seventeen districts of the Metropolitan Region – either individually or jointly – can administer the components of the drinking water and sanitation systems closest to the end user. That is, for the aqueduct, the local drinking water distribution networks; for the sewage system, the embedded elements and secondary wastewater collection systems and, for drainage, the secondary and tertiary urban drainage systems.

Underlying all of these lines is the notion that in order to achieve a sustainable water administration, public policy must have an urbanization counterpart. This subject requires interdisciplinary approximations which bring together contributions from the sociological, economic, political, legal, engineering and other spheres, making it possible to recognize the problems and propose changes that lead to decision-making.

Box 14

Description of the supply of water to the city of Caracas

With regard to the supply of water for distribution, the city of Caracas depends on surface sources (reservoirs) located in remote regions and at altitudes much lower than those of the city. Water reaches the city through a complex of fittings and ducts known as the “Tuy System” (Figures 4 and 5), comprising the following subsystems:

- Tuy System I: Fed by the Lagartijo reservoir (80 x10^{6} m^{3}). It transfers to the La Mariposa reservoir and supplies water to the parts of the city at lowest altitudes (3 m^{3}/second).
- Tuy System II: Fed by the Taguaza reservoir (184 x10^{6} m^{3}). Supplies water to the southeastern zones and intermediate altitude sections of the city (7.2 m^{3}/second).
- Tuy System III (the most important): Fed by the Camatagua reservoir (1,550 x10^{6} m^{3}). Supplies water to the rest of the city and other cities in other states (9 m^{3}/second).
- Tuy System IV (under construction): Fed by the reservoir to be built on the Cuira River. Will furnish 12 m^{3}/second and may furnish up to 21 m^{3}/second.

The water is routed from the reservoirs, usually at less than 400 meters above sea level, through pumping stations to carry the water to the city, which is over 900 meters above sea level.

As may be seen, the supply of drinking water to the Venezuelan capital proves quite complicated, in addition to the problems involved in the translocation of water from other drainage basins to the city, as will be described later in this treatise.

Figure 4. Tuy System. Modified from HIDROCAPITAL.

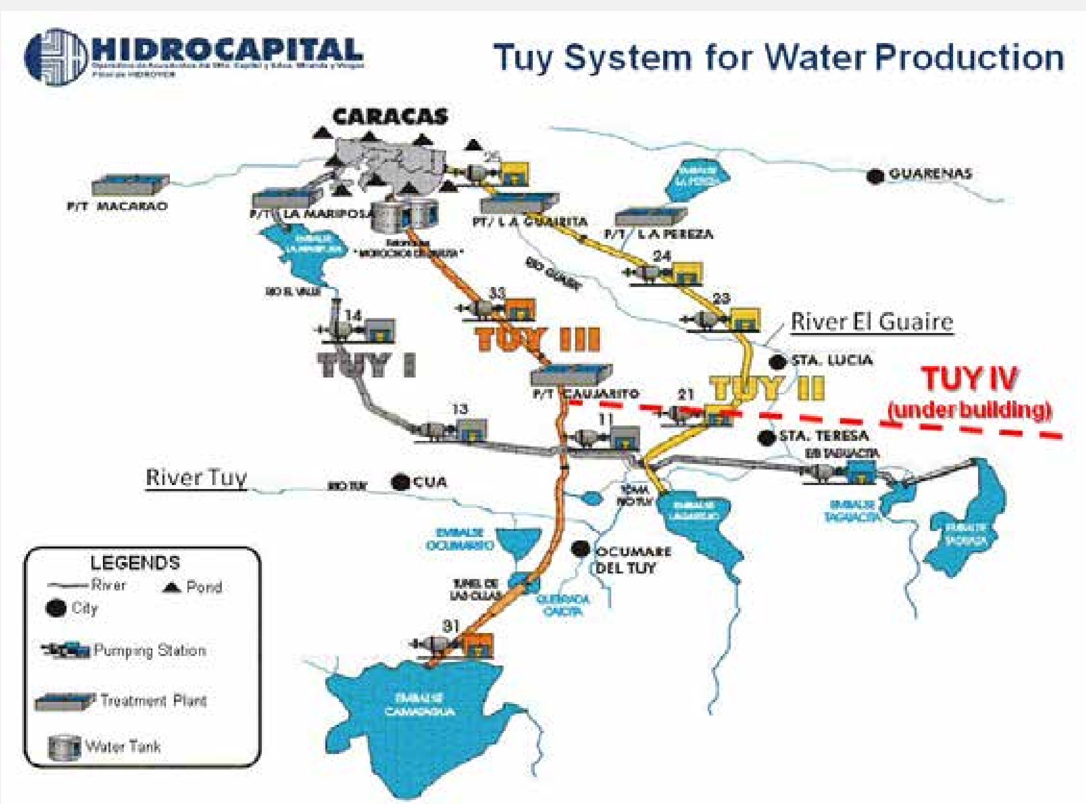
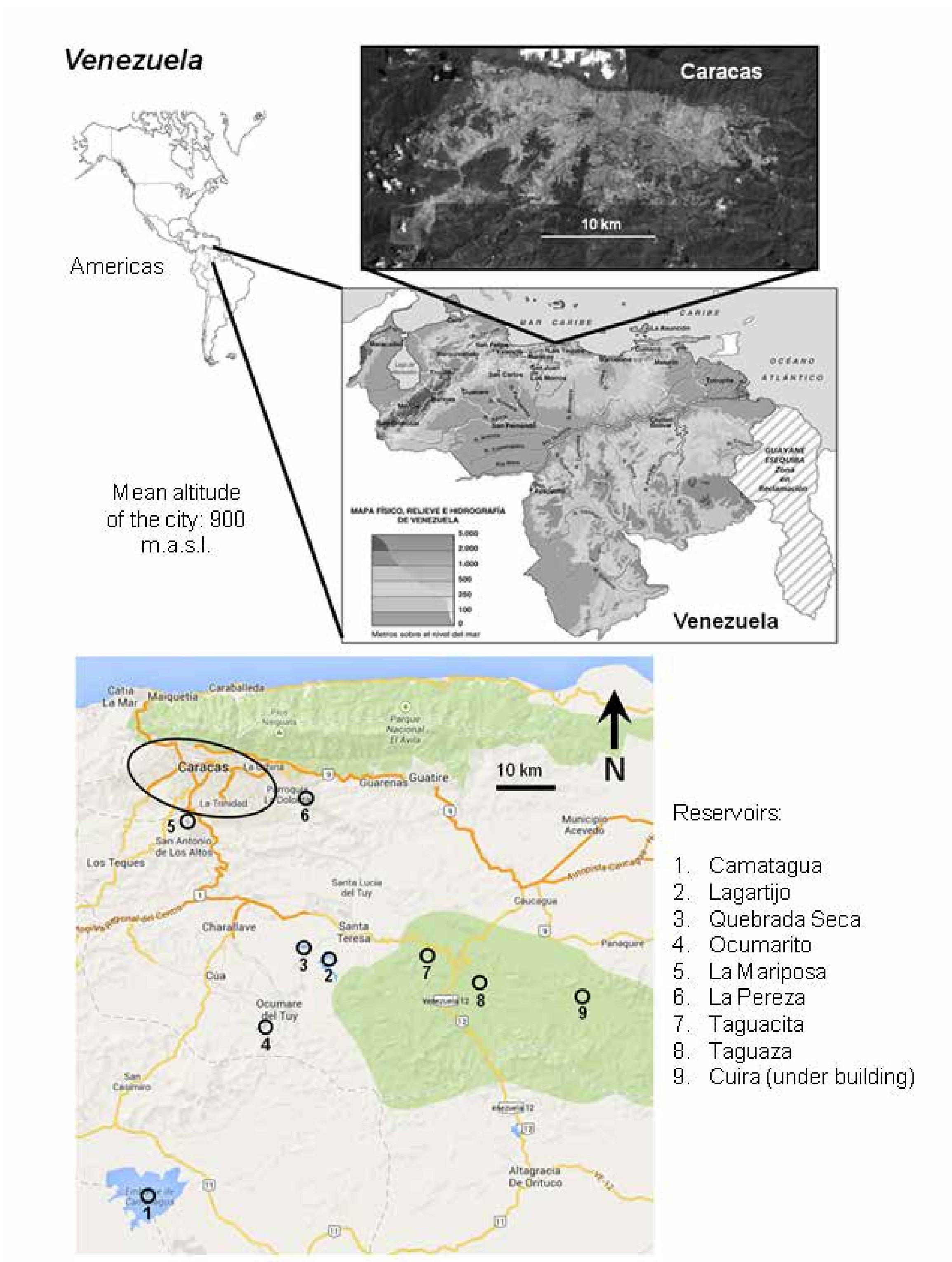


Figure 5. Relative location of the city of Caracas and the reservoirs supplying drinking water



Source: In-house document based on Google Earth images.

2.2 Drinking Water and Sanitation Service Rate Structure

The cost structure for the supply of drinking water and sanitation services dates from 2011, established pursuant to Transitional Provision Nine of the Organic Law for the Supply of Drinking Water and Sanitation Services Law published in the *Official Gazette of the Republic of Venezuela* under Number 39,788, dated October 28, 2011 (GORBV, 2011). This Administrative Ruling establishes the methodology, formulas, model and technical criteria that regulate the rates for the drinking water and sanitary services rendered by the Regional Hydrological Companies affiliated with the Compañía Anónima Hidrológica Venezolana, or HIDROVEN, C.A.

The use made of the water is as follows:

- Business Use "A": Establishments where water is an essential and main input for carrying out business activities or performing services, such as clinics, hotels, boarding houses, carwashes, laundries and/or dry cleaners, nurseries, barber shops, butcher shops, fish markets, shopping centers, restaurants and others.
- Business Use "B": Those establishments in which water is not an essential, main input for the conduct of business activities or the performance of services.
- Industrial "A": Those establishments where water is an essential and main input for the performance of industrial activities.
- Industrial B: Those establishments where water is not an essential and main input for the performance of industrial activities
- Residential: Refers to all real property intended exclusively for housing or family residence. Residential use is classified as follows: Social, 1, 2, 3 and 4. In order to classify a subscriber as belonging to one or another of the residential categories, the drinking water and sanitation service provider follows a methodology which takes into consideration the key variables related to the residential zone or geographical location where the property is located, the cost of the property, the nature of the housing, its services and facilities (gardens, swimming pool, cable television, etc.).

Table 3 presents a rate structure for business and industrial use, while Table 4 presents a structure for residential use. In addition, the Average Reference Price is determined by the geographical location of the property (Table 5). The prices are in Venezuelan Bolivars (Bs) and, for purposes of reference, the value in American dollars (US$) is shown at the official rate of exchange.

This Administrative Ruling also provides that in those systems or population centers in which, apart from the wastewater collection process, the treatment and final disposal of wastewater are also carried out, an ad valorem charge of 25% will be added to the public drinking water and wastewater collection service invoiced.

WSP (2007) has estimated that the providers do not issue invoices to thirty-five percent of the low income population, while sixteen percent of the remaining sixty-five percent are considered subscribers offering services to society. Accordingly, they are charged about twenty percent of the actual applicable rate. This maintains a relationship with the principle of solidarity and recognition of the social obligation in the policies of each sector.

Table 3. Rate structure for industrial and business use. PR= Average Reference Rate

Uses	Fixed rate (1/6 of the allowance is calculated, and a minimum rate established for each use)	Variable rate (up to amount of the allowance)	Excess Use 1 (from the allowance up to 1.5 times the amount of the supply)	Excess Use 2 (from 1.5 times the allowance up)
Industrial A	Minimum of 50 m^3/month (2.50 or 3.00) x PR	(2.50 or 3.00) x PR	4.00 x PR	7.00 x PR
Industrial B	Minimum of 40 m^3/month (2.25 or 2.50) x PR	(2.25 or 2.50) x PR	4.00 x PR	7.00 x PR
Business A	Minimum 30 m^3/month (2.00 or 2.25) x PR	(2.00 or 2.25) x PR	4.00 x PR	7.00 x PR
Business B	Minimum 20 m^3/month (1.50 or 2.00) x PR	(1.50 or 2.00) x PR	4.00 x PR	7.00 x PR

Sources: *Official Gazette of the Republic of Venezuela* (2011).

Table 4. Rate structure for residential use. PR= Average Reference Rate

Uses	Fixed rate (1/6 of the allowance and the minimum rate considered will be 15 m^3/month)	Variable rate (between 15 and 40 m^3/month)	Excess 1 (between 40 and 100 m^3/month)	Excess 2 (over 100 m^3/month)
Lodging	(0.50) x 0.50 x PR	(0.50) x 0.75 x PR	3.50 x PR	5.00 x PR
Residential 1	0.75 x PR	0.75 x PR	3.50 x PR	5.00 x PR
Residential 2	1.00 x PR	1.00 x PR	3.50 x PR	5.00 x PR
Residential 3	1.50 x PR	1.50 x PR	3.50 x PR	5.00 x PR
Residential 4	2.00 x PR	2.00 x PR	3.50 x PR	5.00 x PR

Source: *Official Gazette of the Republic of Venezuela* (2011).

Table 5. Average Reference Rate (PR) according to use and water company

Companies	Residential PR (Bs/m^3 – US$/$m^3$)	Business and industrial PR (Bs/m^3 – US$/$m^3$)
HIDROANDES	1.00 – 0.091	1.90 – 0.173
HIDROCENTRO	1.55 – 0.141	1.90 – 0.173
HIDROCARIBE	1.55 – 0.141	1.90 – 0.173
HIDROCAPITAL	1.55 – 0.141	1.90 – 0.173
HIDROFALCÓN	1.55 – 0.141	1.90 – 0.173
HIDROLAGO	1.55 – 0.141	1.90 – 0.173
HIDROLLANOS	1.00 – 0.091	1.90 – 0.173
HIDROPÁEZ	1.00 – 0.091	1.90 – 0.173
HIDROSUROESTE	1.25 – 0.114	1.90 – 0.173

Source: *Official Gazette of the Republic of Venezuela* (2011). The official rate of exchange of 11 Bs to 1 U.S. dollar (as of February 28, 2014) has been taken as a reference.

Box 15

Technical Roundtables of Water

Community participation in the administration of the supply of drinking water and sanitation services

Within the framework of the new structure of the Venezuelan nation established in the Constitution of Venezuela, HIDROVEN and its Regional Water Companies promote the formation of Technical Roundtables of Water.

Both the Constitution of Venezuela and the Organic Law for the Performance of Drinking Water and Sanitation Services (LOPSAPS, passed in 2001), establish the legal framework and the mechanisms for transferring the administration of water services from the water companies to the districts.

Since 1999, it has comprised Urban-Rural Area based community organizations known as Technical Roundtables of Water (MTAs), are dedicated to improving the supply, maintenance and operation of the drinking water and sanitation services.

These organizations contribute to citizen participation in the Drinking Water and Sanitation Sector (LOSAPS) and have been transformed into a basic mechanism for community participation, for the policies governing the rendering of services and, above all, for the organization of the service companies, since they have transcended their initial objectives and now participate directly in the administration of these companies.

The application of these principals to the development of LOSAPS has given rise to major changes, which may be summarized as two major processes underway. One is the incorporation of community

Box 15

participation in the administration of the service and the development of a new water culture; the other is the expansion of the service, with greater equity, in the framework of a new vision of the public water company which includes, in each such company, the creation of Community Management Committees.

The MTAs channel community participation in order to obtain, improve, maintain and oversee the water and sanitation services for their communities, and to mold a water-conscious culture which values and safeguards this resource.

The relationship of the MTAs with the water companies is predicated on a vision of shared responsibility and identification with the service, since community participation in the initial diagnosis has been achieved. They prepare and carry out projects and perform controlling functions. In addition, as an additional task, these communities are simultaneously building a network of relationships and values which constitute citizenship participation.

From the beginning, the Technical Water Committee program has offered the communities direct participation in the solution of drinking water supply and wastewater treatment problems.

With the creation of the Community Project Financing Fund, the Technical Roundtables of Water have become pioneering community experiences in the direct management of the economic resources required for the execution of water and sanitation projects, designed as well by the communities themselves. By early 2014, there were more than nine Technical Roundtables of Water nationwide.

As of January 2011, the Technical Roundtables of Water had been allocated a total of 481,052,043 Bolivars (US$ 111,872,568.14, at the official rate of exchange on that date, calculated at 4.30 bolivars to the dollar), for the performance of 1,556 Drinking Water and Sanitation Projects. Of these, 1,497 million had been finished with 459 still in progress, benefitting a population of 1,526,329 inhabitants with the projects finished, with an estimated total of 2,975,835 inhabitants who will benefit from the entirety of these Projects.

The Community Water Committees, comprising the Technical Roundtables of specific sectors, are entities organized by regions and water supply cycles throughout the nation.

The Technical Roundtables of Water program thus represents an overall effort to bring quality of life to the population and to empower the communities, which recognize the effort made and feel satisfied with the gains made, since they now participate in the solution of their problems.

This participative strategy has contributed decidedly to the overall objective of broadening the people's access to drinking water or sanitation, so that by 2005, Venezuela had met its Goals for the Millennium which had been foreseen for attainment by 2010. In addition, the MTAs have had a positive impact in strengthening the fiber of the community, forging a socially aware citizenry, constructing a new institutionality such as the creation of a new of Community-Government relations network and the forging of a new water culture.

3. Water Treatment in the Cities

In order for it to be distributed and consumed in the country, the water must meet the Drinking Water Quality Standards established by the Ministry of Health and Social Welfare (now the People's Ministry of Health) in the *Official Gazette of the Republic of Venezuela* under No. 36,395, dated February 13, 1998, as the steering committee for sanitary water oversight. These establish the maximum values of the regulated parameters which the water must meet in order to be considered potable. During the process of the water companies' transporting the water to the distribution networks, the first step is the implementation of these standards. The potability parameters establish the following: that the water shall be odorless, colorless and tasteless. In addition, it shall be tested to determine the presence of lead (with a maximum accepted value of 0.01 mg/l.) On its discharge from the different plants, the water will be chlorinated in order to disinfect it and eliminate bacteria, and to ensure a residual chlorine concentration, thus insuring the microbiological quality of the water in the distribution networks in compliance with the Standards.

The water treatment begins with the application of coagulants such as aluminum sulfate and such polymers as aluminum polychloride, among others, in either the quick mix stage or the coagulation stage. This enables the elimination of the suspended or dissolved solids and solids subject to sedimentation which color and cloud the water.

The floccules formed are subsequently fed through sedimentation tanks, where they are precipitated and settled. A continuous analysis is made of the control parameters to be eliminated in the process of purification when they enter the treatment plants. These include turbidity, apparent and true color, pH, hardness, total alkalinity, metal content, total coliform and fecal bacteria, among the main control parameters.

The purification process ends when the water enters the filters, where the smallest particles and tiny organisms are captured, which could not be captured during sedimentation. These filters use filtration beds comprising gravel and sand of different graduations, and a layer of anthracite.

Chlorine (usually as a gas) is applied during the final treatment stage in order to ensure that the water distributed to the network contains only a residual concentration of this element when it reaches the users' homes pursuant to the provisions of the Drinking Water Quality Standards. Due to the prolonged effect of this element in eliminating microorganisms, this concentration is between 0.3 and 0.5 mg/liter.

According to González Landazábal (2001), 119 water purification plants are in operation in Venezuela, with a total installed capacity of 132,390 liters per second. The existing plants are basically standard, with traditional type units; they are conventional, offering a thorough treatment, which includes flocculation, sedimentation, filtration and disinfection – conventional with partial treatment and unconventional with modular, accelerated, compact and combined design partial treatment. Compliance with the existing standards for bacteriological quality and organoleptic quality is between 85% and 83%, respectively for water receiving only chlorination, and 91% and 85%, respectively, for water subject to conventional treatment.

With regard to wastewater coverage, disposal and treatment, while considerable progress has been made, this last mentioned is still one of the major environmental problems faced by Venezuela (Páez-Pumar, 2010).

Percentage-wise, wastewater cleansing is insufficient (González Landazábal, 2001). The types of treatment generally employed are stabilization or oxidation ponds and prolonged aeration for urban areas, and septic-filter wells and septic drain fields for absorption in a number of rural cities. In general, given the large cities' proximity to the sea, or to the fact that they are discharged directly in rivers which empty into the sea, and most of the untreated effluents contaminate the coast. In the major tourist developments, such as Margarita Island (in Nueva Esparta state), some areas of Falcon state (the city of Coro and the Paraguaná peninsula) and Anzoátegui (the Barcelona-Puerto la Cruz-Guanta axis) and, more recently, the city of Maracaibo, wastewater treatment systems are being implemented (González Landazábal, 2001; Rosillo, 2001). Wastewater treatment systems are also being installed in the cities of Cumaná and Carúpano on the Sucre coast. For Caracas –the city with the largest urban concentration– there is no type of wastewater treatment, and it is discharged in the Tuy River basin and from there into the Caribbean Ocean.

As additional information, the city of Caracas has the experimental type wastewater plant at the Faculty of Engineering of the Central University of Venezuela (Experimental Water Treatment Plant – PETA) and with one of the food distribution companies (POLAR Group).

There are also plants in the north central part of Venezuela, which is the industrial heart of the nation. In this region, private companies generally have their own wastewater treatment plants in order to comply with the established discharge values for the parameters regulated under Decree No. 883 regarding the Standards for the Classification and Quality Control of Waterbodies and Discharges or Liquid Effluents (*Official Gazette of the Republic* *of Venezuela*, *under extraordinary decree No*. 5,021 dated December 18, 1995. The treatment plants at Los Guayos and La Mariposa in Carabobo state, treat two-thousand and two-thousand four-hundred liters per second respectively, while the treatment plant in Taiguaiguay, in Aragua state, treats three-thousand liters per second (MINAMB, 2006).

According to Páez-Pumar (2010), there is sewer coverage of eighty-one percent in Venezuela. However, as the result of the scant existing infrastructure, the wastewater treatment situation is much less. The lack of these services has an impact on the increase of waterborne diseases, a number of which have reemerged in areas where they had previously been eradicated. At present, the districts are in the process of reviewing the management models in order to incorporate new forms of community participation (community committees, technical agencies) and to improve the efficiency of these services (WSP, 2007).

According to WSP (2007), at the beginning of 2007 wastewater treatment coverage was barely 20.2% and, with an investment of three-hundred million dollars, it is expected that a nationwide coverage of 27% will be attained by the end of this year, with the coverage reaching 40% in 2010 and 60% in 2015. In order to achieve this, a total investment of three-billion, six-hundred and twenty-million dollars will be required.

Apart from the waterborne diseases and their foul smell, untreated effluents from factories, swine farms and wastewater in urban centers contaminate rivers, seacoasts, lakes, reservoirs and other water ecosystems, possibly giving rise to changes in the concentration of dissolved oxygen, nitrogen, phosphorous, bio-oxygen demand and chemical-oxygen demand, among other parameters. Such heavy metals as manganese, zinc, iron and copper may accumulate in them, and have other negative environmental impacts such as high temperature, change in salinity, a reduction of the dissolved oxygen concentration, among other conditions.

Prominent among the major sanitation investment projects is the Rio Guaire Sanitation Project, which crosses the city of Caracas west to east. This project (MINAMB, 2012b) is seventy-two kilometers long and is the city's main river, with a basin of 655 square kilometers (Pérez Lecuna, 2005). It also represents Caracas' main wastewater collector. The Guaire River is one of the main tributaries of the Tuy River, in whose basin are located most of the reservoirs which supply the city's drinking water. The sanitation plan for this river is summarized below.

- First Phase (2005–2006): Cleaning and dredging the Guaire river and its tributaries. This phase contemplates hydraulic engineering and sanitary engineering works, with the objective of raising to 75% the collection of wastewaters in the riverbank collectors already in service. It contemplates the construction of 1,500 hectares of collectors, the rehabilitation of the riverbank collectors along several main tributaries of the Guaire River: the San Pedro, Macarao, Caricuao, Mamera, Antímano, Carapita, La Vega, Bella Vista, La Yaguara, San Martín, El Guarataro, Caroata, Catuche and Arauco creeks, and the construction of a treatment plant. The approximate cost is seventy-five million dollars. This phase has been concluded.
- Second phase (2007–2014): The continuation of the hydraulic engineering and sanitation works required to intercept up to 95% of the wastewater in the riverbank collectors, and for the sanitation of 1,500 hectares of collectors in urban areas. The riverbank collectors in the following tributaries will be rehabilitated: El Valle, Chacaíto, Baruta, Tocoma, Agua de Maíz and Quebrada Grande de El Hatillo. This phase will end with the canalization of the Guaire River and the construction of riverbank collectors. Its cost is approximately four-hundred and fifty million dollars, and community participation will play a vital role in this plan. It is anticipated that the river banks can be used as recreational areas once the plan is concluded. This second phase is still unfinished.

Another major sanitation project is the Overall Project for the Sanitation and Control of the Level of the Lake Valencia Basin. This consists in the construction of collectors in Aragua and Carabobo states, with the purpose of transporting wastewater to the wastewater treatment plants in Carabobo state (La Mariposa and Los Guayos) and Aragua state (Taiguaiguay), so they can be treated in order to contribute to the sanitation of the Lake Valencia basin (MINAMB, 2006).

In addition to the construction of collectors, the expansion of the La Mariposa wastewater treatment is underway, with the purpose of increasing to 5,200 liters per second the flow entering the plant, based on the requirements of an increased population in Carabobo state.

This also contemplates the construction of wastewater treatment systems in La Victoria and Tocorón (in Aragua state), and wastewater treatment systems in Güigue, Mariara and San Joaquín (in Carabobo state), in addition to the construction of a dam to protect the cities of La Punta and Mata Redonda in Aragua state against floods caused by the overflowing of Lake Valencia.

This project also includes the Environmental Education Program, whose purpose is to form and organize the communities with regard to their social, economic, environmental, civil, political, cultural and educational rights, thus developing their capabilities and potentialities in order to promote and consolidate an inherent and sustainable development of the Lake Valencia basin. In the western part of the country, the Lake Maracaibo Sanitation Project is under development. Its purpose is to use treatment plants, main collectors, wastewater plants in many districts of the state, torrent control and dredging of the lake basin in order to clean the wastewaters reaching the lake (GeoVenezuela, 2010). In this regard, in 2007 construction began on a 130.2 kilometer aqueduct from the Tres Ríos reservoir to the Maracaibo district, for the supply of drinking water to the Maracai¬bo, San Francisco, Jesús Enrique Lozada, La Cañada de Urdaneta and Mara districts in Zulia state. According to official information from the Ministry of the environment, work on this project was finished in September 2007.

4. Water and Health in the Cities

It is well known that wastewater harbors microorganisms (pathogens) which cause diseases. These include viruses, protozoa and bacteria (Reynolds, 2002). Pathogenic organisms can originate in infected persons, or in domestic or wild animals, which may or may not show signs of disease. Diarrhea and gastroenteritis are among the three main causes of death in the world, and in Latin America. Unsafe drinking water and contamination through improper disposal of sewage are responsible for the vast majority of these deaths.

From the public health standpoint, an inadequate supply of drinking water and of effluent collection services, added to conditions of poverty, involve the appearance of such water-transmitted diseases as amebiasis, diarrhea (mainly in children), giardiasis, helminhtiasis and acute Type A hepatitis (Martínez, 2013).

According to Martínez (2013), in the Capital District over thirty-thousand cases of waterborne diseases were reported during 2012. This represents an index of 15.5 cases per thousand inhabitants. In this index, 42.64% of the cases occurred in among the poorest levels of the population. However, in breaking them down by parishes according to the highest incidence of these cases, we may observe: (1) that in the city's relatively healthy parishes, where twelve or fewer cases of waterborne diseases per thousand inhabitants were recorded, formal aqueducts and sewers are the rule, whereas the average percentage of poor inhabitants is relatively lower (36.48%); (2) in those parishes in which there are between twelve and thirty cases per thousand inhabitants, informal urban settlements are predominant, the networks of some of their sectors are highly precarious and the average percentage of poor population is 43.11%; (3) finally, where the concentration of these cases is over thirty per one thousand inhabitants, overcrowded, informal dwellings and deficient water and sanitation services are relevant factors, and the average percentage of poor population is high (48.95%).

To these results should be added the fact that inadequate water storage in open vessels to compensate for rationing fosters the propagation of such diseases as dengue and malaria, and they may have a geography related distribution. There also tend to be present a number of structures, such as, for example, old automobile tires, which can accumulate water, thus providing ideal habitats for the vehicles which spread some of these diseases.

According to the People's Ministry of Health (MPPS, 2008, 2009, 2010, 2011, 2012, 2013), in Venezuela many cases of waterborne diseases have occurred. Below are a number of instances:

- Diarrhea: Most of the waterborne infectious diseases are diarrheal diseases, caused by microorganisms (bacteria, virus, worm or protozoa eggs), discharged by human or animal excretions. The carriers of these diseases may be found in untreated, contaminated water containing excretions, or persist due to the lack of available water. The most vulnerable sector of the population are children under five years old, and the documented cases number in many hundreds of thousands per year in Venezuela (Figure 6).

- Amebiasis: A parasitic illness caused by amoebas *Entamoeba histolytica, E. dispar* and *E. moshkovskii*. Its incidence is high in areas with deficient environmental sanitation. From 2008 forward a decline in the number of cases has been noted. However, the incidence is still high (Figure 7). As with diarrhea, the most vulnerable population group are children under five years old.
- Malaria (or yellow fever): There are four species of parasites (*Plasmodium vivax, Plasmodium ovale, Plasmodium falciparum* and *Plasmodium malariae*) which may infect humans and cause this disease. Their carriers are several species of mosquitos (*Anopheles*), whose larval phases develop in water. In Venezuela tens of thousands of cases are recorded annually, with a notorious increase in 2013 (Figure 8a); its incidence was high during almost every month of that year (Figure 8b); the greatest number of cases normally appears in the southern region of the country, which is the one with the greatest water availability.

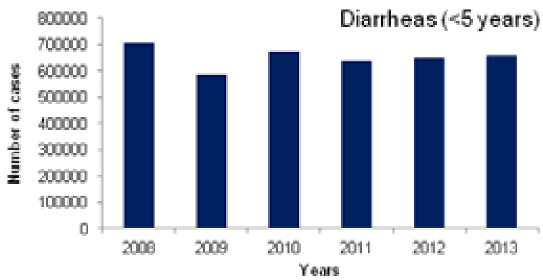
  Delgado Petrocelli et al., (2011) also noted a high incidence of this disease in the Nor-Oriental region of Venezuela, specifically in Sucre state. These researchers found an active malaria epidemic corridor in this region, aligned along communication channels, which is associated with highly concentrated populations living near the habitats of the pre-adult stages of the carrier, low altitudes, gradually sloping terrain and proximity to mangroves and forests, in addition to their relationship to the rainfall patterns (Rodríguez et al., 2013).
- Dengue: This is a disease caused by viruses, whose carriers are mosquitos *Aedes aegypti* and *Aedes albopictus*. In recent years its transmission has increased mainly in urban and semiurban zones and has become a major public health problem. It is estimated that Venezuela accounts for over seventy percent of all known cases in the Americas. In Venezuela, dengue has become a serious public health problem nationwide. According to Barrera et al., (2000) in our country, control of the carrier *Aedes aegypti* is difficult not only because of limited resources but also because of the great expanse and heterogeneous nature of the urban zones, and the lack of sanitation resources such as solid waste collection, drinking water supply and medical attention. Tens of thousands of cases are reported every year (Figure 9a) and the greatest incidence normally occurs during the last few weeks of the year (Figure 9b). These Figures show the total cases of dengue (both classic and hemorrhagic) reported. At present, the greatest incidence of cases of dengue is found mainly on the Andine-Coastal arc, where the highest percentage of the country's urban population is concentrated (MPPS, 2013).

In the Capital District, which has the nation's highest urban population, the prevalence of dengue has been very high (Figure 10a), especially in 2010, when more than ten-thousand cases were reported. The Capital District also reported a higher rate of cases of dengue during the last few weeks of 2013 (Figure 10b).

According to Delgado Petrocelli et al., (2013), dengue in Venezuela has rebounded significantly, especially in the central region of the country, in Aragua state, since Maracay, its capital, has been classified since the first decade of this century as hyperendemic. In addition, the western region, especially Mérida state (in the Venezuelan Andes) has not escaped its impact (Marichal, 2011). There is a relationship between dengue and cultural patterns, both in mobility and in water storage practices. This, in turn, is linked with the shortage of water, caused by a seasonal drought or by the alteration of the weather change patterns due to such weather phenomena as El Niño and Southern Oscillation (ENSO). An epidemic corridor associated with the Transandes highway has also been detected.

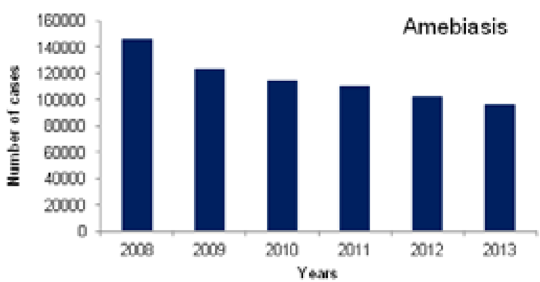
As may be seen, greater wastewater disposal and treatment is necessary in the urban areas specifically, and nationwide generally. Waterborne

Figure 6. The number of cases of diarrhea in children under five years (2008-2013)



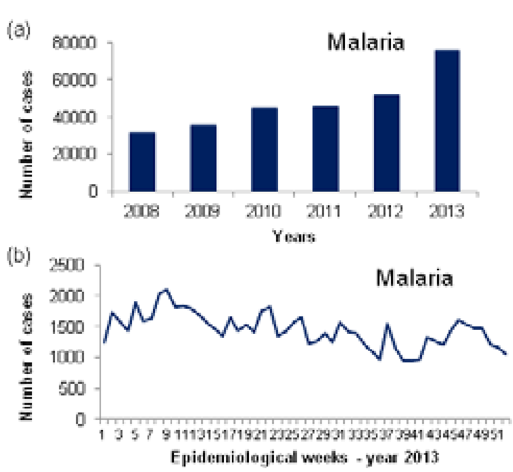
Source: In-house document based on MPPS data (2008, 2009, 2010, 2011, 2012, 2013).

Figure 7. The number of cases of amebiasis (2008-2013)



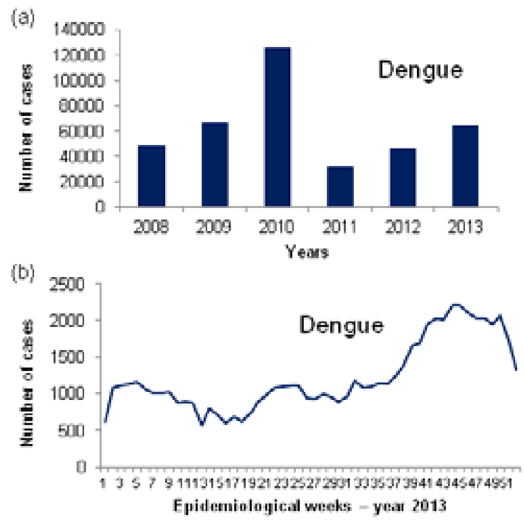
Source: In-house document based on MPPS data (2008, 2009, 2010, 2011, 2012, 2013).

Figure 8. Number of cases of malaria: (a) From 2008-2013, b) for 2013



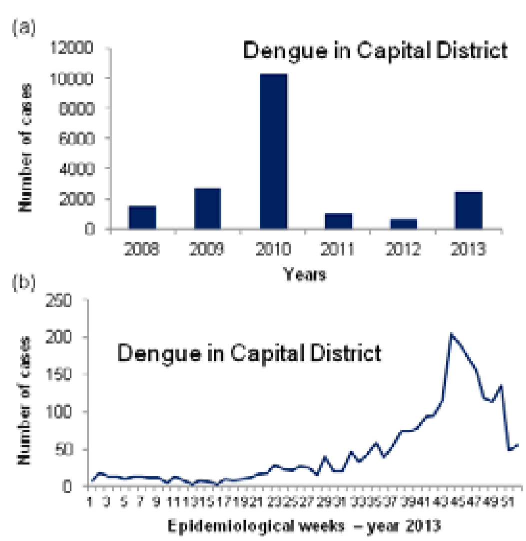
Source: In-house document based on MPPS data (2008, 2009, 2010, 2011, 2012, 2013).

Figure 9. Number of cases of dengue: (a) From 2008-2013, b) for 2013



Source: In-house document based on MPPS data (2008, 2009, 2010, 2011, 2012, 2013).

Figure 10. Number of cases of dengue reported in the Federal District. (a) From 2008-2013, b) for 2013



Source: In-house document based on MPPS data (2008, 2009, 2010, 2011, 2012, 2013).

diseases are more usually found among the poorest strata of the population. Several authors (Faría, 2006; Pineda, 2006; Martínez et al., 2013) state that organized community participation (for example, the Technical Roundtables of Water) and education of the people are key elements in mitigating the incidence of these diseases, as is the necessary public investment in the sanitation of rivers and ravines.

4.1 Another Ddimension of "Water and Health": Gauging Environmental Health in Housing and Public Buildings, and their Relationship with Water

The World Health Organization ("WHO") affirms that environmental health is related to all of a person's external physical, chemical and biological factors (OMS, 2013). Consideration of the environment where humans live goes from rural communities to the large cities and their outlying areas; from the suburbs comprised by single-family houses to the neighborhoods surrounding many of Venezuela's cities. These may be villages, towns, cities or the urban fringe. In the final analysis, in each of them there are dwellings and, perhaps, several homes within these dwellings. Hence, this approximation of environmental health from within dwellings and households, with observations regarding the indicators and indices intended to measure the water-environmental health interaction.

The measurement of environmental health in housing and homes must be related to the basic environmental health indicators, with regard to the drinking water supply, disposal of sewage, domestic hygiene, domestic garbage handling and collection, control of plagues (insects and rodents) in dwelling, in addition to the physical conditions in the residences themselves (roofing, floors, walls and friezes).

4.2 General Information, Indicators and Indices Regarding Environmental Health in the Housing Available in Venezuela

The censuses constitute the national inventory of housing in Venezuela. From the available housing data, three of these are tied to environmental health and water. These are:

a. The drinking water supply: An effort has been made to determine how drinking water is supplied to dwellings. The first option is an aqueduct or piping, which involves a continuous, public supply of drinking water of the quality required by the sanitation standards and in sufficient quantity, with a predetermined daily supply and at a pressure adequate for faucets and sanitary facilities to operate properly. The second option involves tank trucks, which offer irregular service, requiring storage in the home where the potability of the water supplied makes it desirable to have a home disinfection system. It is, therefore, important to discern the quality of the serviced rendered, beyond the simple connection to the aqueduct. An early approximation involves the means of supply. Table 6 offers relevant information in this regard. It shows the high percentage of incorporation of aqueduct systems as a means of receiving an allowance of drinking water. This is a favorable and significant circumstance; however, as mentioned before, it is necessary to ensure the continuity of the service performed. Since Venezuela is a basically urban country, the charts showing the analysis refer to fifty-seven parishes of some of the cities with the largest population: Caracas, Barcelona, Puerto Ordaz, Valencia and Maracaibo. In addition, it must be mentioned that Venezuela has in place a successful rural aqueduct construction program. Accordingly, the figures for rural aqueduct service coverage in that geographical area are high.
b. Frequency of supply: The 2011 Census, aware of the importance of this information in classifying the quality of the water supply service, asked the users about the frequency of the supply of water to their homes: every day, every two or three days, once a week or once every two weeks. Table 7 shows the results for the five cities compared. It may be seen that, despite the high degree of aqueduct connections, the quality of the service with regard to continuity is significantly lower in such cities as Maracaibo, where barely 37.3% of the residences have a permanent supply. In general, the percentage of permanent water supply is around 79% except for the anomalous situation in Maracaibo. In any event, the population receiving water at different frequencies – from every other day to once every two weeks – represents about 20% of

all residences. Interruptions in the supply may cause personal hygiene deficiencies, improper handling of sewage, improper handling of food and kitchen utensils, all of which can cause health problems. These matters require investigation.

c. Home treatment of water: Considering that water is supplied infrequently to homes and, in general, is subject to storage prior to use, the 2011 Census included a question about water treatment carried out at home, prior to use. The options include filtration, boiling, filtration and boiling, chlorination, the use of bottled water as a beverage, or no treatment. Table 8 offers an appreciation of the number of users per type of prior water treatment. These data enable us to have an idea of the degree of confidence in the quality of the water furnished. Valencia shows the highest percentage of bottled water, while in Caracas and Maracaibo, a third of all homes boil their water before using it. In all the cities, twenty percent filter their water; the same percentage applies to those who drink water directly from the tap with no additional treatment. In Caracas and Valencia direct consumption comes down to 15% and 12%, respectively. These figures reveal an awareness, on the part of the population, of the relationship between health and water disinfection, while the variations from city to city offer an idea of the implications of storage as a means of having available water.

d. Means of sewage disposal: Complementing the data regarding living conditions as related to environmental health and water, the 2011 Population and Residence Census obtained information on the disposal of sewage, inquiring about the options shown in Table 9. The "bathroom with no sewer or septic tank connection" is alarming from the environmental health standpoint, since it presupposes discharges into waterways, artificial or open air discharge, which can lead to the accumulation of septic material, foul odors and miasmas serving as hosts for parasites and microbes which can cause diseases in the event of their eventual contact with humans and domestic animals. The figures for the cities selected show a high percentage of toilets connected to sewers or septic tanks. This leads one to contemplate two basic aspects to ensure urban health: (1) control of the quality of drinking water by using water from below these discharge points which, in turn, are related to the design of treatment of water to make it potable, and (2) the need to treat wastewater collected by the sewer systems in order to safeguard the quality of water at the river banks and their use downstream of the points of discharge. Despite the scant rural population in Venezuela and the systematic implementation of basic environmental sanitation in the rural areas, it is possible that there may still be open air discharges in the most isolated communities, giving rise to the transmission of parasitic diseases.

e. Use of communal showers.. For homes, the 2011 Population and Residence Census prepared a question about the matter of environmental

Table 6. Venezuelan cities: Caracas, Barcelona, Puerto Ordaz, Valencia, Maracaibo. Population supplied by aqueduct and tank trucks.

Cities, districts	Population of district	Supplied by aqueduct		Supplied by tank truck	
		Population	%	Population	%
Caracas, Libertador District	1,828,956	1,821,211	99.57	7,745	0.43
Barcelona, Simón Bolívar District	371,702	357,936	96.29	13,766	3.71
Puerto Ordaz, Caroní District	656,386	639,864	97.48	16,522	2.52
Valencia, Valencia District	754,329	739,563	98.04	14,766	1.96
Maracaibo, Maracaibo District	1,385,463	1,336,550	96.47	48,913	3.53
All cities selected	4,996,836	4,895,124	97.96	101,712	2.04

Source: Fourteenth National Population and Housing Census for 2011 (INE, 2013).

Table 7. Frequency of water supply to dwellings

Cities, districts	Dwellings	Continuous supply (every day)		Intermittent supply (every two or three days)		Weekly Supply		Biweekly supply	
		Dwellings	%	Dwellings	%	Dwellings	%	Dwellings	%
Caracas, Libertador District	521,326	384,512	73.8	67,178	12.9	38,151	7.3	31,485	6.0
Barcelona, Simón Bolívar District	93,179	72,328	77.6	16,603	17.8	2,741	2.9	1,507	1.6
Puerto Ordaz, Caroni District	165,424	138,408	83.7	19,344	11.7	5,601	3.4	2,071	1.3
Valencia, Valencia District	202,105	167,283	82.8	31,001	15.3	2,668	1.3	1,153	0.6
Maracaibo, Maracaibo District	329,122	122,606	37.3	195,864	59.5	7,812	2.4	2,840	0.9
All cities selected	1,311,156	885,137	67.5	329,990	25.2	56,973	4.3	39,056	3.0

Source: Fourteenth National Population and Housing Census for 2011 (INE, 2013).

Table 8. Home water treatment

Caracas, Libertador District		
Water used for drinking	Cases	%
Boiled	168,964	31.0
Filtered	151,515	27.8
Filtered and boiled	46,375	8.5
Chlorinated	13,004	2.4
Purchase of bottled water	85,937	15.7
No treatment	79,996	14.7
Total	545,791	100.0

Barcelona, Simón Bolívar District		
Water used for drinking	Cases	%
Boiled	9,467	9.5
Filtered	34,995	35.1
Filtered and boiled	3,887	3.9
Chlorinated	6,403	6.4
Purchase of bottled water	15,188	15.2
No treatment	29,791	29.9
Total	99,731	100.0

Puerto Ordaz, Caroní District		
Water used for drinking	Cases	%
Boiled	10,114	5.8
Filtered	37,267	21.5
Filtered and boiled	5,042	2.9
Chlorinated	8,139	4.7
Purchase of bottled water	56,868	32.8
No treatment	56,038	32.3
Total	173,468	100.0

Valencia, Valencia District		
Water used for drinking	Cases	%
Boiled	11,043	4.8
Filtered	25,951	11.4
Filtered and boiled	5,766	2.5
Chlorinated	3,452	1.5
Purchase of bottled water	155,660	68.2
No treatment	26,472	11.6
Total	228,344	100.0

Maracaibo, Maracaibo District		
Drinking water used	Cases	%
Boiled	141,010	40.6
Filtered	49,282	14.2
Filtered and boiled	28,890	8.3
Chlorinated	5,269	1.5
Purchase of bottled water	50,611	14.6
No treatment	71,907	20.7
Total	346,969	100.0

All cities selected		
Drinking water used	Cases	%
Boiled	340,598	24.4
Filtered	299,010	21.4
Filtered and boiled	89,960	6.5
Chlorinated	36,267	2.6
Purchase of bottled water	364,264	26.1
No treatment	264,204	18.9
Total	1,394,303	100.0

Source: XIV National Population and Residence Census, 2011 (INE, 2013).

health and its relation to the use of communal showers. This is related with the greater possibility of skin diseases and the control of molds producing allergies and respiratory tract diseases. In general, the problem arising from the use of communal showers in homes involves responsibility for cleanliness of the shower room. The possibility of contracting diseases is similar in either an improperly cleaned individual shower room or communal shower room. The percentage of homes with no shower in the bathroom is still around 5%, except in the case of Barcelona, where it climbs to 16.2% (Table 10). The circumstances of living in a home with a showerless bathroom involves sharing showers and assuming joint responsibility for the cleanliness of the facilities. The percentage of bathrooms with showers is significantly higher in the large cities other than Caracas. Maracaibo, in turn –perhaps due to the influence of the weather (high temperatures)– shows the greatest percentage of three or more bathrooms with showers. The information regarding the extremes indicated offers food for thought about the desirability of correlating skin diseases with the situation of several families using the same bathroom, and taking note of whether a greater of number of bathrooms with showers is related to higher water consumption.

Table 9. Sewage disposal services

Cities, districts	Dwellings	Drainage tank connected to sewer		Drainage tank connected to septic tank		Drainage tank with no connection		Hole, or outhouse latrine		No tank or toilet	
		Dwelling	%	Dwelling	%	Dwelling	%	Dwelling	%	Dwelling	%
Caracas, Libertador District	530,694	520,359	98.1	7,745	1.5	1,109	0.2	200	0.0	1,281	0.2
Barcelona, Simón Bolívar District	95,625	64,372	67.3	26,771	28.0	1,055	1.1	829	0.9	2,598	2.7
Puerto Ordaz, Caroni District	168,746	129,733	76.9	35,606	21.1	1,228	0.7	566	0.3	1,613	1.0
Valencia, Valencia District	218,166	198,293	90.9	15,901	7.3	944	0.4	530	0.2	2,498	1.1
Maracaibo, Maracaibo District	335,352	262,967	78.4	57,703	17.2	2,352	0.7	6,596	2.0	5,734	1.7
All cities selected	1,348,583	1,175,724	87.2	143,726	10.7	6,688	0.5	8,721	0.6	13,724	1.0

Fourteenth National Census of the National Statistics Institute for 2011 (INE, 2013).

Table 10. The number of bathrooms with showers per home

Cities, districts	Homes	Zero bathrooms with shower		One bathroom with shower		Two bathrooms with shower		Three or more bathrooms with shower	
		Homes	%	Homes	%	Homes	%	Homes	%
Caracas, Libertador District	545,791	16,257	3.0	431,990	79.1	84,611	15.5	12,933	2.4
Barcelona, Simón Bolívar District	99,731	16,151	16.2	59,938	60.1	21,124	21.2	2,518	2.5
Puerto Ordaz, Caroní District	173,468	8,299	4.8	121,562	70.1	36,231	20.9	7,376	4.2
Valencia, Valencia District	228,344	8,131	3.6	158,885	69.6	50,477	22.1	10,851	4.7
Maracaibo, Maracaibo District	346,969	23,946	6.9	211,670	61.0	86,746	25.0	24,607	7.1
All cities selected	1,394,303	72,784	5.2	984,045	70.6	279,189	20.0	58,286	4.2

Source: Fourteenth National Census of the National Statistics Institute for 2011 (INE, 2013).

4.3 Information Regarding "Poverty due to Unsatisfied Basic Needs" (INE, 2013)

The data regarding Unsatisfied Basic Needs reveals three important data required to determine the environmental health status of the dwellings and households in Venezuela. These are:

- Overcrowding: this refers to the number of homes with more than three persons using the same bedroom. Nationwide, the Fourteenth National Census of the National Statistics Institute for 2011 shows this condition in 15.12% percent of all homes.
- Inadequate living quarters: that is, dwellings classified as farms, tenements, tents, containers and others similar. This figure comprises 9.38% of all dwellings.
- Lack of basic services: the lack of drinking water or sewage disposal services. This means that the figures embrace either one of these two services and, in the case of elimination of sewage, it is described as follows: dwellings with no sewer installed. This figure comprises 14.79% of all dwellings, many of which are connected to septic tanks. This is an acceptable sanitation practice provided that there is an awareness that they require periodic maintenance.

4.4 GeoVenezuela 2010 (GV-2010)

GeoVenezuela (2010), a summary of the state of the environment published by the People's Ministry of the Environment, the Latin American Forest Institute and the United Nations pro-Environment Program, presents information of various kinds regarding cities. However, its degree of diversity does not take in housing and homes. The indications used in the reports on "The State of the Environment", published in 1995 and 1996, report only the following in this new evaluation:

- Mortality, showing the rate per thousand (‰) for the censuses from 1990 to 1994.
- Drinking water and sewage disposal service availability. The following indicators are described and quantified:
  - The percentage of the population with access to drinking water storage. In this regard, it indicates that Venezuela has an installed drinking water infrastructure to supply water to 86% of the population. The figure reported in the Environmental Balance for 1995, carried out by the Ministry of the Environment and Renewal Natural Resources, was 83%.
  - The percentage of the population with wastewater collection services. In this case, GV-2010 reports the state-by-state characterization of sewer coverage. Based on those data it has been determined that the state with the highest coverage is Carabobo, with 91%, while the state with the lowest coverage is Mérida, with 18.85%. The average nationwide coverage is given as 56.9%. However, it is also apparent from the text that the coverage is 63.64% in states on the Caribbean and Atlantic Ocean coasts, and 65.20% in noncoastal states. The figure shown in the 1995 Environmental Balance for Venezuela was 62%.

4.5 The National Indicator and Statistics System for Environmental Management (SIENAGA)

With regard to public health, the Ministry of the Environment (MINAMB)'s National Indicator and Statistics System for Environmental Management contains a series of indicators aggregated either nationwide or by cities. None of them is broken down in accordance with homes and dwellings. These indicators are as follows:

- The percentage of wastewater treated.
- Proper urban generated garbage disposal.
- Final disposal sites of garbage.
- The percentage of the population with access to improved sources of urban water supply.
- The percentage of the population with access to improved sanitation services.
- The percentage of the population with access to garbage collection services.
- The morbidity rate attributable to acute respiratory diseases.
- The morbidity rate attributable to waterborne diseases.

Some of these allow inferences regarding the status of environmental health in dwellings and households. This is the case with the following:

a) The percentage of the population with access to improved sources of urban water supply.

Using data gathered by the National Statistics Institute and processed by HIDROVEN, it is reported that as of 2008, the total population with access to improved drinking water sources was 94.0%. With regard to the urban population, this percentage was 96.0%. SIENAGA states that these data reflect a population with household connections as an improved source of drinking water.

With regard to the proper way to interpret the information gathered by the National Statistics Institute, SIENAGA reports that the criteria of the Joint Monitoring Program (OMS-UNICEF) have been taken into account. These define the access to water supply services, such as the availability of at least twenty liters per person per day from an "improved" source within a kilometer from the user's home. "Improved sources" means all of those which commonly provide healthy water. The following are defined as "improved" water supply sources: household connections, public sources, drilled wells, wells drilled and protected, protected springs and gathered rainwater. The term "Unimproved sources" refers to unprotected wells, unprotected springs, water furnished by vendors, bottled water (based on considerations related on the amount, not the quality, of the water supplied) and water furnished by tank trucks.

b) The percentage of the population with access to improved sanitation services.
From data gathered by the National Statistics Institute and processed by HIDROVEN, it is reported that as of 2008, the total population with access to improved sanitation services was 83.9%. For the urban population, the percentage was 85.5% SIENAGA reports that these data reflect the population with connections to public sewers as an improved sanitation service.
With regard to the interpretation of the information gathered by the National Statistics Institute, SIENAGA reports that the category of improved sanitation includes connections to public sewers, connections to a septic sanitation system, a flush toilet, a single well toilet and a ventilated pit toilet. On the other hand, "unimproved sanitation facilities" refers to a public or shared toilet, an open-pit latrine or bucket latrines. It clarifies, however, that as indicated, only those dwellings with connections to public sewage systems have been taken into account.

c) The morbidity rate attributable to waterborne diseases.
With the morbidity data obtained from the People's Ministry of Health, and population data from the National Statistics Institute, SIENAGA calculates the morbidity rate attributable to waterborne diseases as the number of cases per hundred-thousand inhabitants. The analysis performed is of the tendency behavior for the period from 2002 to 2007. The diseases contemplated in calculating the indicator were typhoid fever, diarrhea in infants less than a year old, diarrhea in children from one to four years old, diarrhea in infants over five years old and type "A" hepatitis.

4.6 Considerations on the Water-Health-Dwelling Relationship

Information concerning indicators and indices designed to define the condition of a healthy environment or the environmental health in dwellings and households, comes from sundry sources and is presented in random order. It is, however, possible to combine the information available in order to produce a reasonably satisfactory system concerning water-related environmental health in dwellings and households. It should look toward accomplishing the task of establishing a basic group of indicators and indices to enable the gathering of information, with the purpose of evaluating the right to a healthy environment in homes and dwellings. A minimum approximation may be, among other criteria, a consideration of the elements which comprise basic environmental sanitation.

In order to combine the available information so as to produce a reasonably satisfactory system with regard to the status of environmental health as it concerns water in homes and dwellings, the country has available diverse official sources of information, as may be seen from the preceding sections. These organizations produce their figures according to different data-gathering criteria, for different dates and using different data gathering processes. This aspect is important, to serve as a warning of the need to stipulate, in each case, not simply the source used but information regarding the date that the data was captured, how it was processed, the criteria used in assembling it and, in general, any inquiries required to interpret the data and compare it with the data from other sources.

5. Climate Variability and Change – its Impact on Water Resources in the Cities

In Venezuela, the First National Communiqué on Climate Change states that the potential impacts which could be felt in the country are an increase in from one to two degrees Celsius in the average temperature by the year 2060, a reduction in rainfall and the change in weather patterns, among others (Martelo, 2004). While the studies indicate that there will be global warming and a trend toward less rainfall in the future, there are major regional differences. The southern part of the country could be the one most affected, while in the Andine and north-central regions –that is, the country's main mountainous zones, there is greater uncertainty.

In general, the country is highly vulnerable due to the population concentration to the north, where water is more scarce. In fact, even slight reductions in rainfall or slight increases in water outlets (as, for example, evapotranspiration, or "ETP") could have serious consequences, especially in the semiarid and sub-humid, dry regions (Martelo, 2004). Therefore, it is vitally important to monitor the effect of climate change on the different sources employed for its supply, since most of the adverse effects are related to the availability of water.

According to Andressen (2005), the impacts of climate change on water resources will depend on the conditions taken as a base for the water systems themselves and of the skill employed in administering those systems in order to respond not only to climate change but also to the growth of the population and their demands, improvements in technology and changes in social and economic conditions, and in legislation. It must be borne in mind that if the there is a decreased availability of water it will increase pressure on it and have a negative impact on its quality.

The adoption of adequate adaptation and mitigation measures in the face of climate change can ensure that population and economic growth in the coming decades can be brought into harmony with the limitations might occur in the water supply (Andressen, 2005). In this sense, projects resulting from a well-planned and conceived interaction among ecology, society, the economy and the existing institutions, must be implemented to manage the water resources, with a view to balancing the supply and demand of this resource when faced with extreme water occurrences.

In November 2013, Venezuela's First National Climate Change Symposium was held, with the purposes of (1) making known to the governmental and non-governmental sectors, the industrial sector and the public in general, the state of the art in activities and research being carried out nationwide to determine the impacts of climate change in Venezuela; (2) to identify the climate change mitigation and adaptation measures which have already been taken in the country, and (3) to detect the existing voids in this area, as well as future requirements. The impact of climate change on water resources was one of the subjects discussed, giving rise to proposals for the use of urban elements as mitigating factors (for example, the use of vegetation on the roofs of dwellings, known as "green roofs") (Bolívar and Cegarra, 2013).

The First National Climate Change Symposium culminated in the "Caracas Declaration", which expressly set forth the following commitments (Scientific Committee of the First National Climate Change Symposium, 2013):

1. To promote and support joint efforts among the nation's public and private institutions for the generation and widespread dissemination of knowledge about climate change.
2. To promote the multidisciplinary study of climate change.
3. To promote and support the creation of a National Climate Change Observatory as a monitor of the needs for research, analysis and preparation of this problem as a platform for the identification of viable options for adaptations to the realities in the country, and as a critical observer and alerting factor to the nation's commitment to the United Nations' Framework Convention on Climate Change.
4. To promote a rapprochement between the Government and all the nation's knowledge generation centers as a natural channel for the effective, overall attention to the problem of climate change.

Box 16

Lakes and reservoirs as sentinels of climate change

Lakes and reservoirs may be considered sentinels for climate change because they respond quickly to changes in solar radiation, rain, wind, hydrology and in a wide variety of changes from both the atmosphere and the earth (Williamson et al., 2009). These waterbodies embody climate change since they store the signs of change in their sediment, incorporating changes not only in the waterway system but also in the surrounding earth ecosystems. They also serve as regulators of climatic change inasmuch as they (1) receive, process and store large quantities of carbon from the surrounding slopes, and from the productivity of water along their coastlines; (2) they are involved in the active interchange of greenhouse effect gases and the atmosphere beneath them, and (3) they can change the regional climate by changing the patterns of sunlight, the formation of clouds, rainfall and evaporation.

Venezuela has more than one hundred reservoirs (Ginez and Olivo, 1984), but there is limnological information available for only about twenty percent of them (González et al., 2004), and for only a few of these is there a historical sequence enabling comparisons with recent events.

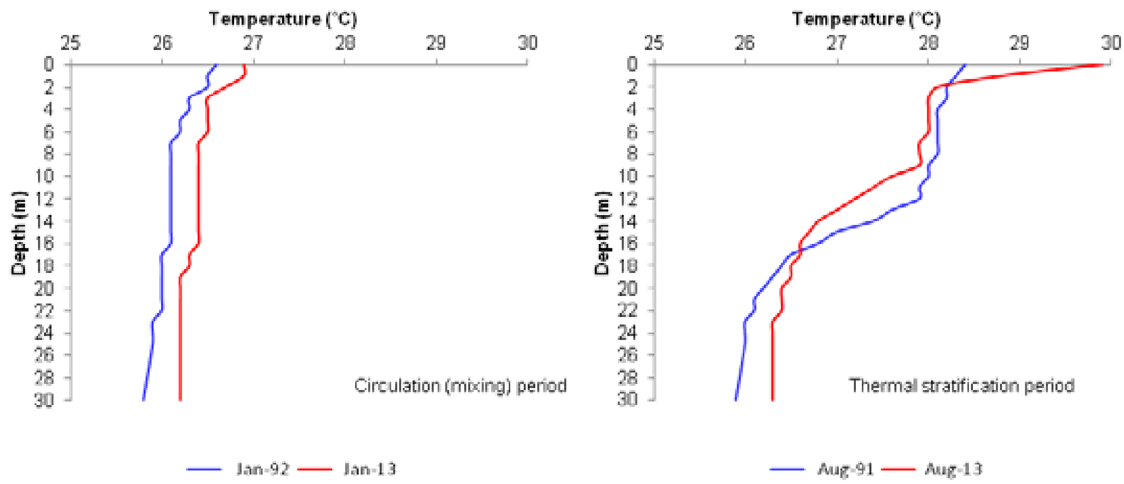
The Camatagua reservoir (in Aragua state), the main water supply reservoir for the city of Caracas, is one of the few reservoirs for which we have information for more than the last twenty years (Infante et al., 1992), and with recent data from projects carried out in the Limnology Laboratory of the Central University of Venezuela (González et al., 2013). This reservoir, being a deep system which develops a stable heat stratification during the rainy season, may serve as a monitor of climate change by measuring the temperature of its waters.

The Camatagua reservoir is more than thirty meters deep at the part nearest the dam. During the rainy season (May to October), when the wind speed is lower, the reservoir's thermoclines are stable. On the other hand, during the dry season (November to April), when the wind velocity increases, it promotes a full circulation of its water and, therefore, a uniform heating. It has, therefore, been classified as a warm monomictic system since there is one period of complete circulation of its waters each year.

Comparing the studies of Infante et al., (1992) and those of González et al., (2013), it may be said that at present, at depths below thirty meters, the temperatures are currently from 0.1 to 0.6°C higher than those recorded over twenty years ago (Figure 11). The increase in temperature raises the thermal stability, reducing the mixing and circulation periods of the waters. All of this may lead to a deterioration in the quality of the water due to the depletion of its oxygen and the formation of hypoxic and anoxic strata, the regeneration of limiting nutrients such as phosphorous, which can foster the growth of cyanobacterias and the release of greenhouse gases from the bottom of these waterbodies (Williamson et al., 2009).

While the data presented are not conclusive as to their effect on climate change in the Camatagua reservoir (since the human-induced effects may overlap those of global warming) it is also true that water temperature is a parameter offering relevant information, which could well be easily and permanently monitored in order to follow the possible effects of climate change, and predict well in advance its consequences on the quality of water which requires treatment before distribution for supply to the city of Caracas, in order to take the measures required to confront and mitigate them.

Figure 11. Profiles of water temperatures in the Camatagua reservoir during the periods of heat circulation and stratification for the years 1991-1992 and 2013



Source: In-house document based on data from Infante et al., (1992) and González et al., (2013).

5.1 Periods of Extreme Drought

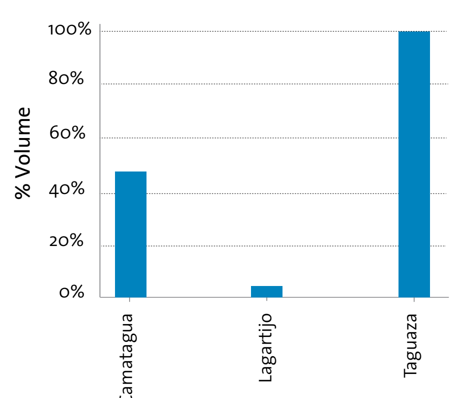
During 2009 and until halfway through 2010, Venezuela suffered one of the most severe droughts of the last few years as the result of the El Niño and Southern Oscillation (ENSO) phenomena.

Over seventy percent of the nation's electric energy (hydroelectric energy) comes from the Guri reservoir, located in Bolívar state in southern Venezuela. The reduction of its volume (a drop to more than twenty meters below its normal operating level), as the result of the drought, had an effect on the electricity supply in nearly the entire country. Electricity had to be rationed to prevent it from collapsing. Among the measures taken was a 900 megawatt energy saving plan, the reduction of working hours in public institutions (with working hours from 8:00 a.m. to 1:00 p.m.), and an electric energy blackout system during given hours in different cities. This emergency situation lasted from the end of 2009 until June 2010.

The water supply was also affected, since a large number of the sources of supply come from reservoirs (surface waters). For the city of Caracas, the situation of the reservoirs at the beginning of the drought, in 2009 is shown in Figure 12, where the water deficits in these reservoirs may be appreciated.

In order to deal with the severe drought, the water company (HIDROCAPITAL) proposed to reduce water consumption in one-hundred liters daily. To do this, it prepared a rationing plan applied to different parts of the city effective November 2, 2009, which was gradually rescinded as the water levels rose in the reservoirs which supply the capital (which was not until about August 2010). This plan was known as the "Special Caracas Water Supply" Plan. The water rationing plan remained in effect until August 2010 and, according to the water company itself, enabled the saving of more than 230 million cubic meters of water, which meant that this plan could be considered a success.

Figure 12. The situation (in blue) of the main reservoirs furnishing drinking water to the city of Caracas at the beginning of the drought in 2009



Source: HIDROCAPITAL (2009).

5.2 Flooding in the Cities

Population growth, with its obligatory occupation of areas whose characteristics are not ideal for the performance of common, routine activities, sometimes requires costly investments in order to adapt these spaces to human requirements. Even worse, the occupation of areas with high risk to the poorest elements of the population and no improvements that would guarantee even a minimal safety of life, has caused a great deal of concern on the part of governments, to the United Nations and to Multilateral Agencies regarding the vulnerability of the people who inhabit these zones (whether or not controlled), and the risk management required to lessen the potential harm to these persons and their property.

In Venezuela, as in many countries, the occupation of floodplains, unstable hillsides and areas below sea level represents a matter for study. These circumstances were viewed with greater emphasis as the result of the landslides which occurred in 1999 over more than three hundred kilometers of the country's waterfront and took a heavy toll in both lives and property damage.

In the majority of cases the origin of many floods is, of course, an extraordinarily heavy rain, while at other times they may be caused by events of lesser magnitude but with days or weeks of constant rains (with the soil completely saturated.)

There is also periodic flooding, usually on the floodplains of the major rivers, caused by phenomena arising from the annual change in the inclination of the planet, with its consequences for the climate. In Venezuela there are several rivers which, given the size of their basins, flood their banks every year. Perhaps the most outstanding of these is the Orinoco River, whose water level at some points climbs to sixteen meters, flooding large areas of the plains along the bank. However, since there are few cities along the river bed down to its mouth at the Atlantic Ocean, the behavior of this river receives scant mention in the public prints. It is only when it affects Ciudad Bolívar, in Bolívar state, or Tucupita, in Delta Amacuro state, that it is mentioned in the country's press. This is not the case with other cities, prominent among them being mainly Cumaná, Barcelona, Valencia and Caracas. In these cases, given their population, any behavior of the waterways receives immediate coverage.

It may, therefore, be said that the floods take on importance to the extent that they affect humans, their daily activities and their property.

A good example of this is what happens with the Guaire River –the primary and most important river in the city of Caracas. This is a small river, with a basin of some 655 square kilometers and an average annual rainfall of 1,500 millimeters a year, whose floods affect, in different ways, some six million inhabitants –about twenty percent of the country's total population.

Canalized along almost its entire length, the Guaire River frequently floods. This is due to several factors:

1. The river was canalized in the 'fifties and 'sixties when the population of the city was barely around a million inhabitants and many areas in the basin were vacant lots, small wooded areas with bushes or pasture. There were sugar cane haciendas and planted areas along its banks. While a basically very high flow was estimated, the present reality is that over the last twenty-five to fifty years its flow has been compromised by the changes in the way land is used, as pointed out by the Institute of Flow Mechanics of the Central University of Venezuela carried out in 2008.
2. The water quantifying data was (and is) scant; accordingly, the statistical series are unreliable due to the short period for which data is available. If you add to this a possible climate variability (or climate change), the possibility of more frequent flooding proves almost evident.
3. The urbanization process (and, accordingly, weatherproofing) of the upper part of the basin and the canalization of the San Pedro River accelerate the flow of the water to the river, causing higher swells and higher levels in the middle basin –precisely, in the city of Caracas.
4. Even if it can be said that these are a minor cause, the accumulation of garbage in sumps, gutters and water collectors also contributes to the flooding of streets and avenues when these projects do not operate at full capacity causing, as a minimum, vehicle traffic jams. There are also cases in which when the streets are repaved, this reduces the opening of gutters, thus reducing their capacity and efficiency.

5. Finally, drainage studies are not usually a course in our universities. There are, therefore, few professionals who can adequately analyze and solve these issues.

These problems recur, with either greater or lesser importance, in many of our cities. As the population grows and occupies the natural floodplains along the rivers, the situation set forth in this document has recurred. For this reason, timely population planning (master plans), with guidelines for the possible uses of the land and an analysis of the potential hazards in the face of extraordinary occurrences, is essential to prevent future damage to persons and property.

According to Ochoa-Iturbe (2011), the sediment found in the drainage systems is usually the result of the natural processes of erosion, decomposition in wooded areas and erosion of the riverbeds, among other causes which are due, among other factors, to such weather changes as droughts and flooding, heavy and unusual rains and seasonal fires. As the population grows, the need for more livable space has created conditions which multiply these natural phenomena many times over. Specifically, during the first stages of urban development and construction, the load of sediment multiplies hundreds of times, upsetting the characteristics of the river and ravine canals (forms and declines). This, in turn, alter their respective flow regimens. In developing countries, this circumstance is aggravated by uncontrolled development –the result of a lack of regulations or insufficient enforcement of codes and standards.

Another source of solids which affects small creeks and drainage collectors, especially in developing countries, is that due to inefficient garbage collection. The citizenry is in the habit of throwing waste into ravines and creeks (Ochoa-Iturbe, 2011). These wastes are generally carried downstream, during the first weeks of the rainy season, plugging urban drainage systems, most especially those of the smaller collectors.

Finally, another urban drainage problem is the increase of landslides caused by extreme weather occurrences, which are often provoked by human interference with the urban riverbeds. In these cases, the loss of property and of human life is sometimes alarming.

In addition, at present large volumes of water are transferred from surface sources (lakes and reservoirs) in remote basins to the cities, consequently upsetting the urban water cycle, Thus, there is the potential risk of floods and of the consequences that they could bring with them in terms of the loss of life and property.

The torrential landslides that occurred in Vargas state (in the central-northern coastal area of Venezuela) in 1999 taught the Venezuelans important lessons (López, 2005). The loss of life might have been less if a program of coordinated prevention and mitigation measures had been implemented.

In view of the above, measures have been recommended and implemented to mitigate the effect of these occurrences (López, 2005). These may be summarized as follows:

Structural measures:

- Canalization of rivers and ravines.
- Control of sediment.
- Control of riverbank erosion.

Nonstructural measures:

- Monitoring of water and weather conditions in the river basins. There are presently twenty-five monitoring stations for the city of Caracas valley and Vargas state).
- Formulation of risk charts.
- Preparation of contingency plans.
- Installation of early warning systems (for example, Doppler radar systems).

As of 2005, twenty-four sediment control dams had been built in Vargas state, shared by the Curucutí, Guanape, Piedra Azul, El Cojo, Alcantarilla, Macuto and Camurí Chico river basins, which offer a certain degree of protection to the villages downstream of these projects (López, 2005). However, it is cause for alarm that these dams quickly clog up with sediment as is the fact that, due to their insufficient storage capacity they will, in the short run, be out of service. This is aggravated by the absence of locks or discharges in some of the dams, thus preventing the passage of the sediment carried by the ordinary currents.

López (2005) states that one of the causes of the tragedy of Vargas (which occurred in 1999) was the lack of alarm systems which could have warned the village residents in advance so that they could have taken appropriate evacuation measures. The possibly of torrential landslides occurring depends on the quantity and intensity of the rain, the degree of saturation of the soil, the presence of pronounced slopes in the basin and the characteristics of the soil to provide sediment material to produce landslides. For this reason, the two most important factors in establishing an early warning system are the continuous monitoring of rain and the moisture of the soil. In order to design an early warning system, it the monitoring stations must be telemetric – that is, that must transmit real time data to a central control station at regular intervals (for example, every five or ten minutes). This system will be charged with sounding the alarm to the competent authorities. However, of the twenty-five stations spread over Vargas state (14) and Caracas (11), only nine of them are telemetric. Most of the telemetric stations are located in the San José de Galipán basin where the Flow Mechanics Institute, working together with the Department of Hydrometeorological Engineering of the Central University of Venezuela (UCV), is carrying out a research project on the generation of torrential landslides and the means of preventing them.

In addition, in 2004 the Fluid Mechanics Institute installed a Doppler meteorological radar in the Tovar section of the city. This represents a major tool in predicting rain, several hours or even days in advance. The radar enables an atmospheric sweep with a with a radius of up to 150 km. and is based on the Doppler effect, issuing waves that bounce off the raindrops from the clouds. Therefore, the amount of water they transport can be measured.

Researchers from the Fluid Mechanics Institute have developed a methodology for the creation of maps showing the threat of extreme flooding. These use mathematical models which simulate torrential flows, coupled to digital terrain models and geographical information systems (López, 2005). This methodology has been applied in nineteen basins in Vargas state and seven basins in the Caracas Valley, in a project carried out jointly with the Venezuelan Simon Bolivar Geographical Institute within the framework of the Avila Project. The results of the threat maps show that major urban areas in Vargas state and the Caracas Valley are located in the area subject to high risk of extreme flooding.

The experts recommend the intensification of efforts to implement early warning systems in Vargas state and the Caracas Valley. The installation of a monitoring and early warning network for twelve top priority basins will entail a cost on the order of 900,000 thousand dollars. The management, operation and maintenance of this network will be carried out directly by the control centers to be created at the regional level, where the affected communities are involved, in order for them to participate in these activities.

Another case related to the flooding problem, as the result of the transfer of large volumes of water, involves Lake Valencia (in Aragua and Carabobo states).

At the end of the seventies, Lake Valencia suffered a natural drying out, which was hastened by human activities, causing it to reach its minimum level (402 meters above sea level). Due to this, the water from several rivers in neighboring basins, chiefly the Cabriales River, was diverted through the main pipeline.

As a result of this transfer from the rivers, the water level in Lake Valencia rose, flooding farming and urban areas. Urban settlements around the lake were prohibited, but this was not enough to prevent them. At present its high-water mark is over 413 meters above sea level. This has caused serious flooding in such Aragua state urban areas as Mata Redonda, which have been widely reported by the nation's press in view of the property losses which have been widely reported in the nation's press because of the property losses they have caused.

Due to this and to the pressure brought by both the population and the press, beginning in November 2005 the Maruria and Cabriales rivers were diverted to the Pao River basin –one of the main tributaries of the Pao-Cachinche reservoir, from which drinking water is supplied to the cities of Valencia (Carabobo state), Maracay (Aragua state and San Carlos (Cojedes state). The high organic content of these rivers depleted the oxygen in the reservoir's water column, which provides drinking water o the cities of Valencia (Carabobo state), Maracay (Aragua state) and San Carlos (Cojedes state) and several outlying cities (González and Matos, 2012). The high organic content of these rivers caused the depletion of the oxygen in the reservoir's water column, reducing part of the benefits obtained. This was followed by the artificial breakdown of the layers in this reservoir beginning in 2001 (Estaba et al., 2006).

Another method used to mitigate the effects of the swelling of Lake Valencia was the extraction of water through transfers to the Pao River basin. In addition, the discharges from the Taiguaiguay water treatment plant (in Aragua state) were diverted to the Taiguaiguay reservoir. From there water is pumped o the Tucutunemo River for the construction of an irrigation system for the valleys in this zone. However, since this project has not been completely finished, a part of the effluent from this system is being emptied into the Guárico River –the main tributary of the Camatagua reservoir (in Aragua state). This has caused a deterioration of the quality of the water in this body of water, which in the last few years has gone from mesotrophic to eutrophic (González et al., 2014). Quality-wise, the change in the color of the water (from blue to green) is a clear reflection of the change in the trophic condition that the Camatagua basin has undergone following the transfer of water from low water quality sources (Figure 13).

As far as solid waste handling is concerned, Ochoa-Iturbe (2011) observed that in developing countries, the middle and upper classes in the urban areas usually have adequate garbage collection systems. However, the poorest residents have limited garbage collection systems (in some cases, once or twice weekly) and for these inhabitants the usual practice is to take their own garbage to a dump – sometimes at a distance from their homes. In some cities with high mountain slopes (as is the case with the city of Caracas), it could be easier to dump garbage in the ravines or on nearby slopes, with the knowledge that the next rains will carry them downstream. It is for this reason that the authorities must make a major effort, working along two main lines: (1) education, to teach the residents that throwing waste in ravines could produce an environmental risk, which would be counterproductive to it (an increased propagation of flies and mosquitos, among other effects), and (2) the creation of garbage collection systems to make it easier for the residents to dispose of these wastes and, in turn, to encourage them to use these systems.

Figure 13. The change in the trophic state of the Camatagua reservoir may be observed quality-wise in the change in the color of its waters

Photographs taken by Ernesto J. González in September 1997 and September 2012.

Box 17

Limnology and the management of water resources

Venezuela's limnologists have gathered abundant data concerning the physical, chemical and biological characteristics of several waterbodies. The data may be classified, thus being transformed into useful tools for prediction (González and Quirós, 2011).

A number of generalities and trends may be observed from the classification of the data from the fifteen waterbodies (Figure 14), studied by the Limnology Laboratory of the Central University of Venezuela. Most of these are used to supply drinking water.

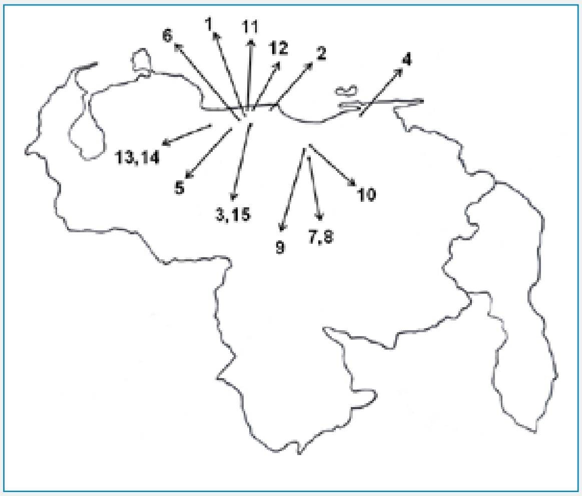
A clear linear relationship between the total phosphorous and total nitrogen, and the phytoplankton biomass (as chlorophyll-*a*) may be noted in the reservoirs studied (Figure 15).

Despite the fact that there is no apparent relationship between the variables involved, their empirical relationships make it possible to gather valuable data. At first glance, the distribution of the reservoirs according to total phosphorous and the nitrate-ammonium quotient (NO_3:NH_4) shows a high data spread (Figure 16). In this case, it is possible to identify three major groups of reservoirs. The first group comprises those reservoirs with low total phosphorous concentrations (<20 μg/l, shown in the black circles) while in the group of reservoirs with a moderate to high phosphorous concentration (>20 μg/l). Two more clearly identifiable groups may be observed: one of them (the lower, in black triangles) is represented by the reservoirs in which ammonium predominates over the nitrates, and some with relatively high residence times. In these, the cyanobacteria are dominant. The third group (at the top, in black rhombi) includes those reservoirs in which nitrates dominate over ammonium, with relatively low residence times, where the dominant groups of phytoplankton are different from the cyanobacteria – for example, diatoms, green algae or flagella. The exception would be represented by the Loma de Niquel reservoir (shown in the white circle), which is very near the total low and high phosphorous concentration limits and showed a predominance of cyanobacteria during the period under study, for which reason it has not been included in any of the three above-descried groups. Hence, the preponderance of cyanobacteria – some of them in strains which could be poisonous and cause public health problems – may be predicted when the water in the reservoirs is physically and chemically characterized.

Based on these studies it is evident that in order to control the eutrophication in these waterbodies, the input of nutrients, especially phosphorous and nitrogen, must be controlled.

Figure 14. Reservoirs studied by the Limnology Laboratory of the Central University of Venezuela:

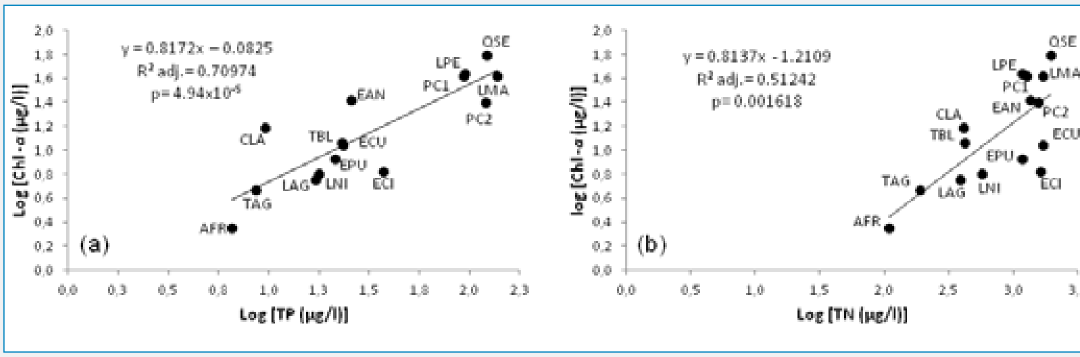
1. Agua Fría,
2. Taguaza,
3. Lagartijo,
4. Clavellinos,
5. Tierra Blanca,
6. Loma de Níquel,
7. El Cigarrón,
8. El Pueblito,
9. El Cují,
10. El Andino,
11. La Mariposa,
12. La Pereza,
13. Pao-Cachinche (western wing),
14. Pao-Cachinche (eastern wing),
15. Quebrada Seca.



Source: González and Quirós (2011).

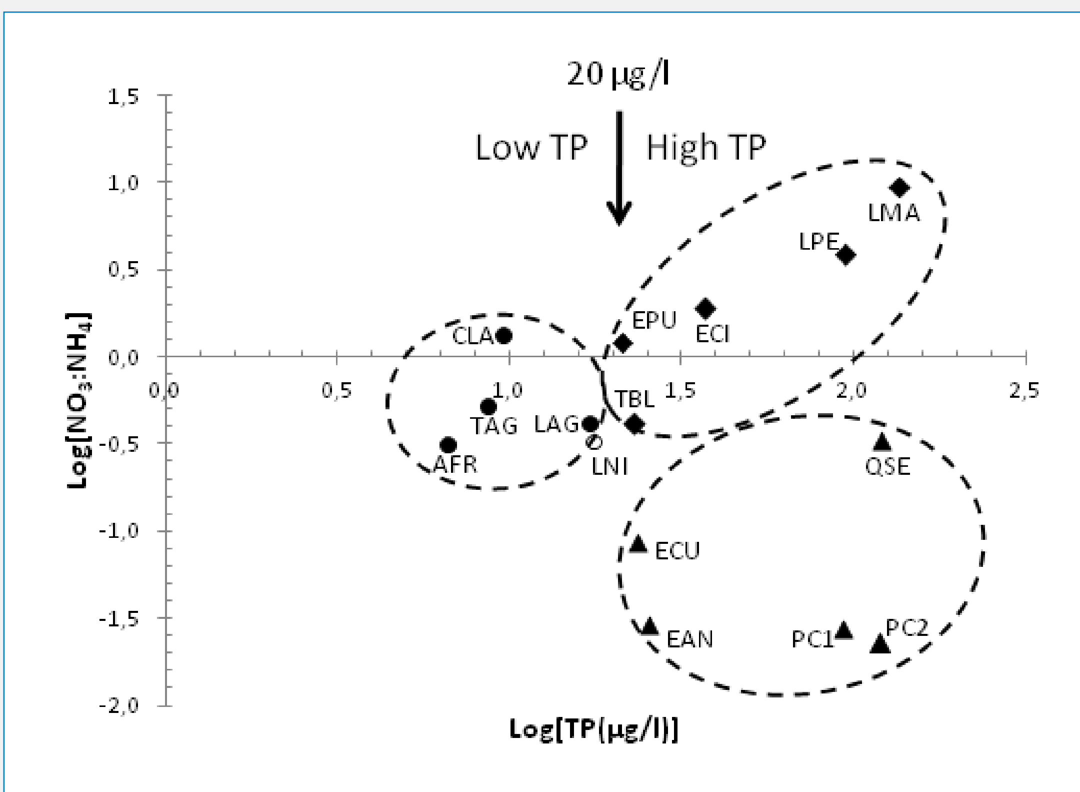
Box 17

Figure 15. The relationship between (a) total phosphorous (TP) and chlorophyll-*a* (Chl-*a*) and (b) b) total nitrogen (TN) and chlorophyll in Venezuela's reservoirs
Key: AFR: Agua Fría, TAG: Taguaza, LAG: Lagartijo, CLA: Clavellinos, TBL: Tierra Blanca, LNI: Loma de Níquel, ECI: El Cigarrón, EPU: El Pueblito, ECU: El Cují, EAN: El Andino, LMA: La Mariposa, LPE: La Pereza, QSE: Quebrada Seca, PC1: Pao-Cachinche –western wing with a spillway and tower pump; PC2: Pao-Cachinche –eastern wing with no spillway.



Modified from González and Quirós (2011).

Figure 16. Relationship between total phosphorous and the NO3:NH4 quotient in Venezuela's reservoirs. Legend as per Figure 15



Modified from González and Quirós (2011).

Box 18

Factors producing changes in the water cycle and their effect on the biodiversity of the Orinico River basin and nearby basins

Scope of study

Venezuela owns (jointly with Colombia) one of the largest water basins and water reservoirs in the world. The Orinoco River basin is the third largest on the planet. Along its two-thousand kilometer course, it drains an area of about 90,000 kilometers, representing 94.44% of the total volume drained from Venezuela's water basins. It is a river of considerable size, with rapids and abundant suspended sediment (200 x 10^6 tons per year). It has a weather regimen dominated by two seasons (rainy and dry), each approximately equal: rainy (June to November) and dry (December to May). During the former, water covers substantial areas of the plain, forming shallow lagoons (estuaries) and penetrating into the forests along the banks. During the latter, there is a drastic reduction in the level of its waters, draining the plains and eliminating thousands of square kilometers of aquatic habitats. These two seasons regulate the biological cycles of the water flora and fauna (Table 11). Any change in either the weather or the water cycle could affect, wholly or in part, the system's living organisms.

Table 11. Summary of the environmental factors regulating communities

Rainy season	Dry season
Physical and chemical changes in the water; an increase of dissolved hydrogen and transparency; reduction of pH; lower temperature; nutrients.	Physical and chemical changes in the water; reduction of dissolved oxygen; reduced transparency; higher temperature, sediment and nutrient concentrations; higher pH.
Increase in aquatic habitats: rivers, ducts, lagoons, estuaries, flooded forests.	Reduced habitats and trophic levels; drying out of forests and plains; reduction or elimination of channels, estuaries, flooded forests and lagoons; reduction of volume of river flow.
Increase in primary and secondary productivity; reproduction and growth; dietary diversification; sexual preparation and maturity; preparation and sexual maturity.	High mortality rate and/or migration to canals and rivers holding water. Reduction of growth; maturation of gonads.
Processes of decomposition of the organic material deposited on the soil, in forests and plains.	Accumulation on the soil of organic material produced or transported during the prior phase.

Source: In-house document

Factors producing changes or impacts due to the use of water for human development purposes in the water cycle

Water resources are vital to human development. For millenniums, villages were established in relation to this vital liquid and its sources. We have interfered with its cycle somehow, often without taking into account how it benefits wildlife (Figure 17).

There are few research projects that can quantitatively and qualitatively document the biological impact caused by changes in the water cycle or by changes in Venezuela's continental waters. However, based on research carried out by Petts (1985; 1990a,b), governmental plans and technical reports (Rangel, 1979; Taphorn, 1980; Machado-Allison, 1990; Taphorn and García, 1991; Machado-Allison, 1994; Veillon, 1997; Machado-Allison, 1999; Marrero, 2000; Machado-Allison, 2005; Andrade and Machado-Allison, 2008; and Machado-Allison et al., 2011), the interference with the water may be classified as follows:

1. Damming of water for domestic or agricultural use. Dams built for farming or domestic use were widely built over the last fifty years, when the headwaters of nearly all the main tributaries of

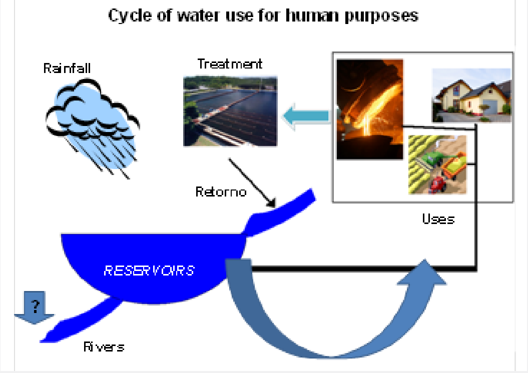
Box 18

the Orinoco River's north slope of had been dammed, as is the case with the following rivers: the Apure, Boconó, Cojedes, Guanare, Guárico, Masparro, Portuguesa and San Domingo and on the southern slope, the Caroni River (used mainly for hydroelectric power). Other rivers of lesser national importance, but still of regional importance, are the headwaters of the Manzanares, Neverí, Unare and Tuy rivers in the northern part of the country (Figure 18).

Dams (see Table 12) cause:

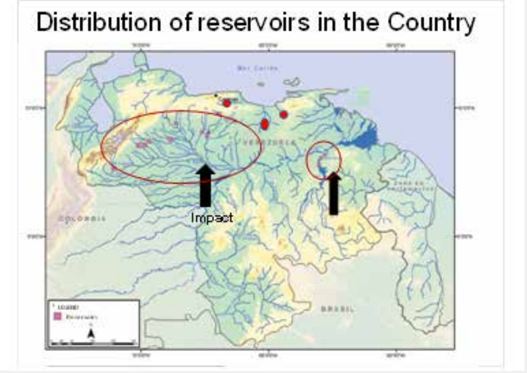
- Alteration or regulation of the annual water flow, affecting the vital cycles for the animals and plants that depend on it (for example, the migration of fish for reproduction, the flooding of riparian plains and forests).
- Contamination, through home (urban) and/or farm use. The waters used in urban and farming areas (for washing) are discharged again as wastewater. Although national regulations make their treatment obligatory, it is evident that they are not enforced. Hence, discharges of hydrocarbon-bearing waters (oils), fertilizers, insecticides and industrial waste (heavy metals) enter the aquatic environment, thus affecting the quality of the water, with physiological and biochemical impacts on the organisms which inhabit it.

Figure 17. The water cycle and its use in human development



Source: In-house document.

Figure 18. Main dams built in Venezuela



Source: Machado-Allison and collaborators (2011).

Table 12. Scheme showing activities, actions, effects and impacts on the water ecosystem

Activities	Actions	Effects	Impacts
- River closed (dammed)	- Flow blocked by construction of dikes - Variations in the hydrodynamics of the flow system, both in the main channel and its areas of influence (for example, riparian plains and forests)	- Reduction of the flow downstream or across the bed - Increase in the temperature and the reduction of dissolved oxygen - Effects on migration of species - Rise in water level on alternate routes upstream - Obstruction of passage of water organisms - Colonization and changes in the use of the land - Acidification of planted soils and loss of fertility - Deposits of and increases in sediment upstream and downstream - Elimination of threats of flooding	- Reduction of the richness of habitats and species; impact on biodiversity - Reduction in interchange of organisms; loss of biodiversity - Reduction in water transportation - Changes in the structure of the related water and land organisms

Source: In-house document

Box 18

2) Deforestation for urban or agricultural purposes: Figure 19 shows an area cleared for agricultural purposes in the Venezuelan foothills region. These areas have been extensively and intensively altered (Centeno, 1999). Deforestation has caused a reduction in rain intensity and, naturally, a substantial reduction in the flow of our rivers. In addition, solid waste (sediments) have increased due to erosion. This has caused changes in the quality of water for life-sustaining purposes (changes in temperature, pH and transparency) and the physical elimination of its microscopic inhabitants.

Figure 19. Deforestation and its effect on rivers

Source: In-house document based on "Google Earth" images

The situation of certain Venezuelan rivers

Studies and follow-up of documents prepared by the personnel in charge of environmental sanitation maintenance (http://www.monografias.com/trabajos/contamagua.shtml) have determined that there are several regions or basins in the country with serious water environmental deterioration.

Among these are:

- The Guaire and Tuy rivers in the Capital region.
- Lake Valencia and its tributary rivers.
- The Toyuco and Aroa River valleys.
- The systems of the Guárico and Portuguesa rivers.
- The Unare, Neverí, Manzanares and Guarapiche rivers and their tributaries.
- Lake Maracaibo.

The aforementioned rivers and waterbodies are located in highly populated areas. They receive contaminated urban wastewater with domestic, industrial and, in many cases, agricultural waste. When the treatment plants fail, these contaminated waters flow freely, affecting reservoirs and the cities downstream from them. Today, for example, there are serious problems due to the transfer of contaminated waters from Lake Valencia to the reservoir supplying water to the city. The same thing happens with the Guárico and Portuguesa rivers, which empty their waters into reservoirs which supply water to populated areas in the plain region and the nation's capital.

Recommendations regarding the factors producing changes in the water cycle and its impact on the biodiversity of the Rio Orinoco basin and neighboring basins

Box 18

An effort has been made to describe succinctly the natural and human-driven factors that regulate or shape the vital cycles in Venezuela's water ecosystems, with emphasis on those human activities which directly imperil the aquatic life communities. The researchers must be aware of how these ecosystems behave before they are biologically, productively, socially and culturally altered. There must be, and there is, the obligation to educate and influence those who make decisions regarding how they may be altered while causing the least possible damage and ensuring the sustainable use of this resource. The following, then are required:

- Ensuring adequate management and control of these activities.
- Compliance with the sundry national norms (Laws, Regulations and Norms governing water and the environment).
- Applying international conventions and standards regarding the use of substances (for example, pesticides, insecticides, fertilizers, etc.
- Education at all levels regarding the risks of owning contaminated water.
- Promoting scientific studies to form a basis for rigorous support and formation of adequate technical personnel.

In conclusion

Venezuela has one of the world's largest and most extensive waterway networks. For millenniums, this had led to the creation of one of the most interesting biological processes on our planet, and has turned Venezuela in a widely diverse country. The Orinico River basin represents one of the most extensive wetlands in the Neotropical region (Hamilton and Lewis, 1990; Machado-Allison, 1990), supporting thousands of species, many of them important from both an economic standpoint and as food for the villages. There is a historic responsibility to preserve them for the enjoyment of future generations.

From the Andes to the Orinoco Delta, large cities and concentrations of human population are established on the banks or in the vicinities of the major rivers, the tributaries of the Orinoco, the Caribbean Coast, Lake Maracaibo and Lake Valencia. These rivers have been dammed or have served for withdrawing water for home, agricultural or industrial use, thus guaranteeing our nation's development. However, the cost paid by the environment is enormous. Waters contaminated with detergents, oils, heavy metals, insecticides and many other contaminants flow downstream, with repercussions on rivers, oceans or lakes. This situation not only endangers the wildlife inhabiting these bodies of water; it also creates the possibility of affecting human life in the villages located outside the area where the contaminant originates. Considering that the basins are interconnected systems, the contaminants, once in one of them, affect all of them.

6. Conclusions

- The most densely populated areas of Venezuela are located in regions with the least water availability. This involves high costs in supplying water to the cities.
- Coverage of the drinking water supply and wastewater collection is increasing fast in Venezuela. However, the percentage of wastewater treated is still low.
- Major sanitation plans are being carried out, such as the Rio Guaire Sanitation Project and the Overall Sanitation and Water Level Control Project for the Lake Valencia Basin.
- There is the need to address and resolve water-related problems and diseases.
- Given the climate change, projects for the management of water resources must be implemented –projects well planned and conceived by the available technology, society, the economy and the existing institutions, with a view to balancing the supply and demand for this resource in order to confront scenarios of the occurrence of extreme hydrological events.
- It is necessary to address the problems created by the swelling of bodies of water (flooding) and its consequences. Some structural and nonstructural measures have already been taken.
- The used of limnological information can help in managing the nation's water resources.
- Plans for the management of water resources and the mitigation of the problems involved in water cycles in urban areas must involve the participation of the organized communities.

7. Acknowledgements

The authors are grateful for the support of the Venezuelan Academy of Physical, Mathematical and Natural Sciences and the members of the Water Program from the Interamerican Network of Academies of Sciences (IANAS).

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9. Acronyms

AMC: Caracas Metropolitan Area
CVG: Venezuelan Corporation of Guayana
ENSO: El Niño and Southern Oscillation
FUNDAMBIENTE: Environmental Education Foundation
GORBV: Official Gazette of the Bolivarian Republic of Venezuela
GORV: Official Gazette of the Republic of Venezuela
GOSH: Manager of Sanitation and Water Projects
HIDROVEN: Venezuelan Hydrological Water Company
IMUTC: Metropolitan Institute of Urban Planning "Taller Caracas"
INE: National Statistics Institute
LOPSAPS: Organic Law for the Performance of Drinking Water and Sanitation Services
MINAMB: People's Ministry of the Environment
MPPS: People's Ministry of Health
MTA: Technical Roundtables of Water
OMS: World Health Organization
RMC: Caracas Metropolitan Area
SIENAGA: System of National Environmental Management Indicators and Statistics
WSP: Water and Sanitation Program.

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Biographies

Argentina

Raúl Antonio Lopardo (Chapter Coordinator)
BS in hydraulic engineering and civil engineering (National University of La Plata, Argentina). PhD in physics from the University of Toulouse, France. President of the National Water Institute. Professor at the National University of La Plata School of Engineering. Full member of the National Academy of Exact, Physical and Natural Sciences, the National Academy of Engineering and the Academy of Engineering of the Province of Buenos Aires. National Focal Point of the InterAmerican Network of Academies of Sciences (IANAS) Water Program. **Email: rlopardo@ina.gob.ar**

Jorge Daniel Bacchiega
BS in hydraulic engineering and civil engineering (National University of La Plata, Argentina); Director of the National Water Institute Hydraulic Structures Program. Professor at the National University of La Plata School of Engineering and the University of Buenos Aires. Independent Hydraulic Engineering Consultant. Full Member of the Academy of Engineering of the Province of Buenos Aires. **Email: dbacchiega@gmail.com**

Luis E. Higa
BS in chemical engineering (National Technological University, Argentina). Director of the National Water Institute of Water Use Technology Center. Professor in the Occupational Safety and Hygiene Bachelor's Degree Program (School of Exact and Natural Sciences at the University of Buenos Aires), and in the Environmental Engineering Bachelor's and Master's Degree Programs (National University of Cuyo School of Engineering), and Professor in the Water and Sanitation Business Administration Bachelor's Degree Program (Universidad Nacional 3 de Febrero). **Email: ctua@ina.gob.ar**

Bolivia

Fernando Urquidi-Barrau (Chapter Coordinator)
BS in Geological Engineering. MS in Industrial Business Administration. MS in Security, Defense and Development. PhD in Applied Geo-Chemistry. Full Member of the National Academy of Sciences of Bolivia. National Focal Point for the InterAmerican Network of National Academies of Sciences (IANAS) Water Program. Email: **erurquidi@gmail.com**

Brazil

José Galizia Tundisi (Chapter Coordinator)
President of International Institute of Ecology, Focal Point for Brazil in the InterAmerican Network for Academies of Science (IANAS), Water Program. He is a retired professor of Environmental Science at the University of São Paulo, São Carlos. He is specialized in reservoir limnology and ecology of inland waters, watershed management, water resources management and environmental planning. He served for 20 years as a member of scientific committee of ILEC, in Japan and was President of National Research Council in Brazil (1995-1999). He was President of the International Advisory Board of the Millenium Institutes Initiative from the government of Brazil. **Email: tundisi@iie.com.br**

Marcos Cortesão Barnsley Scheuenstuhl
Is a program director at the Brazilian Academy of Sciences, where he coordinates several programs and working groups. With undergraduate and graduate training in economics and the impact of public policies in higher education in Brazil, most of his work is currently dedicated to institutional S&T capacity building and networking. **Email: mcbs@abc.org.br**

Carlos Eduardo Morelli Tucci
Is a Civil Engineer (1971) He obtained his M.Sc. in Water Resources (1975) from UFRGS, Brazil and his Ph.D. in Water Resources Engineering from the Colorado State University, USA (1978). He was a Full Professor at the Institute of Hydraulic Research, UFRGS (1972-2003); the Coordinator of the Research Activities in Urban Water Management and Modeling; and the Head of the Graduate Program on Water Resources (1993-1997). Dr. Tucci has worked in the fields of: Hydrology and Hydraulics, simulation of water resources systems, urban water management, water resources management, climate variability and flow forecasting and Integrated Environment assessment. Dr. Tucci has also been a consultant on a broad range of topics world-wide for many national and international organizations and companies including UNDP, UNESCO, WMO and the World Bank. **Email: rhamaca@gmail.com**

Fernando Rosado Spilki
Holds a Veterinary degree (DVM , 2001) and Master's in Veterinary Sciences (2004) from the Federal University of Rio Grande do Sul, Brazil. He earned his PhD in Genetics and Molecular Biology from State University of Campinas (2006), Brazil. Dr. Spilki is now Professor at Feevale University, Novo Hamburgo, Brazil and his main research focus is on the detection and characterization of enteric viruses from human beings and domestic animals in water samples. **Email: fernandors@feevale.br**

Ivanildo Hespanhol
Full Professor, Polytechnic School of the University of São Paulo. He is a Civil and Sanitary Engineer. He received his Ph.D. in Public Health from the University of São Paulo (USP), and his M.Sc. and Ph.D. in Environmental Engineering from the University of California at Berkeley, USA. He joined the WHO as a Scientific Member in 1987, and remained until 1995, within the Urban Environmental Health Unit, Division of Environmental Health, Geneva, Switzerland, collaborating with the preparation of guidelines for water reuse, and as a Coordinator of the UNEP/WHO GEMS/WATER. He is currently a Temporary Adviser to the WHO, PAHO, the Brazilian Water National Agency (ANA) and other public and private organizations in Brazil and in South America. He is also an adviser to the State of São Paulo Foundation for Research Support (FAPESP); CAPES; FINEP and CNPq, the last two from the Ministry of Science and Technology. **Email: ivanhes@usp.br**

José Almir Cirilo
Has a BS in civil engineering from the Federal University of Pernambucoand He has a MS and Ph.D. in civil engineering from the Federal University of Rio de Janeiro. Presently he is Full Professor at the Federal University of Pernambucoand. He is at present Executive Secretary of Water Resources of the Secretariat for Economic Development of Pernambuco. He was Director of Water Resources and Deputy Director of Science, Technology and Environment of Pernambuco. **Email: almir.cirilo@gmail.com**

Natalia Andricioli Periotto
Has a Biology degree (2004), a Master's degree in Ecology and Natural Resources from the Federal University of São Carlos (2011), and is currently a PhD fellow at the University of São Carlos, developing her research on the sustainability of ecosystem services in a Brazilian hydrographic basin, using the concept of Eco-Exergy as a tool for this assessment. **Email: nataliaperiotto@gmail.com**

Canada

Banu Örmeci (Chapter Coordinator)
Prof. Banu Örmeci completed her MS and PhD in Civil and Environmental Engineering at Duke University (North Carolina, USA). She is a Professor and Canada Research Chair in Wastewater Treatment Engineering in the Department of Civil and Environmental Engineering at Carleton University (Ottawa, Canada), and the recipient of numerous research, teaching, and mentoring awards. **Email:Ormeci@carleton.ca**

Michael D'Andrea (Chapter Coordinator)
Is the Executive Director of Engineering & Construction Services for the City of Toronto, where he leads a division of approximately 540 professional/technical staff and is responsible for the engineering design and construction of the City of Toronto's water, wastewater, stormwater, transportation and solid waste infrastructure. Previously, Michael was the Director of Water Infrastructure Management for Toronto Water, where he was responsible for asset management, infrastructure planning, capital programming and policy development in support of the City of Toronto's water, wastewater and stormwater management infrastructure. Michael earned a master's degree in civil engineering from Western University. He worked in engineering consulting and with the Ontario Ministry of the Environment before joining the City of Toronto in 1997. **Email: mdandre@toronto.ca**

Chile

James McPhee (Chapter Coordinator)
BS in civil engineering from the University of Chile, PhD in hydraulic resources engineering at the University of California – Los Angeles (UCLA). Associate Professor in the Department of Civil Engineering and Associate Researcher at the Advanced Mining Technology Center (AMTC) in the School of Physical Sciences and Mathematics at the University of Chile. **Email: jmcphee@ing.uchile.cl**

Jorge Gironás
BS in civil engineering with an MS in engineering from the Pontifical Catholic University of Chile. PhD from Colorado State University. Associate Professor at the School of Engineering, Pontifical Catholic University of Chile. Associate Researcher at the FONDAP Center for Sustainable Urban Development (CEDEUS) and FONDAP Center for Research on Integrated Management of Natural Disasters (CIGIDEN). **Email: jgironas@ing.puc.cl**

Bonifacio Fernández
BS in civil engineering from the Pontifical Catholic University of Chile. PhD in engineering from Colorado State University. Full Professor at the Department of Hydraulic and Environmental Engineering at the Pontifical Catholic University of Chile School of Engineering. **Email: bfernand@ing.puc.cl**

Pablo Pastén
PhD in civil engineering from the Pontifical Catholic University of Chile. BS in environmental engineering from Northwestern University, Evanston, Illinois. Associate Professor at the Department of Hydraulic and Environmental Engineering at the Pontifical Catholic University of Chile. Principal Investigator at the Center for Sustainable Urban Development (CEDEUS). **Email: ppasten@ing.puc.cl**

José Vargas
BS in civil engineering (University of Concepcion, Chile). PhD in Environmental Sciences from the University of Concepcion. Associate Professor at the Department of Civil Engineering in the School of Engineering at the University of Concepción. Associate Researcher at the Center for Water Resources for Agriculture and Mining (CRHIAM). IHP-UNESCO International Flood Initiative (IFI) Program Coordinator. President of the Chilean Hydraulic Engineering Society. Vice President of the Latin American Council of the International Association of Hydro-Environment Engineering and Research (IAHR). **Email: jvargas@udec.cl**

Alejandra Vega
BS in civil engineering (Pontifical Catholic University of Chile). Doctoral Candidate in environmental engineering sciences (Pontifical Catholic University of Chile). Engineer at the Sustainable Urban Development Center (CEDEUS). **Email: asvega@ing.puc.cl**

Sebastián Vicuña
BS in civil engineering (Pontifical Catholic University of Chile). PhD in civil and environmental engineering and MA in Public Policy from the University of California – Berkeley. Executive Director of the UC Global Change Center. National Coordinator of the Regional Study on the Economics of Chilean Climate Change. UNFCCC Expert Consultant on vulnerability and adaptation studies with emphasis on water resources. **Email: svicuna@uc.cl**

Colombia

Gabriel Roldán (Chapter Coordinator)
BS in biology and chemistry from the University of Antioquia (Medellín, Colombia), MS in Science from the Kansas State Teachers College (Emporia, Kansas) and PhD in Science from the University of Kassel (Germany). Currently Corresponding Member and Publications Director of the Colombian Academy of Exact, Physical and Natural Sciences, as well as the Director of the Limnology and Water Resources Research Group of the Catholic University of the East (Rionegro, Antioquia, Colombia). **Email: groldan@une.net.co**

Claudia Patricia Campuzano Ochoa (Chapter Coordinator)
BS in civil engineering with MS in Water Resources Administration from the National University of Colombia – Medellín. Director of Water and Environment, and Coordinator of the Inter-Institutional Water Agreement at the Antioquia Science and Technology Center Corporation. Current activities include the management and

coordination of stakeholders in the collective construction of strategic thought; research and technological development in the area of water and the environment; construction of policy framework/guidelines; environmental planning; watershed management; comprehensive water resource management s, education and environmental culture; comprehensive society, earth and environment management; coordination of efforts by other entities in developing joint projects including the Strategic Administration or General Coordination of more than thirty projects. Lecturer in comprehensive water resource management in the sustainable construction of the "Colegio Mayor de Antoquia" University. **Email: ccampuzano@cta.org.co**

Luis Javier Montoya Jaramillo

BS in civil engineering, MS in Water Resource Management and PhD in Water Resource Engineering from the National University of Colombia – Medellín. Currently Associate Professor at the School of Engineering in the Civil Engineering program at the University of Medellín. **Email: ljmontoya@udem.edu.co**

Carlos Daniel Ruiz Carrascal

BS in civil engineering and MS water resource management from the National University of Colombia – Medellín. MS in Environmental Science Philosophy and MSin climate and society from Columbia University (New York). PhD in earth and environmental engineering, also from Columbia University. Currently a research fellow and associate professor in the Environmental Engineering Program at the School of Engineering of Antioquía (Colombia) and Associate Scientific Researcher at the International Research Institute for Climate and Society at Columbia University. Principal Investigator in hydro-climatology in the "Environmental Management Research – IGEA" group at the School of Engineering of Antioquía. Areas of expertise include hydrology, climatology, water resources and environmental health. Research interests focus on environmental change, climate variability and climate change, along with impacts on ecosystems in the highlands and human health. Currently leads a project entitled "Impacts of Climate Change on Tropical Andean Biodiversity; climatic risk, vulnerability and tools for decision-making for the conservation of biodiversity and ground use planning", administered by the Inter-American Institute for Global Change Research (IAI) with the support of the MacArthur Foundation.

Andrés Torres

BS in civil engineering and Specialist in Engineering Management Systems at the Javeriana Pontifical University– Bogotá. MS in civil engineering. PhD in Urban Hydrology from the University of Lyon – INSA, Lyon, France. Currently Associate Professor at the Javeriana Pontifical University – Bogotá campus and a member of the Water and Environment Science and Engineering research group. Dr. Torres' teaching activities focus principally on civil engineering, the Master's Program in Hydro-systems and the Doctoral program in Engineering at the Javeriana Pontifical University. Currently a researcher in the area of urban hydrology, particularly in topics related to urban sustainable drainage systems, water quality metrology and sewage system assets management. **Email: andres.torres@javeriana.edu.co**

Jaime Andrés Lara-Borrero

BS in civil engineering (Javeriana Pontifical University) with an MS in engineering and environmental management from the Poliorcetica University of Cataluña and PhD in engineering in roadways, canals and ports, with specialty in sanitary and environmental engineering from the Polytechnical University of Madrid. Currently Associate Professor at the School of Engineering at the Javeriana Pontifical University where he is the Director of the Master's Degree Program in Hydro-systems. Director of the Experimental Biology Institute and a member of the Water and Environment Science and Engineering Research Group at the Javeriana Pontifical University. **Email: laraj@javeriana.edu.co**

Sandra Lorena Galarza Molina
MS in civil engineering (2005) with a master's degree in hydro-systems (2011) from the Javeriana Pontifical University in Bogotá, Colombia. She began her doctoral degree studies in 2011 at the same university with research related to environmental evaluation of the Urban Sustainable Drainage System (SUDS) using the element of rainwater capture in a pilot basin. **Email: sgalarza@javeriana.edu.co** or **salogamo@gmail.com**

Juan Diego Giraldo Osorio
Assistant Professor at the Javeriana Pontifical University – Bogotá campus. BS in civil engineering from the National University of Colombia – Medellín campus. MS in civil engineering with specialty in water resource management from the University of the Andes. PhD in water resources management from the Polytechnical University of Cartagena (Spain). Currently Director of the Water and Environment Science and Engineering Research Group. Research interests focus on topics of climate change and adaptation, assimilation of remote sensing data in modeling, and hydrology. **Email: j.giraldoo@javeriana.edu.co**

Costa Rica

Hugo G. Hidalgo (Chapter Coordinator)
Research fellow in surface water hydrology, with a special interest in hydro-climatology. BS in civil engineering from the University of Costa Rica (1992). MS in science (1998) and PhD in Civil and Environmental Engineering with speciality in Water Resources (2001) from the University of California, Los Angeles. Currently a professor at the University of Costa Rica, School of Physics. He coordinates the Master's Degree Program in Hydrology and is the National Focal Point for the Inter American Network of Academies of Sciences Water Program and deputy director of the Geophysics Research Center at the University of Costa Rica. Dr. Hidalgo is the author of more than thirty publications and has participated in more than 100 conferences, seminars and workshops.
Email: hugo.hidalgo@ucr.ac.cr

Ángel G. Muñoz
Researcher in climate sciences at the International Research Institute for Climate and Society (IRI) at Columbia University. Doctoral degree student in the Department of Earth and Environmental Engineering at Columbia University. After graduating from the University of Zulia with a BS in physics, Mr. Muñoz received a MS in earth and environmental engineering from Columbia University. His research focuses on extreme climate phenomenon in Latin America. Previously, associate professor in the Physics Department at the University of Zulia and coordinator of the Geo-sciences Area in the Scientific Modeling Center in Venezuela.
Email: ude.aibmuloc.iri@zonumga

Carolina Herrero
BS in civil engineering from the Isaac Newton University. Currently a master's degree student in hydrology at the University of Costa Rica. Professional background includes work in infrastructure in the Urbasco construction company and in the Franz Sauter and Associates company as a designer of outdoor works. She subsequently set up her own business, Ph-C Ingenieros Consultores, which provides project designs and inspections of infrastructure including hydrological studies and rainwater retention tanks.

Eric J. Alfaro
BS in meteorology from the University of Costa Rica. PhD in oceanography from the University of Concepción, Chile. Previously a meteorologist in the National Meteorological Institute. Currently Assistant Professor at

the University of Costa Rica, School of Physics where he began teaching in 1989. Member of the Graduate Commission on Atmospheric Sciences and Member of the Graduate Commission on Comprehensive Management of Tropical Coastal Areas, both of which are within the Graduate Studies System of the University of Costa Rica. Dr. Alfaro has also been a researcher at the Geophysics Research Center since 1992, where he is currently director, and a researcher at the Ocean Sciences and Limnology Research Center at the University of Costa Rica, since 2000. **Email: erick.alfaro@ucr.ac.cr**

Natalie Mora

Currently a student of meteorology at the University of Costa Rica, School of Physics and has collaborated as an assistant in various research projects at the Center for Geophysical Research at the University of Costa Rica. **Email: natali.mora@ucr.ac.cr**

Víctor H. Chacón

Systems analyst (Informatics Division), support analyst (AyA Auditing System), trainer and instructor for the Aya–Regional Technical Committee for Community Participation, Sanitary Education and Personal Hygiene – CAPRE, systems analyst in Watershed Basins – CARE, Rural Aqueducts Process – administrative technical advice promoter – WKF, environmental director for the Municipality of Pérez Zeledon, C.N.E. Planning Area, National Coordinator in CONIFOR of AyA, specialist in communal systems during disasters, specialist in socio-environmental communal systems.

Darner A. Mora

Affiliated to the Costa Rican Institute for Aqueducts and Sewers since 1977 and director of the National Waters Laboratory since 1989. He studied at the Republic of Nicaragua School and Nuevo Colegio in San JosÉ. BS in microbiology and clinical chemistry from the University of Costa Rica. MS in public health from the University of Costa Rica. Mr. Mora has published three books, approximately 150 opinion articles in various national newspapers and has conducted more than 100 research projects on water, the environment and health, making him an authority on these topics, which are crucial to Costa Rica's public health.

Mary L. Moreno (Box Environmental Services)

MA in economics of natural resources and the environment from the University of Concepción, Chile. Her research at the International Center on Economic Policy for Sustainable Development (CINPE) at the National University of Costa Rica (CINPE) concerns the evaluation of the economics of natural resources and environmental policies. Specific areas of research include protected wilderness areas, private forest areas and coastal zones. She teaches courses at the National University of Costa Rica in economic evaluation; economics, ecology and sustainable development; and microeconomics in the Master's Degree Program in Economic Policy with specialty in ecological economics. **Email: mary.moreno.diaz@una.cr**

Cuba

Daniela Mercedes Arellano (Chapter Coordinator)

BS in Geophysical Engineering from the Technical Institute, José A. Echevarría, La Habana. PhD in geological sciences from the University of Carolina in Prague, Czech Republic. Research Assistant. Director of project UNEP/GEF Sabana Camagüey, Cuba. Agency of Environment, Ministry of Science, Techology and Environment. Focal Point for Cuba of the InterAmerican Network for Academies of Science (IANAS). **Email: marell@ama.cu**

María Isabel González González
BS in biological sciences with a specialty in microbiology (University of Havana). PhD in health sciences (Ministry of Public Health). Researcher and full professor at the National Institute of Hygiene, Epidemiology and Microbiology, Havana, Cuba. Head of the Microbiology Laboratory at the National Institute of Hygiene, Epidemiology and Microbiology.

Leslie F. Molerio-León
BS in geology in mineral and hydro-geological deposits. MS in science with a specialty in isotope hydrology. Visiting Professor at the National Autonomous University of Mexico. Assistant professor (graduate level) at the School of Geology, University of Pinar del Río, Cuba. Environmental Auditor. Currently Principal Specialist at GRANIK HOLDINGS Ltd (Dominican Republic). Consultant in hydrogeology and water resources management, INVERSIONES GAMMA, S.A. (Cuba). Consultant for GROUPE-CONSEIL BAASTEL (BAASTEL) (Belgium-Canada). Environmental advisor for Sherritt International Oil & Gas (Canada) and Sherritt Power-ENERGAS (Cuba). Advisor to the National Risk Evaluation Group of Cuba. United Nations Development Program (UNDP) regional expert on vulnerability and quantitative risk analysis for the Dutch and British OCTs (UNDP-Bahamas). United Nations Development Program karst aquifer expert (UNDP-Dominican Republic). Member of the Cuban Academy of Sciences Water Commission. **Email: especialistaprincipal@gmail.com**

Eduardo O. Planos Gutiérrez
BS in geography (University of Havana). MS in general and applied hydrology (Center for Hydrographic Studies, Spain). PhD in geographic sciences (University of Havana). Assistant researcher, Cuban Meteorology Institute. Full Professor, Higher Institute of Applied Technologies and Sciences and at the School of Geography of the University of Havana. Currently President of the Cuban National Program on Climate Change Sciences: Impacts, Mitigation and Adaptation. Researcher at the Meteorological Institute. Coordinator of Studies on Adaptation to Climate Change for National Communication. Coordinator of the IHP UNESCO FRIEND Program for Latin America and the Caribbean. Hydrology Advisor for the IV Region of the WMO for North America, Central America and the Caribbean.

Dominican Republic

Rafael Osiris de Leon (Chapter Coordinator)
BS in Geological Engineering and Mines from the Pontificial Catholic University Madre y Maestra, Santo Domingo, Dominican Republic. Posterior formation in geology, hydrogeology and environmental sciences in the Instituto de Pesquisas Espaciales in Sao Paolo, Brazil (1994), in the University of Campina, Brazil (2000), in the Polytechnical José A. Echeverría, Habana, Cuba (2002), in the Latin American Faculty of Social Sciences (FLACSO) (2003) and studies in Geophysics in the Kansas Geological Service of the University of Kansas in USA (2004). Focal Point for the Dominican Republic of the InterAmerican Network for Academies of Science (IANAS). **Email: osirisdeleon@gmail.com**

Grenada

Martin St. Clair Forde (Chapter Coordinator)
Martin Forde is a full professor at St. Georges University, Grenada, within the Department of Public Health & Preventive Medicine. His main teaching and research activities are centered on environmental health, environmental health management, occupational health, ergonomics and industrial hygiene, and global

population health research. Dr. Forde is actively involved in several technical and governmental committees that focus on environmental and occupational health issues. Recently, Dr. Forde has received grant funding from the World Bank, the Pan American Health and Education Foundation, and the Canadian International Development Research Centre to research issues ranging from biomedical waste management systems to determining the prevalence of human exposures to persistent organic pollutants, pesticides, and heavy metals such as lead and mercury, within the Caribbean region, to examining the ethical challenges and issues faced by researchers involved in global population health research collaborations. National Focal Point for Grenada in the InterAmerican Network of Academies of Sciences (IANAS), Water Project.
Email: martinforde@mac.com

Brian P. Neff, Ph.D.
Dr. Neff has lived in Grenada since 2006, working as an academic and consultant. In principle, Dr. Neff is a hydrologist, although he is comfortable and credentialed in applying social sciences to water issues. His recent research draws from complex systems and political science and determines why Grenadian water management is trapped in an administratively fragmented state. More importantly, Dr. Neff's research explains why well-funded reform efforts have failed and how future efforts can overcome obstacles to change. His present research interests include human dimensions of sustainability and resilience of social-ecological systems. Dr. Neff enjoys traveling, kayak fishing, and writing about himself in the third person.
LinkedIn: linkedin.com/in/1brianneff | Google Scholar: tinyurl.com/BNeff-GoogleScholarPage

EL Salvador

Julio C. Quiñonez Basagoitia
BS in civil engineering from the José Simeón Cañas Central American University, El Salvador. MS in Hydrology (CEDEX, Spain). Post graduate studies in mathematical modeling in hydrology (Technological University of Panama). Advanced International Programme "Management of Hydro Power Development and Use" (Vattenfall Power Consultant AB, SIDA, Sweden-Peru). Consultant in hydrology and hydraulics for various national and international public and private entities. Local assigned researcher and presenter for international IWRA conferences and member of the GWP as a professional in the field of water resources.
Email: julioquinonezb@gmail.com

Guatemala

Dr. Manuel Basterrechea (Chapter Coordinator)
BS in civil engineering, MS in water resources and PhD in civil and environmental engineering from the University of Iowa, USA. Member of the Academy of Physical, Medical and Natural Sciences of Guatemala. Focal Point for Guatemala of the InterAmerican Network for Academies of Science (IANAS). Private consultant since 1990 for national and international organizations. **Email: asebaste@gmail.com**

Carlos Roberto Cobos
BS in civil engineering from the University of San Carlos, Guatemala. MS in water resources from Oregon State University. Professor of hydrology, watershed basin management and hydraulics (Rafael Landivar University, Mariano Gálvez University and Del Valle University). Previously Deputy Director of the Engineering Research Center at Mariano Gálvez University (until 2013). UNICEF, FAO, UNDP, World Bank and WWF consultant. Member of the Inter-American Water Resources Network Board. **Email: carlos.cobos@maga.gob.gt**

Juan Carlos Fuentes

BS in hydrology from the University of San Carlos, Guatemala and the University of Costa Rica. Previous experience with INSIVUMEH and the Central American Network for Water Resource Management. Professor of physical properties of soils; environmental statistics; climatology; hydrology; soil degradation; watershed basins; and irrigation and drainage. Bachelor's and master's degree thesis advisor and evaluator. Author of various articles in journals and active in national and international events. Awarded for academic performance. Currently working at the National Electrification Institute and professor at the Regional Sanitary Engineering School and the School of Graduate Studies in the Engineering Department of the University of San Carlos, Guatemala (USAC).

Norma Edith Gil Rodas de Castillo

BS in chemistry and biology. MS in environmental science and technology. Full Professor at the Oceans and Aquiculture Studies Center –CEMA University of San Carlos, Guatemala –USAC. Member of the Intersectoral Commission on the Environment –CIMA- of the National Science and Technology Council –CONCYT. Principal investigator for research projects related to limnology within the National Science and Technology Fund –FODECYT. Member of the Mesoamerican Network of Macroinvertebrate Scientists -REDMADMESO

Jeanette Herrera de Noack

Attorney and Notary Public at the School of Judicial and Social Sciences of the University of San Carlos, Guatemala, with experience in Guatemalan law and legislation on water and the environment. Member of the Environmental Law Alliance Worldwide (E-LAW). National liaison in Guatemala for the National Alliance for Water and Secretary of the National Water Association of Global Water Partnership. Also a member of the Environmental Rights Commission of the World Conservation Union (UICN) and director of the Alliance for Environmental Rights and Water in Guatemala.

Ana Beatriz Suárez

BS in Biochemistry from the University of San Carlos, Guatemala. Currently a master's degree student in Christian leadership (Master's Program in Accessible Theological Studies –Pro-META). Currently lab coordinator for Ecological and Chemical Laboratory, S.A. and Treasurer for the Integral Environmental Development Association -ASODAMI, in Guatemala. Previously Head of Lake Management, Environmental Quality and Control Division of the Amatitlán Lake Authority-AMSA, in Guatemala.

Honduras

Marco Antonio Blair Chávez (Chapter Coordinator)

BSin civil engineering from the National Autonomous University of Honduras. MSin sanitary engineering from the National Autonomous University of Mexico. MSin Water Resource Management from the University of Newcastle upon Tyne, United Kingdom. Professor of various subjects including water storage and applied hydraulics at the National Autonomous University of Honduras; water treatment processes for potable water and advanced engineering topics at the Catholic University of Honduras; and Sanitary Engineering I and II and Applied Hydraulics at the Central American Technological University. Science and technology; and water and sanitation consultant in . Member of the College of Civil Engineers of Honduras, the Honduran Academy of Sciences and the InterAmerican Association of Sanitary Engineering. Focal Point for the Honduras in the Inter-American Network for Academies of Science (IANAS). **Email: thonyblair@yahoo.co.uk**

Manuel Figueroa

Bon October 11, 1932, Dr. Figueroa received a BSin Chemistry from the National Autonomous University of Honduras (UNAH). He obtained a PhD in microbiology in 1967 from the University of Kentucky, United States.

He has been a professor and department chair of microbiology at UNAH. He has undertaken numerous studies on infectious diseases, including water-borne diseases. Dr. Figueroa is currently a member of the Board of Directors of the National Academy of Sciences of Honduras. **Email: manuel_figueroas@yahoo.com**

Mexico

María Luisa Torregrosa y Armentia (Chapter Coordinator)
BS in sociology from the National Autonomous University of Mexico. MS and PhD in social science with specialization in sociology from El Colegio de México . Professor and researcher at the Latin American Faculty of Social Sciences (FLACSO), Mexico Office. Coordinator of the Mexican Academy of Sciences Water Network. National Focal Point for Mexico in the InterAmerican Network of Academies of Sciences.
Email: marialuisatorregrosa@gmail.com

Jacinta Palerm
BA in Social Anthropology from the Iberoamericana University. MS and PhD from the University of Toulouse-le-Mirail, France. Full Professor/Researcher in Rural Development Studies at the graduate level, Mexico. Currently a member of the Mexican Academy of Sciences. Email: jacinta.palerm@gmail.com

Ricardo Sandoval Minero
BS and MS in economic and financial water engineering from the National Autonomous University of Mexico (UNAM), School of Engineering. MS in modeling, optimization, decision-making and organization from Paris University – Dauphine. External Consultant for the World Bank, International Development Bank and other international and national organizations. Secretary of the International Water Association (IWA) Council in Mexico and Member of the InterAmerican Water Resources Network Board. President and Director of Sextante Consulting Services, S.C.

Karina Kloster
BA in Sociology from the University of Buenos Aires (UBA). MA from the Latin American Faculty of Social Sciences (FLACSO-Mexico Office). PhDin Political and Social Sciences from the National Autonomous University of Mexico (UNAM). Professor and researcher at the Autonomous University of Mexico City (UACM), Cuauhtepec Campus and assistant professor at UNAM.

Blanca Jiménez-Cisneros
BS in environmental engineering from the Metropolitan Autonomous University, Mexico. PhD in engineering with specialty in treatment and conditioning of water (National Institute of Applied Sciences, France). Principal Investigator at the National Autonomous University of Mexico, Engineering Institute. Coordinator of the Treatment and Re-use Group. Director of the Water Sciences Division and Secretary of UNESCO's International Hydrology Program. Member of the Mexican Academy of Sciences Water Network and the InterAmerican Network of Academies of Sciences (IANAS). **Email: b.jimenez-cisneros@unesco.org**

Polioptro F. Martínez Austria
BS in civil engineering from the National Polytechnical Institute. MS and PhD in hydraulic engineering from the School of Engineering of the National Autonomous University of Mexico. Currently General Director of Research, Graduate Studies and International Relations within the Vice President's Office of the University of the Americas, Puebla. Member of the Mexican Academy of Sciences, the Academy of Engineering, the International Association for Hydro-Environment Engineering and Research, the International Water Resources Association, of the American Waterworks Association and the Mexican Hydraulics Association, and former president of the latter. **Email: polioptro.martinez@udlap.mx**

Jordi Vera Cartas
BS in Biology from the University of Barcelona, Spain. MS in Environmental Sciences from the University of Wageningen, Holland. Researcher in European Union projects at FLACSO, Mexico Office. Has served as a consultant for CONAGUA, AECID and the World Bank, among others. Currently working with the non-governmental organization Fondo Golfo de Mexico A.C., responsible for monitoring the GEF project (Coastal Watersheds Conservation in the Context of Climate Change Project).

Dr. Ismael Aguilar Barajas
BS in civil engineering from the Michoacana de San Nicolas de Hidalgo University. PhD in economics from the London School of Economics and Political Science. Full Professor at the Department of Economics and Associate Researchers in the Water Center for Latin America and the Caribbean at the Monterrey Institute of Technology. Member of Mexico's National System of Researchers. Three-time recipient of the Monterrey Prize in Technology for Teaching and Research. Represents the Monterrey Institute of Technology in the Water Advisory Council whose primary mission is to support the design of the country's water policy. Dr. Aguilar Barajas also represents the Monterrey Institute at the Inter-institutional Program of Studies of the North American Region, at El Colegio de México. **Email: iaguilar@itesm.mx**

Nicaragua

Katherine Vammen (Chapter Coordinator)
PhD with specialty in biochemistry and microbiology of water from the University of Salzburg (Paris Lodron), Austria. Specialist in water quality and management. Deputy director of the Nicaraguan Research Center for Aquatic Resources at the National Autonomous University of Nicaragua (CIRA/UNAN). Founder and coordinator of the Central American Regional Master's Program in Water Sciences. National Focal Point for Nicaragua in the Inter-American Network of Academies of Sciences (IANAS) Water Program. Co-editor of Urban Waters in the Americas, IANAS and Co-Chair Water Program, IANAS.
Email: kvammen@cira-unan.edu.ni

Yelba Flores Meza
BS in mining engineering and geology from the Mining Institute of St. Petersburg, Russia). Ms in water sciences with a specialty in water quality (National Autonomous University of Nicaragua-UNAN). Full Professor with master's degree at UNAN. Research fellow, Head of Hydrogeology Laboratory at the Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN). **Email: yelba.flores@cira-unan.edu.ni**

Selvia Flores Sánchez
BS in agro-chemical engineering from the School of Agro-Chemical Engineering and Crop Protection, Halle/Saale, Germany). MS in environmental management and natural resources from the Autonomous University of Barcelona and UNAN-Managua. Analyst at the Natural Waters Laboratory and Co-Lecturer in Water and Society, Limnology and Contamination of Water Resources at the Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN-Managua). **Email: selvia.flores@cira-unan.edu.ni**

Iris Hurtado García
BS in chemical engineering from the National Engineering University of Nicaragua (UNI). MS in environmental engineering with specialty in sanitary engineering (UNI). Full Professor with Adjunct Specialty at the National Autonomous University of Nicaragua (UNAN). Research fellow, head of Analytics Section, Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN). **Email: iris.hurtado@cira-unan.edu.ni**

Mario Jiménez García
BA in education sciences with specialty in Biology. PhD in Medicine and Surgery and MS in Epidemiology from the National Autonomous University of Nicaragua (UNAN). Full Professor with Master's Degree at UNAN. Water and health researcher at the Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN). **Email: mjimenezgarcia72@yahoo.com**

Francisco J. Picado Pavón
Bachelor's Degree in chemical engineering from the National Engineering University of Nicaragua (UNI). Master's Degree in Chemical Ecology and Eco-Toxicology from the University of Lund, Sweden. Doctoral Degree in Science with emphasis on Ecology and specialization in Chemical Ecology and Ecotoxicology from the University of Lund, Sweden. Lecturer and Researcher and Head of Metal Contaminants Laboratory at the Nicaraguan Research Center for Aquatic Resources (CIRA) at the National Autonomous University of Nicaragua (UNAN). **Email: francisco.picado@cira-unan.edu.ni**

Gustavo Sequeira Peña
PhD in Medicine and Surgery from the National Autonomous University of Nicaragua, Leon Campus (UNAN-Leon). PhD in medical sciences with honorable mention in immunology from Friedrich-Schiller University, Germany. Specialist training in immunology, and sub-specialty in allergology from the General Medical Council of Thuringia, Germany. Full Professor at the Nicaraguan Research Center for Water Resources (CIRA/UNAN). **Email: gustavoseq@gmail.com**

Panama

José Rogelio Fábrega Duque (Chapter Coordinator)
BS in Civil Engineering from the Santa Maria La Antigua University. MS and PhDin civil engineering with specialty in environmental engineering from Purdue University. Part-time professor at the Civil and Mechanical Engineering Faculties at the Technological University of Panama. Director and Principal Investigator of the Center for Hydraulic and Hydrotechnical Studies at the Technological University of Panama. National Focal Point for the InterAmerican Network of Academies of Sciences (IANAS) Water Program. **Email: jose.fabrega@utp.ac.pa**

Miroslava Morán Montaño
Environmental Engineering (Autonomous University of Guadalajara, Mexico); MS in Management and Conservation of Tropical Forests and Biodiversity (CATIE, Costa Rica); MA in Environmental Education (University of Guadalajara, Mexico); Specialist in Water Resources and Education in the Humid Tropics of Latin America and the Caribbean (CATHALAC).

Elsa Lilibeth Flores Hernández
BA in civil engineering (Technological University of Panama). Special Researcher III; Center for Hydraulic and Hydrotechnical Research, Technological University of Panama. Outreach Coordinator.

Icela Ibeth Márquez Solano de Rojas
BS in civil engineering (University of Panama), MS in basic engineering sciences (Technological University of Panama), Post graduate degree and MS in environmental engineering (Technological University of Panama), international diploma in environmental risk (National Autonomous University of Mexico), Full Professor of sanitary engineering and basic sciences engineering at the Technological University of Panama, consultant and environmental auditor, environmental tutor at the Iberoamerican University Foundation (FUNIBER).

Argentina Ying B

BS in biology with specialization in medical technology: University of Panama MS in medical entomology. University of Panama part-time professor of parasitology, Faculty of Medicine, Department of Microbiology. University of Panama.

Casilda Saavedra

PhD in environmental sciences (Washington State University, USA). MS in environmental sciences (Washington State University, USA). Post graduate degree in geographic information systems (Technological University of Panama). Specialist in higher education (University of Panama). BA in Civil Engineering (Technological University of Panama). Full professor, Civil Engineering Faculty, Technological University of Panama. Member of the National Research System of Panama in National Researcher Category I. Focal Point of Panama to the Intergovernmental Panel on Climate Change (IPCC). Focal Point of the Technological University of Panama to the National Committee on Climate Change (CONACCP).

Berta Alicia Olmedo Vernaza

Meteorology Technician (University of Panama). Meteorologist Class II WMO (Institute of Meteorology-Madrid, Spain). BS in Statistics (University of Panama). Postgraduate degree in applied meteorology (University of Costa Rica). Professor of Climatology in the Bachelor's Degree Course in Meteorology. Responsible for the group of Variability and Climate Change, ETESA Hydrometeorology Management.

Pilar López Palacios

Meteorology Technician (University of Panama). Undergraduate student of meteorology (University of Panama). Works in ETESA Climatology, Hydrometeorology Management.

Peru

Nicole Bernex Weiss (Chapter Coordinator)

PhD in geography (Paul Valéry University, Montpellier, France). Principal Professor in the Humanities Department of the Pontifical Catholic University of Peru. Academic Director of the Applied Geography Research Center at the Pontifical Catholic University of Peru (CIGA-PUCP). Member of the Technical Committee of the Global Water Partnership (GWP). Numerical Member of the National Academy of Sciences of Peru. National Focal Point for Peru in the InterAmerican Network of Academies of Sciences (IANAS) Water Program.

Email: nbernex@pucp.edu.pe

Victor Carlotto Caillaux

PhD in geology (Joseph Fourier University of Grenoble, France. Principal Professor at the San Antonio National University of Cusco and professor at the Pontifical Catholic University of Peru. Previously Geo-Scientific Director of the Geological, Mining and Metallurgy Institute (INGEMMET). Numerical Member of the National Academy of Sciences of Peru.

César Cabezas Sánchez

Surgeon, National University of San Marcos. Specialist in infectious and tropical diseases. Director of the National Health Institute of Peru (INS). Associate Member of the National Academy of Medicine of Peru.

Email: ccabezas@ins.gob.pe

Ruth Shady Solis
PhD in archeology from the National University of San Marcos. Principal Professor at the National University of San Marcos. Director of Caral-Supe Special Archeological Project. Numerical Member of the National Academy of Sciences of Peru. National Focal Point for Peru in the InterAmerican Network of Academies of Sciences (IANAS) Women for Science Program. **Email: rshady@zonacaral.gob.pe**

Fernando Roca
PhD in social anthropology and ethnobotany (School for Advanced Studies in the Social Sciences, Paris). Principal Professor in the Communications Department of the Pontifical Catholic University of Peru. Director of the Amazon Advanced Studies Master's Degree Program at the PUCP Graduate School.

Mathieu Durand
PhD in geography from the University of Maine, France. Professor of Land Use Planning at the University of Maine, France, and Member of the ESO Research Center (Space and Society) of the National Center for Scientific Research (CNRS).

Eduardo Ismodes Cascón
PhD in Latin American history from the Pablo de Olavide University, Seville, Spain. BS in mechanical engineering. Principal Professor at the Engineering Department of the Pontifical Catholic University of Peru.

Julio Kuroiwa Zevallos
PhD in civil engineering from Colorado State University, USA. Associate Professor at the School of Civil Engineering at the National Engineering University. Director of the National Hydraulic Laboratory of the National Engineering University. **Email: kuroiwa@mk.com.pe**

United States of America

Henry J. Vaux, JR. (Chapter Coordinator)
Henry Vaux, Jr. is Professor Emeritus of Resource Economics at the University of California, Riverside and Associate Vice President Emeritus of the University of California System. His academic field is the economics of water resources in which he is widely published. Professor Vaux was formerly Director of the University of California Water Resources Center. He continues to chair the Rosenberg International Forum on Water Policy for the University. Professor Vaux is a National Associate of the U.S. National Academy of Sciences and served as Chair of the Water Science and Technology Board of the National Research Council. He has led scientific delegations to Iran, Tunisia and Mexico on behalf of the National Research Council. He currently serves on the InterAmerican Network of Academies of Science's Water Committee. Professor Vaux is President Emeritus of the Board of Directors of the California-based Water Education Foundation. **Email: vaux0@att.net**

Uruguay

Daniel Conde Scalone (Chapter Coordinator)
BS in biological oceanography and PhD in aquatic ecology, specializing in coastal lake ecology and integrated coastal management. Associate professor in the Limnology Section of the School of Sciences (UdelaR). Researcher Level II-ANII and First Level of PEDECIBA. Leader of Coastal Management Interdisciplinary Group and Coordinator of the Interdisciplinary Center for Southern Cone Integrated Coastal Management (UdelaR). National Focal Point for Uruguay in the InterAmerican Network of Academies of Sciences (IANAS), Water Program. **Email: vladddcc@gmail.com**

Adriana Piperno de Santiago
BA in architecture. Professor at the Theory and Urbanism Institute, School of Architecture, University of the Republic (UdelaR). Joint Leader of Urban Waters and Risk Management Research Team and of the Water and City optional course. Co-Coordinator of the Urban Waters Group of PHI-LAC UNESCO and Advisor of the Water Directorate in relation to flooding and urban drainage. Member of the National System of Researchers – ANII and of the R+D sub-commissions and Research Initiation (CSIC). **Email: apiperno@farq.edu.uy**

Federico Quintans Sives
BS in biology from the University of the Republic (UdelaR). MS in environmental sciences from the UdelaR. Assistant Professor in the Limnology Section of the Institute of Ecology and Environmental Sciences, School of Sciences (UdelaR). Advisor in decentralized sanitation systems in the National Water Directorate, Ministry of Housing, Land Use Planning and the Environment. **Email: Federico.quintans@gmail.com**

Authors
The team of authors is comprised of teachers from the UdelaR and independent professionals belonging to different areas of management: **Jimena Alonso** (**jimealonsop@gmail.com**), **Christian Chreties** (**chreties@fing.edu.uy**), **Nicolás Rezzano** (**nrezzano@gmail.com**), **Julieta López** (**jlopez@fing.edu.uy**), **Elizabeth González** (**aliceelizabethgonzalez@gmail.com**) and **Luis Silveira** (**lesy@fing.edu.uy**) are civil engineers specializing in environmental hydraulics, and teachers at the School of Engineering; **Javier Task** (**jtaks@adinet.com.uy**) and **Carlos Santos** (**santos.carlos@gmail.com**) are anthropologists and teachers at the School of Humanities and Education Sciences; **Pablo Sierra** (**p.sierra.uy@gmail.com**) and **Amancay Matos** (**amancay.matos@gmail.com**) are architects, and teachers ata the School of Architecture; **Rafael Arocena** (**rafaelarocena37@gmail.com**) and **Luis Aubriot** (**luis.aubriot@gmail.com**) are biologists, and teachers at the School of Sciences; **Nestor Mazzeo** (**mazzeobeyhaut@yahoo.com**) and **Guillermo Goyenola** (**goyenola@gmail.com**) are biologists at the Eastern Region University Center; **Alvaro Capandeguy** (**acapand@gmail.com**) is an engineer with URSEA. **Attorneys Gabriela Sanguinet** (**asanguinet@mvotma.gub.uy**) and **Matilde Saravia** (**matildesaravia@gmail.com**), sociologists **Andrea Gamarra** (**agamarraparodi@gmail.com**) and **Alejandra Cuadrado** (**alejacuadrado@gmail.com**), **Juan Pablo Martinez Penades** (**juanmartinezpenades@gmail.com**), environmental hydraulic engineer, and **Osvaldo Sabaño** (**sabano.osvaldo@gmail.com**), architect, are all technicians of DINAGUA-MVOTMA. **Pablo Guido** (**pablo.luis.guido@gmail.com**) and **Maria Mena** (**mariaceliamena@gmail.com**) are hydraulic engineers with the Montevideo City Government.

Venezuela

Ernesto José González (Chapter Coordinator)
BS in biology (University of Central Venezuela). PhD in Science, mention in Ecology (Central University of Venezuela). Full Professor, Faculty of Science (Central University of Venezuela). Head of the Limnology Laboratory at the Experimental Biological Institute, Faculty of Science, Central University of Venezuela. Director of the Institute of Experimental Biology. National Focal Point for Venezuela in the InterAmerican Network of Academies of Sciences (IANAS), Water Program. **Email: ernesto.gonzalez@ciens.ucv.ve**

María Leny Matos
Bs in biology (University of the Andes). Magister Scientiarum of Science; Botanical Mention (University of Central Venezuela): Director of the HIDROVEN Plankton Laboratory. Formerly Director of the Department of Environmental Quality of the People's Ministry of the Environment. Specialist in Technical Assistance and Superintendent of Services for HIDROVEN. Secretary of the Venezuelan National Technical Water Quality Committee. **Email: lenymatos@gmail.com**

Eduardo Buroz
BS in agricultural engineering (University of Central Venezuela). Magister Scientiarum in use, engineering and planning of water resources (University of Eastern Venezuela); Stanford University, California, USA). Specialist in environmental sciences (Metropolitan University of Venezuela), Full Professor, Environmental Engineering Postgraduate Studies, Andrés Bello Catholic University, Corresponding Member of the Academy of Physical, Mathematical and Natural Sciences. Fellow (elect) of the National Academy for Engineering and Habitat. **Email: eduardo.buroz@gmail.com**

José Ochoa-Iturbe
BS in civil engineering (Andrés Bello Catholic University), MBA(majoring in Environment), Florida Atlantic University. Doctoral candidate, Andrés Bello Catholic University; Former President of the Venezuelan Society of Hydraulic Engineering. Former President of the Interamerican Water Resources Network. Associate Professor, Metropolitan University; Associate Professor, Faculty of Engineering, North Carolina State University. Dean of the School of Engineering of the Andrés Bello Catholic University. **Email: jochoai@gmail.com**

Antonio Machado-Allison
BS in biology (Central University of Venezuela); PhD (George Washington University); Full Professor (Retired), Faculty of Sciences (Central University of Venezuela). Fish Biosystem Laboratory, Institute of Tropical Ecology and Zoology, Central University of Venezuela; associate researcher, Association of the American Museum of Natural History (New York); Field Museum of Natural History (Chicago) and the Smithsonian Institute (Washington, D.C.). Fellow (Seat III) of the Academy of Physical, Mathematical and Natural Sciences. Librarian and currently academic secretary of the Academy. President of the Foundation of the Academy (FUDECI) and president of the Foundation Palace of the Academies. Manager of Research Centers and Public Lectures of the assistant academic rector (Central University of Venezuela). **Email: antonio.machado@ciens.ucv.ve**

Róger Martínez
BS in urban planning (Simón Bolívar University); Magister in systems engineering (Simón Bolívar University); PhD in architecture (Central University of Venezuela). Full Professor, Department of Urban Planning, Simón Bolívar University, Director of Social Sciences and Humanities, Simón Bolívar University.
Email: rmartine@usb.ve

Ramón Montero
BS in chemistry, with major in geochemistry (Central University of Venezuela); associate professor, Faculty of Science, Central University of Venezuela; head of Laboratory of Hydrogeochemistry and Laboratory of Atomic Absorption and Emissions and Chromatography, Institute of Earth Sciences, Faculty of Science, Central University of Venezuela. **Email: ramon.montero@ciens.ucv.ve**

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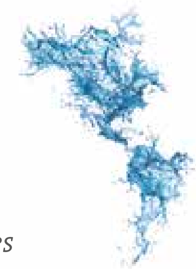
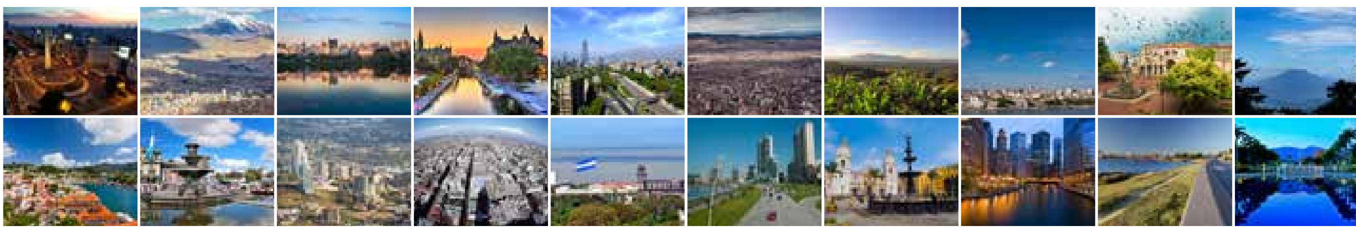
URBAN WATER CHALLENGES IN THE AMERICAS

A perspective from the Academies of Sciences





The Americas are among the most urbanized regions of the world (>80%). Urbanization goes hand in hand with intensification in the use of **water resources for human needs**; in turn, hydrological systems play a role in the development and growth of cities, not only as a source of drinking water but also for the deposition of wastes. ***Urban Water Challenges in the Americas*** describes and analyzes the problems of water in urban centers in 20 countries of the Americas: spanning from South America, Central America, Mexico and the Caribbean to the United States and Canada. This unique collection of experiences with urban waters in the Americas rests on a wide geographical representation that includes differences in water resource availability and levels of economic development.

The main challenges touched upon in this book of the IANAS Water Program are: Can the problems of urban water supply and sanitation be solved with better management? Can access to safe drinking water be improved? Can the challenge of improving sanitation and wastewater management be met? Can water related health problems and water-borne disease be better addressed in urban areas? What are the water related challenges in adapting to climate change for urban areas and how can they be met? What are good models and concepts for helping to improve water management in urban areas?

The goal of this volume is to look for different answers to these questions in the search for solutions to the challenges of properly managing water resources in urban areas.

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