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Preliminary climate assessment and scoping note for Sindh: revised

A CSIRO contribution to support the development of the proposed *Sindh Water and Agriculture Climate Resilience Project*

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Introduction

With a population of over 50 million, Sindh is the second most populous province in Pakistan. Its economy accounts for more than one third of the economy of Pakistan. It is the most downstream province of the Indus River Basin and depends almost exclusively on the water resources of the Indus river for a variety of uses and users. Because of the aridity of the province, agriculture is dependent on irrigation, and irrigated agriculture (which accounts for almost 20 % of Sindh's GDP and 70 % of employment) has traditionally been the largest user of freshwater resources. Water resources in the province are distributed through the Indus Basin Irrigation System (IBIS), which comprises three main barrages on the Indus River mainstream which divert water into fourteen main canals that serve a total designed area of 5.1 million hectares. Undoubtedly, this system has shaped the economic development of Sindh, and has delivered critical irrigation services. However, water resources in Sindh – as in the larger Indus Basin – are under significant pressure, a situation which is likely to be exacerbated by climate change.

Recognising the severity of the situation, the World Bank is designing the *Sindh Water and Agriculture Climate Resilience Project (SWACR)* which aims to transform water management from its dominant focus on irrigated agriculture, towards a more balanced integrated water resources management (IWRM) approach. This transformation is critical to: (a) addressing water security challenges that result from socio-economic drivers; (b) ensuring adequate water allocation to critical ecosystems to maintain and/or restore the many services they provide; and (c) introducing practices that are resilient to the impacts of climate change, including the potentially significant reductions in Indus river flows that Sindh province relies on almost exclusively for most of its water uses.

This objective will be achieved through: (a) policy reforms in the irrigation and agriculture sectors to induce more productive use of water; (b) institutional and legal reforms to establish effective mechanisms to implement IWRM; (c) critical investments in irrigation and drainage systems to ensure more reliable water delivery to stakeholders; and (d) technical assistance and investments to foster climate resilient agricultural practices and improve value chains.

The current document aims to support the development of a concept note that is part of the overall project development of the SWACR Project.

In **Part 1** of the document which has six short issues briefs, we outline potential climate change impacts on: a) crop water supply and crop water requirement; b) flows, salinity, waterlogging, floods, droughts and their potential impact on agricultural livelihoods; c) the environment; in particular the Indus Delta including sea level rise and sea water intrusion; d) municipal and industrial water demands; and, e) greenhouse emissions related waterlogging. The sixth issues brief gives in f) a general outline of potential water and agriculture-related adaptation and mitigation measures. In describing adaptations, we suggest a number of specific measures, but overall we stress the potential benefits of a basin approach in which agricultural policy and management, and integrated water resources policy and management are developed together.

In **Part 2**, we describe a general approach for a more detailed assessment of projected climate impacts and their relationship to the project. The general approach is one of scenario exploration, in which the potential outcomes of climate change and population growth on water resources and agriculture under business-as-usual scenarios are contrasted with the outcomes under changed policy / management scenarios.

The main elements of work proposed for the next phase are:

- the water balance of canal commands in Sindh; that is, the balance of supply and crop water demand, and the implications of any imbalance for sustainable water use. The water balance is in turn built upon an assessment of trends over the last 30 or more years in crop areas, productivity and implied water use.

This allows us to set the projected climate change impacts in the context of historical trends and variability;

- the delivery of water to Sindh and the distribution of water delivery within Sindh; the detailed distribution to be worked out initially for one canal command with a refinement made for this purpose to the Indus River System Model, with other canal commands to be added later if the initial results are useful.
- The above assessments of projected impacts are also built upon an assessment of the General Circulation Model results and uncertainties of the projected changes to rainfall and temperature in Pakistan. This includes an assessment of which GCMs perform best in Sindh.

In addition to these main elements, there are some smaller elements mainly to be pursued as literature / desk studies. These cover issues such as the environment, urban water, waterlogging, and greenhouse gas emissions.

In **Part 3**, we make some comments on three specific areas of the World Bank's Preliminary Concept Note for the SWACR Project. The three areas are a) water informatics (subcomponent 1.5), b) climate smart and high value agriculture (subcomponents 2.3 and 2.5), and c) service, distribution and use of irrigation water (subcomponent 3.2).

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Abbreviations/short forms

GCM	Global Climate Model
GDP	Gross Domestic Product
IBIS	Indus Basin Irrigation System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IRSM	Indus River System Model
IWRM	Integrated Water Resource Management
SWACR	Sindh Water and Agriculture Climate Resilience (project)

Part 1: Issues briefs on water and agriculture related climate change impacts and potential adaptations

a. Climate change impact on supply and crop water requirement

Context (why this aspect is important to consider)

- Pakistan is highly dependent on agriculture for food, exports (cotton, rice) and livelihoods (42.3 % workforce, 19.5 % GDP and about 80% per of total export earnings).
- Climate change will add to an increasingly critical and unsustainable water supply situation. Pakistan's water use depends on the supply of the Indus and, particularly in the Punjab, on groundwater. The water in the Indus is more-or-less fully committed to irrigation and other uses, with a small flow to the sea nominally for maintenance of the delta. The groundwater use is generally considered to be unsustainable (Kirby et al., 2017). With a growing population, and in the absence of other changes, even more groundwater will likely be used for irrigation to maintain the food supply (Kirby et al., 2017).
- Sindh province is highly dependent on the flows of the Indus for irrigation (and other) water supply. The irrigation infrastructure was more-or-less fully developed, and the water supply mostly committed, by about 1980. As a result, the areas planted to major crops and crop groups in Sindh have, in general, changed little since 1980 (Kirby and Ahmad, 2016). However, years of drought with low river water supply (such as the period around 2000-02) and flood (such as the 2010 floods), caused major reductions in crop areas in the province.
- The expected impacts of climate change on both the supply and demand for water might jeopardise food production and hence livelihoods.

Specific relevance of the above for Pakistan with particular focus on the Sindh province

- A preliminary check of general circulation models (GCMs; that is, models of the global climate) suggests that not all produce useful results for Sindh. Those that produce a useful result indicate that crop water demand (specifically, potential evapotranspiration) in the province is projected to be higher by some 2 to 10 %, depending on the GCM, for warming scenarios RCP 4.5 and RCP 8.5. The potential evapotranspiration of the province is about 2000 mm, so this represents an increase of 40 to 200 mm in crop water demand.
- A preliminary check of rainfall from the same set of GCMs and scenarios suggests that Sindh rainfall is projected to increase by up to 40 % (with one GCM outlier at +60 % for RCP 8.5) or decrease by up to 20 %. The total rainfall of Sindh is about 170 mm, so the change is from about +70 mm to -34 mm.
- Based on the above considerations, the main supply issue for irrigated crops in Sindh is river flows from areas outside of Sindh; Sindh flows mainly depend on Indus (main stem) and Kabul River.
- Several studies show medium term warming will increase the volume and variability of flows in the Upper Indus basin due to glacier melt and a greater proportion of precipitation falling as rain than snow. The long term (end of 21st century) will see declines in river flows when the glacier melting phase ends, with uncertain flows due to uncertain timing and amounts of precipitation. The future flows from the Kabul River (mostly rainfed) are more uncertain as precipitation could increase or decrease.
- Changes to rainfall could be more critical for areas of rainfed bajra in southern Sindh and rainfed pasture for the livestock sector (dairy and meat).
- The direct impact of climate change on crops (other than water supply and demand – e.g. direct temperature effects) has great uncertainty in Pakistan, though some authors suggest a decline in crop

yields (eg. 10 % declines across Pakistan in wheat suggested by Yu et al, as reviewed in Kirby et al. 2017), though the declines could be offset by adaptations such as changed sowing dates (as briefly reviewed in Kirby et al.). According to UNDP (2016) there will be negative impacts of temperature on cotton production; a 1°C rise in temperature during the vegetative and flowering stages of growth would reduce yield by 24 percent and 8 percent respectively.

Key trends/learnings and/or knowledge gaps for detailed assessment

- The effects of increases in population and wealth on agricultural crop requirements and hence overall water demand are large and more certain than those due to climate change. Furthermore, the rate of yield increases in Pakistan is insufficient to provide enough food for the growing population. Unless Pakistan imports large quantities of food in coming decades, it must: 1) continue to unsustainably use ever more groundwater (mostly in the Punjab); 2) stop exporting high water use crops (mostly cotton and rice); 3) greatly improve crop yields (at a rate much higher than in the past); and / or 4) change the crop mix to lower water using crops (Kirby et al., 2017). Sindh does not have the option of using more groundwater, so it has fewer options than the Punjab.
- There are few Sindh specific studies of the direct impacts of climate change on crop yields.
- There is great uncertainty in climate change impacts on rainfall, snow fall and glacier melt.
- The uncertainty above results in a great uncertainty in flows, both in the short to medium term (the period of enhanced glacier melting) and in the long term (post 2100 changes to rainfall – snow mix, and amount of precipitation). The impact of the uncertainty for Sindh has generally not been assessed.

How the work proposed in Part 2 will address the issues above

- The proposed work will allow an assessment of the likely climate change impacts on water supply and crop production in Sindh. The uncertainty in the assessments will also be examined. The projected changes in crop water demand and rainfall will be directly assessed from the available GCM results. The projected changes in water supply from the Indus river will be assessed using the Indus River System Model (Stewart et al., 2018).
- The work will also permit a comparison of climate related impacts with those resulting from the increased demand under development scenarios.
- The assessment of adaptations in the proposed work is discussed below in Section f.
- The proposed work cannot reduce the underlying uncertainty in GCMs and the projected climate change impacts on rainfall, snow fall and glacier melt.
- The proposed work does not address the lack of Sindh specific studies on the direct impacts of climate on crop yields.

b. Climate change impact on flows (also above), salinity, waterlogging, floods, droughts and their potential impact on agricultural livelihoods

Context (why this aspect is important to consider)

- Flows feed irrigation crops which provide food and exports for Pakistan – as discussed in the previous section.
- Salinity and waterlogging damage crop production, and also salinize the water resource.
- Droughts (eg 2001-01) and floods (eg 2010, 2011) lower agricultural production.
- Floods directly damage life and property.
- All the issues listed damage agricultural livelihoods, with cascading livelihood impacts in other sectors.

Specific relevance of the above for Pakistan with particular focus on the Sindh province

- As noted in the previous section, several studies show medium term warming will increase flows and its timing in the Upper Indus basin due to glacier melt and a relatively greater proportion of precipitation as rainfall than snow. The long term (post 2100) will see declines in river flows when the glacier melting phase ends, with uncertain flows due to uncertain timing and amounts of precipitation. The future flows from the Kabul River (mostly rainfed) are more uncertain. As Sindh is the last/downstream province in the Indus river system, any change in flow regime is likely to impact the water availability and agricultural livelihood in Sindh.
- Across the Indus Basin, 30 % of the irrigated area (amounting to 4.7 m ha) is estimated to have groundwater within 1.5 m of the surface at the end of the monsoon, reducing to 13 % (2 m ha) at the end of the dry season. In years of higher rainfall, 60 % of Sindh is severely waterlogged post-monsoon. In 2011, 70 % of Sindh was affected, amounting to 2.2 m ha. Across the Indus Basin, about 40,000 ha are abandoned each year due to secondary salinization that results from the rising groundwater.
- The 2000-01 drought and 2010 floods led to declines in agricultural output in Sindh. The areas of crops in Sindh decreased by 25 % from 1998-9 to 2002-03, and by 24 % from 2008-09 to 2011-12 (based on the data collated by Kirby and Ahmad (2016)). In the 2000-01 drought, the declines in wheat, rice and cotton production were 26, 21 and 10 % respectively, mainly due to the reduction in the areas cropped. Following the 2010 floods, the declines in rice and cotton production were 49 and 17 % respectively, again mainly due to the reduction in the areas cropped; wheat production, however, rose about 16 %, due to a 5 % increase in area and an 11 % increase in yield.
- The 2000-01 drought led to some reduction in waterlogging in Sindh. Reduced waterlogging in areas of saline groundwater may also have reduced salinity in the root zone. Possibly as a result of reduced waterlogging and salinity, the yield of wheat, rice and cotton increased by 5, 1 and 9 % respectively in this drought year. (Note that these increases in yields were insufficient to compensate for the large reductions in area, and production overall declined, as described above.)
- Studies suggest that floods and droughts may both be more severe and frequent due to climate change in the future, so the impacts described above could be greater.
- Livelihoods are impacted by climate change in several ways, with the uncertainty of irrigation water supply being especially important (Qaisrani et al., 2018). How well households cope with the impacts depends on their coping strategies, and these vary across Pakistan (Qaisrani et al., 2018). One coping strategy to diversify incomes (Qaisrani et al., 2018) is via migration. Heat stress (which is projected to increase in the future) causes migration away from rural areas in Pakistan more than flooding does (Mueller et al., 2014). Farmers across the wealth distribution, whether land-owners or landless, migrate in response to climate change, but with most significant effect on the poor (Mueller et al., 2014). Ali and Erenstein (2017) found that farmers who adopt a range of coping strategies (who were generally better educated, had more land, and better access to credit and other assets) had higher levels of food security and lower levels of poverty than those who did not. Ali and Erenstein (2017) also found that

farmers in Sindh and southern Punjab were more likely to adopt more coping strategies than other parts of Pakistan, but they attributed this to the greater need in the hotter and drier climate. Malik et al. (2012) assessed vulnerability to climate change in Pakistan, with a particular focus on human health impacts, and concluded that the cotton/wheat agro-climatic zone in Sindh was one of the most vulnerable regions, with high sensitivity to climate change and low adaptive capacity.

Key trends/learnings and/or knowledge gaps for detailed assessment

- As noted in the previous section, there is uncertainty in glacier contribution to flows and hence in climate change glacier melting impacts on flows.
- Despite a generally agreed expectation of an increase in future extreme events – floods and droughts – there is great uncertainty in the expected magnitude and frequency.
- There is a requirement for a repeatable system/evidence base to quantify the major water balance terms and then objectively plan for climate, infrastructure, development and Sindh's water entitlement/share according to interprovincial water accord.
- While there are many studies on the livelihood impacts of climate change in Pakistan, including the impacts in Sindh, they deal with a large set of issues (from farm income generally to specific issues such as gender), and also with a large set of coping strategies. There appears to be no systematic collation or review of the many studies into an overall picture, much less into a consistent set of policy recommendations.

How the work proposed in Part 2 will address the issues above

- The proposed work will allow an assessment of projected changes to rainfall and river flows and hence the likelihood of increased flood or drought extent and frequency. This in turn will allow a semi-quantitative assessment of the potential changes to waterlogging and salinity. The uncertainty in the assessments will also be examined.
- The proposed work will allow a qualitative assessment of potential livelihood impacts, done as a desk study. (Research encompassing extensive stakeholder survey would be preferable, but would take far longer, and fall outside the timeframes of the next phase of the overall World Bank project.)
- The work will also permit a comparison of climate related impacts with those resulting from the increased demand under development scenarios.
- The assessment of adaptations in the proposed work is discussed below in Section f.
- As noted in a. above, the proposed work cannot reduce the underlying uncertainty in GCMs and the projected changes to temperature, rainfall and river flows.

c. Climate change impacts on the environment; in particular the Indus Delta including sea level rise and sea water intrusion

Context (why this aspect is important to consider)

- Ecosystems in Sindh bring many different kinds of benefits to people, including fulfilling instrumental values (e.g. flood protection, provisioning of clean water and food, income from natural resource use such as fisheries), relational values (e.g. health, cultural identity, sense of place) and intrinsic values (e.g. the existence of Indus dolphins). When Sindh ecosystems are impacted by climate change, these human values also stand to be affected.
- There are public health risks associated with changing environmental conditions, including altered vulnerability to natural hazards, changing dynamics of water-borne or vector-borne diseases, and different contaminant pathways due to changing hydrological and biogeochemical cycles.
- Changing environmental conditions also influence choices to migrate. Some climate-induced migration will be occurring not because of direct climate impacts on people, but impacts mediated through changes to other environmental conditions.
- There are legal risks associated with international treaty obligations. Sindh has 10 Ramsar sites, including the Indus Delta and a 200 km stretch of the Indus River designated as an Indus Dolphin Reserve, home to the largest population of the endangered dolphin species.

Specific relevance of the above for Pakistan with particular focus on the Sindh province

- Sea water intrusion is already seen due to declining inflows to the delta, and particularly affects some channels. 426 sq km of the Delta are already degraded by sea water intrusion, and the degradation includes declines in mangroves. The Delta is home to 97 % of Pakistan's mangrove forests. Sindh's coastline contains approximately 70 % of Pakistan's fisheries resources, and there are estimates that 75 % commercially caught fish may inhabit mangrove forests at some point in their life (Adhikari et al., 2010). According to the Government of Sindh, Fisheries in Pakistan provide direct employment to 400,000 people and another 600,000 are engaged with an associated industry. There is a shift in livelihoods in the Delta, with 87 % of people engaged in fisheries as opposed to 43 % two decades ago (Memon and Thapa, 2011).
- With changing climate, sea level rise will endanger the Delta; the current rate of rise is about 1.1 mm/yr. Further decline in mangroves are expected with sea level rise.
- Salik et al. (2016) estimated environmental flow requirements for the Delta. Increased river flows due to more glacier melt may help maintain reference environmental flow requirements. However, if accompanied by more extreme climatic variability, it could see increased risk of flood damage in the Indus delta. However, decreased flows due to vanishing glaciers in the long term may make it impossible to maintain environmental flow requirements, so adding to deterioration of deltaic ecosystems.
- Fish stocks are jeopardised by the impacts of climate change on mangroves; Adhikari et al. (2010) state that Pakistan's shrimp fisheries (worth USD$100 million annually in exports) depend almost entirely on mangrove ecosystems, and over 100 species of fish have been recorded in Pakistan mangrove forests. In Balochistan, the poorest households are most vulnerable because a high proportion (nearly 80 %) of their total income is directly dependent on mangrove ecosystems for onsite fishing; and they have fewer options for switching to different income sources (Adhikari et al., 2010).
- The impact of climate change on Ramsar sites will be site specific, and dependent on many factors. Taking the Indus Dolphin Reserve as an example, the decline of the species is due to the declines in river flows and associated habitat fragmentation (building of barrages) (Braulick et al., 2015). To the extent that climate change alters flows (either through changes to river inflows, or through changes to water diversions for irrigation or other uses), it will affect the dolphins. Potentially, short to medium term

warming could enhance the flows of the Indus due to enhanced glacier melting which, in the absence of other change, could benefit the dolphins. However, warming is also projected to increase crop water demand in Sindh and elsewhere in Pakistan, which could lead to greater diversions and hence lower flows. In the longer term, decreased flows are expected which, in the absence of other change, would harm the dolphins.

- With climate change, more severe cyclones are expected in the coastal / delta region.
- The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) provides a framework for assessing a full suite of 'nature's contributions to people', recognising multiple values and associated valuation approaches. Such a comprehensive assessment has not yet been conducted for Sindh ecosystems, with only a regional assessment for Asia and the Pacific available (IPBES, 2018), and there is even less knowledge of how the impacts of climate change on Sindh ecosystems will affect people (e.g. effects on livelihoods, migration, health, and protection from extreme events).

Key trends/learnings and/or knowledge gaps for detailed assessment

- Irrigation development impacts on flows are large, known and have already mostly happened. This has impacted on the Delta and other key environmental assets (such as the Indus Dolphin Reserve Ramsar site), but the full extent of the impacts may not have yet been realised. Climate change is expected to add to the impacts, disadvantageously in the long term, but possibly beneficially in the medium term with greater flows due to glacier melting.
- As noted in sections a. and b., climate change impacts on flows are uncertain.
- For the Delta and coastal regions, climate change impacts include sea level rise. This will lead to greater vulnerability to waterlogging and salinity in the coastal / delta areas.
- Whereas climate change impacts on Ramsar sites and other environmental assets are likely to be site specific, there are few assessments of impacts specific to Sindh and its environments.
- Ramsar sites are intended to be managed to maintain their ecological character. If climate change leads to a change in character, there is no guidance about how they respond. It can be difficult to separate climate change from other impacts.

How the work proposed in Part 2 will address the issues above

- The proposed work will allow an assessment of projected changes to river flows, and hence the potential for changed hydrology of the Indus in Sindh. The uncertainty in the assessments will also be examined.
- The work will allow a comparison of projected climate related impacts with those resulting from the increased demand under development scenarios.
- The assessment of adaptations in the proposed work is discussed below in Section f.
- As noted in a. above, the proposed work cannot reduce the underlying uncertainty in GCMs and the projected changes to temperature, rainfall and river flows.
- The proposed work will not include direct modelling or other direct assessment of environmental impacts, beyond the assessment of hydrological indicators noted above.

d. Climate change impacts on municipal and industrial water demands

Context (why this aspect is important to consider)

- The water availability in the Sindh province is dominated by the Indus River system. Climate change research in the last few decades increasingly indicates significant changes in the precipitation pattern and glacier- and snow-melt of the Hindu Kush Mountain (Farooqi et al., 2005; Briscoe et al., 2005). These changes will increase competition for water amongst the use sectors and may have direct repercussions on municipal and industrial water supply.
- Climate change in terms of changes in temperature and rainfall, and to a lesser extent rainfall, wind speed, evaporation, evapotranspiration, humidity and solar exposure, influence municipal and industrial water demands (Babel et al. 2014).
- Municipal water contamination has been considered as a major cause of waterborne diseases like diarrhoea, nausea, gastroenteritis, typhoid, dysentery, and other health problems in Pakistan. Researchers (Nabeela et al., 2014) reported that 60 % of the sampled water in Karachi and 45.7 % of the sampled water in Khairpur City in the Sindh province were polluted with total and fecal coliforms. Climate change can increase pollution load in the supplied water (Delpla et al., 2009).
- The impact of climate change on municipal and industrial water supply, water quality and demand will have a significantly adverse consequence on the socioeconomic development of Pakistan.

Specific relevance of the above for Pakistan with particular focus on the Sindh province

- About 25 million people live in urban areas in the Sindh province. An additional 17 million people will live in urban areas in the next thirty years (PWD, 2018).
- Current municipal and industrial water supply service is poor. An intermittent water supply is common in urban areas. ADB estimated continuous water supply rates of one to 10 hours in Karachi.
- Municipal water demand in urban Sindh is mostly met by surface water sources and complemented by irrigation infrastructure since the groundwater is too saline for municipal and industrial use. Industries along the Indus River system mostly use water from the river.
- Climate change impact on the Indus River system will disrupt water supply to Pakistan's premier industrial and financial centre Karachi and large cities like Hyderabad, and will be transmitted in the form of changes in GDP, employment, and input–output demand across the nation.
- A one degree average increase in temperature is expected to increase municipal and industrial water demand by about 4 % by 2050 in Pakistan (Amir and Habib, 2015). A similar conclusion can be drawn for the Sindh province in the absence of detailed analysis based on water demand modelling.

Key trends/learnings and/or knowledge gaps for detailed assessment

- Municipal water demand in urban Sindh is mostly met by surface water sources and complemented by irrigation infrastructure in rural Sindh. Industries along the Indus River system mostly use water from the river.
- About 52 % of Sindh's population live in the urban areas which will continue to rise. An additional 34 million people are expected to live in urban areas by 2050 compared to 2017 under constant contraceptive prevalence rate (CPR) putting pressure on water supply.
- Temperature change is the most prominent climate variable influencing on municipal and industrial water demand, though rainfall, wind speed, evaporation, evapotranspiration, humidity and solar exposure may influence demand.
- A one degree average increase in temperature is expected to increase municipal and industrial water demand by about 4 % by 2050 in Pakistan. A similar conclusion can be drawn for the Sindh province in the absence of detailed analysis based in water demand modelling.

- The average annual projected demand change may not highlight seasonal variation. It is suggested that the impact of climate change on future municipal water demand be identified through developing a water demand model at monthly time step.
- A key knowledge gap is the development of integrated analyses of the future water demand and supply options covering all supply sources (mainly surface and groundwater, but potentially including desalination in some areas) and all uses (irrigation, urban, industrial and the environment).
- Another key knowledge gap is water quality. There are some studies of particular locations and issues but no overall assessment that we know of.

How the work proposed in Part 2 will address the issues above

- The proposed work will allow an assessment of projected changes to river flows, and hence the potential for changed water availability to urban and industrial centres. The uncertainty in the assessments will also be examined.
- The work will allow a qualitative comparison of climate related impacts to the increased demand under development scenarios.
- The assessment of adaptations in the proposed work is discussed below in Section f.
- As noted in a. above, the proposed work cannot reduce the underlying uncertainty in GCMs and the projected changes to temperature, rainfall and river flows.
- The proposed work will not include work on water quality; the prospects for developing such work in later phases of the project will be scoped out.

e. Greenhouse gas emissions related to waterlogging

Context (why this aspect is important to consider)

- Agriculture is a major greenhouse gas emitter, and thus a major contributor to global warming.
- Waterlogging leads to enhanced greenhouse gas emissions.
- Rice cultivation is a major greenhouse gas emitter, and Pakistan is a major rice growing nation.

Specific relevance of the above for Pakistan with particular focus on the Sindh province

- Pakistan overall and Sindh in particular have large areas affected by waterlogging and salinity, especially at the end of the monsoon season, as noted in b. above.
- Rice is a major crop in Pakistan overall, and particularly in Sindh.
- Waterlogging and associated salinity reduce yield and will increase nitrous oxide emissions. Essentially the crop does not use all of the applied nitrogen fertiliser because it is stressed due to the waterlogging. The residual soil nitrogen is converted to nitrous oxide. During droughts cotton yields (t/ha) increase probably due to reduce waterlogging and improved performance (also as noted in b. above).
- Areas of waterlogging reduced during large droughts (but waterlogging remains severe even during droughts in rice-wheat zone, probably because of the more intense irrigation).
- Drought also probably reduces greenhouse gas related emissions, partly because the areas of cropping reduce, and partly because the amount of greenhouse gas from each area reduces with the reduced level of waterlogging.
- Yields are below expectations and nitrogen use efficiency can be significantly increased. Is waterlogging the underlying cause?
- Methane and nitrous oxide are both emitted from waterlogged soils.

Key trends/learnings and/or knowledge gaps for detailed assessment

- The impact of seasonally waterlogged soils on greenhouse gas emission in semi-arid regions is not well known.
- The interaction between fluctuating ground water height and greenhouse gas emissions is not well quantified.
- There are opportunities to improve water management and fertiliser use efficiency. Irrigation and fertiliser management systems should be designed to increase yields and reduce greenhouse gas emissions and waterlogging.

How the work proposed in Part 2 will address the issues above

- The proposed work will allow an assessment of the potential for climate change impacts on waterlogging and salinity and the uncertainty in the projections of impact, as outlined in b. above. As a result, the proposed work will allow qualitative comment on the potential impacts on greenhouse gas emissions, done as a desk study.
- The assessment of adaptations in the proposed work is discussed below in Section f.
- As noted in a. above, the proposed work cannot reduce the underlying uncertainty in general circulation models and the projected changes to temperature, rainfall and river flows.
- The work does not include new research on the effects in semi-arid regions or in the presence of fluctuating groundwater height, noted above as knowledge gaps.

f. General outline of potential water and agriculture-related adaptation and mitigation measures

Context (why this aspect is important to consider)

- Mitigation matters: the recent IPCC Special report on Global Warming of 1.5°C highlights that limiting global warming to 1.5°C will require ‘rapid, far-reaching and unprecedented changes in all aspects of society’, whereas ‘…warming of 1.5°C or higher increases the risk associated with long-lasting or irreversible changes’ (quotations from IPCC press release at http://www.ipcc.ch/pdf/session48/pr_181008_P48_spm_en.pdf).
- Adaptation matters: ‘we are already seeing the consequences of 1°C of global warming through more extreme weather, rising sea levels and diminishing Arctic sea ice, among other changes’ (IPCC special report, press release). In other words, some adaptation is already required. Adaptation to climate change is doubly important because the adaptation measures for climate change are mostly the same as those required to combat current unsustainable water use which, in the absence of adaptation, will become more unsustainable with the growing population.

Specific relevance of the above for Pakistan with particular focus on the Sindh province

A. Mitigation (excluding general mitigation measures such as fuel efficiency in transport)

- Greenhouse gas specific mitigation measures, including: 1) reduce the areas of waterlogging through improved water and drainage management; 2) reduce nitrous oxide emissions through better fertiliser management; 3) potentially reduce the areas planted to rice, and 4) use alternate wetting and drying, and improved fertilizer management in rice production to reduce emissions.
- Measure and monitor direct and indirect energy use in agriculture in order to make more informed greenhouse gas accounting and life cycle assessments, and target opportunities for improved efficiencies. Memon et al. (2015) suggested that nitrogen inputs represented the highest energy input for wheat production in Sindh. They concluded that energy-intensive chemical inputs (fertilizers, pesticides and herbicides) are being wasted at present.
- There is potential for managing carbon dynamics in Indus Delta mangroves (Crooks et al., 2011) and maintain soil organic carbon in irrigated cropping soils.

B. Adaptation

- Two major, and related, areas for adaptation are integrated basin water resources planning and management, and agricultural planning and management.
- Integrated basin water resources planning includes supply side measures (new dams or other infrastructure, en-route storages, upgrading old infrastructure, modernizing irrigation systems, new / improved drainage systems, rainwater harvesting in urban centres, wastewater reuse); and demand side measures (demand management, water pricing, reducing waste).
- Agricultural planning and management includes: improved crop varieties; changing crop mixes – e.g. smaller area of high water use crops such as cotton and rice, with larger areas of other crops such as pulses and oilseeds (which will also carry nutritional benefits for poor households); changing to more nutritious and higher value crops may improve livelihoods of rural poor; improved crop varieties and improved crop and soil management; introduction/promotion of drought and salt tolerant crops and fodder; reducing deep percolation from irrigated fields and irrigation canals, especially in saline groundwater and waterlogged areas of Sindh; enhancing agro-forestry options for lowering of groundwater table and manage salinity.
- The above measures will require monitoring and evaluation to determine the effectiveness of implementation. This will generate a requirement for an evidence base and modelling system to quantify the major water balance terms and then objectively plan for climate, infrastructure,

development, taking account of Sindh's water entitlement/share according to interprovincial water accord.

- The above measures would lead to an increase in water use efficiency – both at the irrigation system level to supply the right amount of water at the right time, and at the crop level to get optimum productivity per unit of water input.
- Sindh province has a large coastline. Government policy to promote desalinisation of sea water may provide an additional water sources in the province. Brackish water desalination should be considered as a potentially cheaper alternative.
- Climate change research should be incorporated into municipal and industrial water planning, with assessment of climate change impact on future demand (Haque et.al., 2015). Water treatment facilities should be prepared for possible water quality deterioration in climate change induced floods and droughts. This may include water quality monitoring, complementary treatment steps and process control even for small supply systems. More generally, wastewater reuse should be considered as an option, and is part of an integrated basin approach described in the second dot point above.
- Adaptation planning is broader than basin planning, and includes strategies for changing social determinants of vulnerability to climate change, such as those identified by Malik et al. (2012) who identified the cotton-wheat zone in Sindh as a priority area for adaptation planning. This area has low adaptation capacity. Salik et al. (2015) identified Thatta as particularly vulnerable.
- Adaptation planning is necessarily cross-sectoral and requires system-level understanding and coordination so that actions in one sector do not inadvertently undermine the goals being pursued in another sector. Best practice in adaptation planning involves multi-sector participatory engagement with scenarios tailored to local conditions and stakeholder interests. See Kebede et al. (2018) for an example of such an approach used to explore mitigation and adaptation options for deltas in South Asia, which could be considered for Sindh.
- Managed aquifer recharge is frequently mentioned as an approach for Pakistan (e.g. Qureshi, 2011), but generally with the Punjab in mind. The groundwater salinity issues in Sindh may limit this option, though it may be worth considering in some locations where salinity is less serious.

Key trends/learnings and/or knowledge gaps for detailed assessment

- The key learning is that no single policy or development (such as a new dam) will alone solve the water resources and agricultural production problems of Pakistan. An overall basin approach is required for water resources, agriculture and food policy, planning and management. This was a major conclusion of the recent International Symposium on Creating a Water-Secure Pakistan held at the Law and Justice Commission of Pakistan, Islamabad, 19-20 October 2018.
- The key knowledge gaps are the required steps and their sequence to effectively implement an overall basin approach with demand management. The Australian experience of water reform is a useful lesson, but will require adaptation to work with Pakistani history and experience.
- The overall approach should be based on adaptive management to cope with the uncertainty in climate change projections, as well as uncertainties in future demand and water use in Pakistan resulting from the growing population and increasing economic output of Pakistan.
- A quantified understanding and knowledge of snow and glacier melt flow contributions in major tributaries of upper Indus is required. Detailed tracer studies and hydro-climate monitoring network can help address these knowledge gaps.
- Improving short, medium and long term weather forecast services.
- Water quality monitoring and careful disposal and management of urban and industrial wastage.
- Governance can be improved. Even the best designed policies in Pakistan may not translate into effective implementation. For example, Memon and Thapa (2016) point to significant institutional challenges in implementing the mangrove protection adaptation measures in the Government of

Pakistan National Climate Change Policy. Similarly, integrated water basin management will require water governance reforms. Further institutional analysis and change will be a necessary part of effective adaptation.

How the work proposed in Part 2 will address the issues above

- The proposed work will allow an assessment of both the supply side and demand side options, through the scenario exploration described in Part 2. The options will impact all the aspects discussed in a. to e. above – water supply, crop production, waterlogging and salinity, greenhouse gas emissions, agricultural livelihoods, the environment, and urban and industrial supply.
- The proposed work will allow an assessment of the effectiveness of the options in relation to both projected climate change impacts and development impacts (growing population, etc.).
- As noted in a. above, the proposed work cannot reduce the underlying uncertainty in GCMs and the projected changes to temperature, rainfall and river flows.
- While CSIRO anticipates that the SWACR project will have a stakeholder engagement component, the proposed work does not include the broader social planning and multi-sector participatory engagement noted above.

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(Note: not all references are cited directly in the text, but all substantiate points made in the text.)

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Part 2: A general approach for a more detailed assessment of climate impacts and their relationship to the proposed Sindh Water and Agriculture Climate Resilience Project

Assuming that the concept note leads to the next phase of a detailed proposal, a more detailed assessment of climate change impacts and potential adaptations (ie the six areas a. to f. above) will be required.

CSIRO is already undertaking work (though not specific to Sindh and not to the level of detail required for a Sindh study) in the areas of:

- climate change projections for the Indus basin (and other areas of South Asia) (including work published in Charles, 2016, and Zheng et al., 2018, and the datasets published in Zheng, 2016)
- river flows (Charles et al., 2018; Stewart et al., 2018)
- water balances (including groundwater use) in the districts and canal commands of Pakistan (Kirby et al., 2017, and crop water demand work currently under revision with a journal)
- crop area, types and water use, including some assessment of the economics of crop production (somewhat covered in Kirby et al., 2017, and the datasets published in Kirby and Ahmad, 2016; see also the cropping system modelling tool at https://research.csiro.au/sdip/?ddownload=312).

This work could be readily extended to provide greater detail in the Sindh.

The general approach in our work is to establish an understanding of the issue (which includes consultation with stakeholders), assemble the available data, develop (an) appropriate model(s), and then use the model(s) for scenario exploration.

In the context of the proposed SWACR Project, we propose to use a simple spreadsheet water balance and a detailed numerical river model, the Indus River System Model (Stewart et al., 2018). The water balance spreadsheet was developed at CSIRO as part of our current project. It is based in part on an analysis of the historic trends over the last 30 years or more in the areas and types of crops, their productivity and their implied water use. This includes remote sensing assessments of land use and spatial crop evapotranspiration from 2000 onwards, which could become part of this project. We are using it to investigate the groundwater use in the canal commands of the Indus Basin Irrigation System, including the projected impacts on use of climate change and changes to demand resulting from changes to the areas of irrigated crops. We propose to develop this investigation in greater detail for Sindh; we would expect also to focus more on the surface water supply and use for Sindh, since groundwater use is less there than in the Punjab. The river model was also developed at CSIRO as part of our current project. We are using it to investigate water supply and distribution issues, including the potential impact of new infrastructure on supply and distribution. We propose to extend the model to give greater detail in Sindh, including adding more definition to the canals and hence diversion of water to the irrigation districts. This would be done for one canal command initially, with other canal commands to be added later if the initial results are useful. With the model thus upgraded for Sindh, we propose to investigate the impacts on Sindh (initially one canal command) of various scenarios, including climate change. Our work with the river model in Pakistan to date has involved much capacity building and the transfer of the model and knowledge to Pakistan institutions and users; potentially, some capacity building might also be considered in the development of the river model for Sindh studies.

The river model simulates the river flows from the rim stations onwards. The amount of water reaching the rim stations from the Upper Indus basin also requires assessment. Within the timeframes available for the next phase, this will be done only at a coarse level. There is great uncertainty in the literature over key factors such as the amounts of river flow that are due to rainfall directly, due to snowmelt, and due to glacier melting. This is an area of ongoing detailed research by several international institutions. The impact of climate change on the flows from the Upper Indus basin is, as a consequence, most uncertain, and is also the subject of much ongoing research. Therefore, a coarse level, indicative study is appropriate.

The two models are complementary. The river model, combined with indicative assessments of flows out of the Upper Indus basin, is used to assess how much water will reach irrigation areas (canal commands) and how this will be impacted by climate change and water resources development. The water balance model is used to assess the changing balance of supply and use within an irrigation area (canal command) under the chosen scenarios. Together, they thus allow assessment of the impact of changes of supply, which occur largely outside Sindh, and the impacts and options for adaptation within Sindh.

We propose that the details of the scenarios should be developed in discussion with the World Bank, to ensure that they are targeted to the Bank's proposed developments. However, we expect that the scenarios would include the following:

- Climate change scenarios, in which we would explore the dimensions of greater precipitation and greater potential evapotranspiration (ie greater water demand), both for flows from the upper Indus (with the river model) and for the climate in Sindh (with the water balance model). We propose to use a climate scaling factor approach, as already used in CSIRO and described in Zheng (2016) and Zheng et al. (2018). As noted in Section a. of Part 1, not all GCMs appear to be useful for Sindh; a more detailed assessment of which GCMs are suitable could be incorporated into this area of work. If desired, we can readily supplement the approach with other generated climate change input data, such as the downscaled results developed by the Pakistan Meteorological Department (with which we have contact).
- Population and development (increasing urbanisation, industrialisation and wealth) scenarios, leading to greater water demand both directly (for drinking water) and indirectly (through food and hence irrigation water demand). We have used some relevant scenarios in earlier work (Kirby et al., 2017), but would anticipate supplementing them with scenarios more specific to the Sindh study.
- Policy / management option scenarios, demand side measures such as a changed crop mix (as outlined in section f of Part 1), supply side measures (as outlined in section f of Part 1), more efficient and effective water distribution for irrigation, or installing a drainage system. Water reforms such as water pricing could also be investigated. We have assessed some scenarios both in the earlier work of Kirby et al (2017) and in unpublished work using the Indus River System Model. Again, we would anticipate supplementing them with scenarios more specific to the Sindh study.

The assessments outlined could be done for the whole of Sindh, and could also be done at a more detailed level for a single canal command. At the canal command level, there would be a need for more detailed data (such as canal flow data) than we have worked with to date. How much can be achieved in the timeframe envisaged for the next phase will be determined by the availability of such data.

The assessment of such scenarios will support the development of a provincial water plan. It will also help the assessment of climate smart and high value agriculture systems (as envisaged by the World Bank), by looking both at the potential impacts of climate change and other scenarios, and at the adaptation options such as changing crops (as further discussed in Part 3). It will also help the assessment of distribution and use of irrigation water, as discussed further in Part 3. Model development and use is complementary to the development of a hydroinformatics system, as discussed in Part 3 below. Water information helps develop, calibrate and use a hydrological model, and a model can highlight areas where the informatics base can be improved. A hydroinformatics system would require a lead agency other than CSIRO, and would also take considerable time to build. It is therefore not part of the proposed work in the next phase.

The work outlined above forms the main part of the proposed work for the next phase. In other areas, we propose a more limited effort. We do not currently have much effort (in Pakistan) in the areas of waterlogging and greenhouse gas emissions, the Sindh environment (including the delta) or urban issues. In all these cases, work elsewhere could be transferred into Sindh, but it would require some time to establish a record of experience within Pakistan and Sindh. For the next proposal phase of the SWACR Project, therefore, we propose that our main contribution on these issues would be through literature survey and design of potential project activities. The impacts of sea level rise in the delta region would also be through literature survey and design of potential project activities. The work in all these areas is essentially an expansion of what we have described in Part 1.

In the proposed work, we have not suggested any particular decision-making framework. Rather, we see the work as providing input to the World Bank's / Government of Sindh's decision-making. The proposed work is compatible with the World Bank's Water Global Practice Decision Tree Framework (Ray and Brown, 2015). However, we note below some work of CSIRO's Climate Risks and Resilience Group, which is a framework for designing a project well suited to the SWACR Project, and which could be used as an alternative approach.

The Climate Risks and Resilience Group in CSIRO Land and Water specializes in climate adaptation planning, using well-tested methods and tools to identify what the most impactful interventions are likely to be given rapid global change and the uncertainties around it. Their work suggests that many existing adaptation actions are unlikely to achieve much benefit in the long run, but more impactful interventions are possible and can be identified using the new techniques developed by the Group. These approaches are most effective when co-developed with relevant stakeholders who bring knowledge and experience from multiple perspectives. Examples include:

- Building capacity for sustainable and responsible development in the Bismarck Sea, Papua New Guinea (https://research.csiro.au/bismarcksea/)
- Making 'resilience', 'adaptation', and 'transformation' real for the design of sustainable development projects in Ethiopia (https://research.csiro.au/eap/piloting-rapta-for-design-of-sustainable-development-projects-ethiopian-case-studies-for-food-security/)
- Supporting an assessment of Australia's vulnerability to natural hazards in a changing climate (https://doi.org/10.25919/5bc778a6a4d34).

Finally, it should be noted that, while CSIRO anticipates some stakeholder engagement, and perhaps also some capacity building, as part of the above work, Australian Government protocols regarding travel of government agencies and staff restricts the potential for this. We require security authorisations and, usually, travel in bullet-proof vehicles; this requires advance warning, and clearance is not guaranteed for more sensitive areas. Limited travel to major centres such as Karachi and Hyderabad is easier to arrange.

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Part 3: Brief comments on three specific areas of the World Bank's Preliminary Concept Note

a. Informatics (subcomponent 1.5)

Good water information is key for: judicious infrastructure investment, accurate and timely flood warnings, prudent environmental flow allocations, fair pricing and equitable sharing of a scarce resource, greater efficiency in water use and properly functioning water markets.

Recognising the need for good quality (standardised and quality assured), timely and easily accessible water datasets and value-added water information products and services for the nation, under the 2007 National Plan for Water Security (~AU$10 billion – later became AU$13 billion), Australia has invested over AU$400 millions over ten years to improve water data and provide a range of value-added water information products and services for the nation. An independent study found that after only a few years, the program had conservatively yielded a benefit/cost ratio of between 2:1 and 8:1, and that the benefits are expected to increase in future.

Pakistan operates one of the largest continuous irrigation system in the world and collects datasets (though limited) on climate, flows, irrigation diversion, agricultural areas and production, hydropower generation, groundwater, surface and groundwater quality…etc. Most of the collected datasets in Pakistan (including in Sindh) are not well-managed, or quality assured or readily available to support robust decision making. This leads to mistrust between different stakeholders.

As part of CSIRO's work in water resources in Pakistan, we have collated and cleaned some datasets, such as the nationwide data on district level crop areas (Kirby and Ahmad, 2016). We are also actively using remote sensing datasets to develop time series estimates of actual evapotranspiration at high resolution across the Indus basin in Pakistan. This is a key input to our water balance work which we are pursuing at district and canal command level. We are also, with key collaborators in Pakistan, actively developing and using an advanced river flow model, based on the Source modelling platform. We are also actively supporting the implementation (by Kisters) within WAPDA of the Hydstra hydrological data management system for Pakistan.

Based on this experience, we suggest that, in tandem with improving the monitoring network in Pakistan in particular for Sindh, immediate actions are required in the following areas in all water jurisdictions:

- time-series data management systems (like Hydstra) and associated IT infrastructure
- data standard development and implementation: this will entail:
  - establishment and adoption of appropriate standards and terminology
  - development of practical field operational procedures
  - establishment of processing procedure including QA and QC process
  - auditing of application of the standards and procedures
- increasing the density of meteorological station network
- considered data collection activities (network design, remote data collection technologies and methods, instrument installation, calibration and maintenance procedures, field data collection and processing procedures, data dissemination and data use)
- near real-time online data climate and hydrological sharing
- improving short, medium and long term weather forecast services
- include cropping patterns, ET, tracking soil moisture, water balance
- include flood and drought monitoring

- appropriate institutional arrangements
- establishment of a profession for water data collection.

Informatics platforms can be designed to be able to accommodate a broader suite of measures and indicators that are suitable for assessing resilience and adaptive capacity (e.g. see indicators used by Malik et al. (2012) for assessing exposure to climate change, sensitivity and adaptive capacity in Sindh), or for reporting on progress against multiple goals and objectives (e.g. compliance with Ramsar obligations, progress towards UN Sustainable Development Goals, indicators for IPBES assessments).

A complete hydroinformatics system, integrated into practice, is a long-term undertaking. The Australian experience is that it will well repay the investment.

CSIRO can help with the development of a hydroinformatics system, but a fully developed, comprehensive system will entail components and lead expertise from outside CSIRO – such as from the Australian Bureau of Meteorology, Kisters, and others.

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b. Climate smart and high value agriculture (subcomponents 2.3 and 2.5)

Climate smart agriculture integrates landscape management (of crops, livestock, forests and fisheries) to address food security and climate change.

Pakistan is using water unsustainably now; the growing population will increase the demand for water in the future and climate change is projected to increase the demand again. Yet Pakistan in general and Sindh in particular has several options for substantially reducing its current water requirements, thus enabling sustainable and climate resilient use well into the future. Some of the options could also result in higher value agriculture and lower greenhouse gas emissions. The options include:

- reducing the areas of high water use crops (in particular, rice, cotton and sugar cane) and increasing the areas of crops such as pulses, which are often of higher value and are also an important source of protein in the diets of poor people. (But note: since much cotton and rice is exported from Pakistan, there are trade implications which must be taken into consideration.) Achieving these benefits implies changes to agricultural policy and institutions. International experience (including Australian experience) suggests that a market approach, free of distortions such as subsidies, is a robust solution. Implementing such a solution takes time.
- improving the effectiveness of water delivery for irrigation – this includes:
  - improvements to seasonal climate forecasting, enabling better matching of the planting of crops to the expected water availability
  - water policy reform, possibly including pricing, to provide the right institutions and incentives to promote more effective use of water, a move to higher value crops, and greater system-wide resilience to major climate shocks such as droughts. The Australian experience with water reform provides evidence that all these benefits may be realised – but it also shows that water reform is a long, hard journey.
- more effective water distribution and use – covered in next section.
- drainage to reduce waterlogging, improve productivity and reduce greenhouse gas emissions.
- research and extension to promote higher crop productivity, higher water use efficiency at field, farm and irrigation district scale. Crop productivity in Sindh, and in Pakistan more generally, is lower than expected from international comparisons, including comparisons of similar areas in nearby India.
- Farm mechanisation and promotion of resource conservation technologies.
- research to evaluate the feasibility of farm fish production/aquaculture potential and, if feasible, its promotion.

Several of the dot points above can be addressed in the next phase of the SWACR project as part of the water balance and river modelling assessment outlined in Part 2.

A note of caution is in order. As we have outlined, a key component of 'climate smart' agriculture is the more effective use of the available water resource. This in turn is partly about increasing the efficiency of water use. It is generally assumed that increasing the efficiency of water delivery and field application will decrease water use. However, Perry and Steduto (2017) point out that this is generally not what happens; water use often increases with greater delivery and application efficiency. In the context of the Sindh, it might be expected that an improvement in water use efficiency will release water for urban use. The key learning from this and other similar studies is that careful attention must be paid to the institutions involved in water allocation and use, and controlled quotas may be required.

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c. Service, distribution and use of irrigation water (subcomponent 3.2)

Sindh has fairly large accounted water differences (losses) between different headworks which leads to waterlogging and secondary salinisation. It appears that there are opportunities to reduce this through efficient operations of headworks.

The Indus River System Model (Stewart et al., 2018) or other river system modelling studies could assist in identifying the operational procedures which could lead to efficient water delivery system and explore hydropower potential at various headwork.

Training of hydrographers will help to promote standardised data collection, processing, management/storage and sharing. This in turn will lead to identifying and helping solve areas of inefficient delivery and excessive losses. This is a counterpart to the development of an informatics capability.

The distribution and use of irrigation water will be promoted by:

- water reform in irrigation districts – pricing, water trading, conjunctive use (minor issue in Sindh) – an area in which Australia has much experience
- re-design of distribution systems to remove the pancho irrigation system (Aslam and Prathapar, 2001, van Steenbergen et al, 2015)
- provision of en-route storages at watercourse or distributary level and High Value Horticulture Systems– an area in which Australia has experience from Murrumbidgee Irrigation.

With respect to the former, the Australian experience is that water reform is a long, and sometimes hard journey (Connel and Grafton, 2011).

The work outlined in Part 2 will help with this assessment.

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