Queensland **the Smart State**

# Guidelines for constructing and maintaining aquaculture containment structures

**Queensland** Government

PR07–2840

The Department of Primary Industries and Fisheries (DPI&F) seeks to maximise the economic potential of Queensland's primary industries on a sustainable basis.



In these guidelines a containment structure is defined as earthen containment or proposed containment—whether permanent or temporary—designed to contain, divert or control liquids. Typical containment structures for aquaculture include intake reservoirs, supply and discharge channels, production ponds and water treatment ponds. However, fabricated or manufactured tanks or containers designed to a recognised standard are also containment structures.

**The Department of Primary Industries and Fisheries would like to acknowledge the assistance of the Queensland Aquaculture Industry and the significant contribution made by departmental representatives on the working group, including representatives from the Department of State Development, the Department of Natural Resources and Water, and the Environmental Protection Agency.**

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# Using these guidelines

These guidelines have been prepared to assist proponents of pond aquaculture enterprises to assess the requirements for constructing ponds and supply and discharge channels. The guidelines will also help others involved in construction, such as contractors, consultants, project managers and regulators.

The guidelines are based on risk assessment, and offer advice and recommendations for appropriate action based on the level of risk identified.

- Section 1 explains the issues involved in the risk assessment.
- Section 2 explains the factors to be considered in site selection and risk assessment.
- Section 3 explains how to conduct the risk assessment to identify the level of risk involved in a proposal.
- Section 4 provides information to help proponents prepare a site assessment report to support a development application that includes information supporting the risk assessment.

Subsequent sections and the appendixes provide additional information about the design, construction and monitoring requirements. In some cases, these requirements are determined by the level of risk identified.

# 1. Introduction

## 1.1 Background

Pond-based aquaculture is a significant industry in Queensland that offers real environmental, economic and social benefits. Aquaculture containment structures may include intake reservoirs, supply channels, production ponds, discharge channels and water treatment ponds. Usually, aquaculture is undertaken in earthen ponds 1–2 metres (m) in depth formed by a combination of cut and fill earthworks,

However, the state government and the aquaculture industry acknowledge that there are inherent risks in storing water in aquaculture containment structures, that all earthen ponds have the capacity to leak, and that this can affect groundwater or adjacent environments.

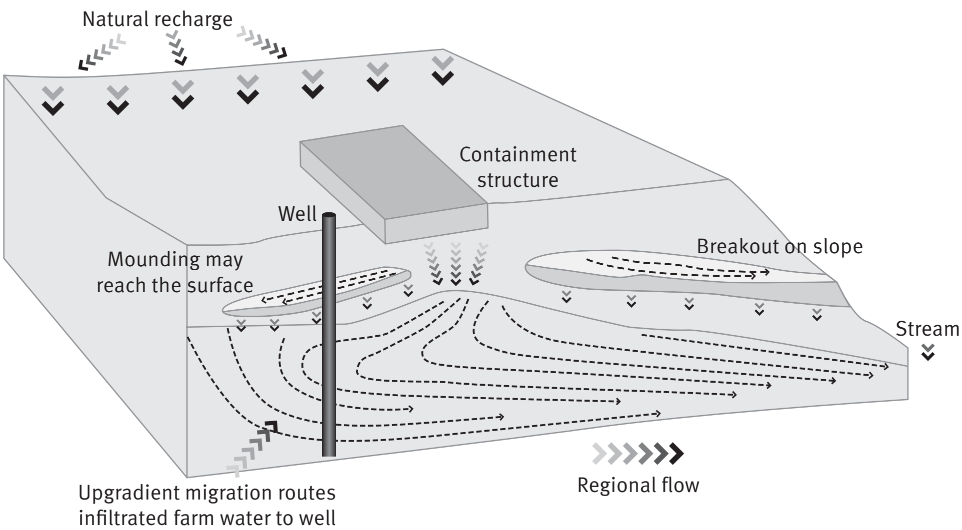
Water stored in aquaculture ponds is often characterised by biological and chemical properties that differ from those in natural surface or groundwater. Poor design, construction and maintenance of aquaculture containment structures may result in vertical or horizontal flow into soil and groundwater, or embankment failure. This may cause:

- localised increases in the groundwater level
- impacts on groundwater quality (salinity or nutrients)
- waterlogging
- vegetation dieback.

(See **Figure 1.**)

In addition, storing large volumes of water above the watertable may result in 'mounding' of the watertable in proximity to the farm. This mounding may not necessarily indicate excessive leakage, but may be due to complex interaction between hydrostatic pressure and hydraulic resistance in the aquifer.

**Figure 1: Conceptual model of the risks associated with the storage of water in containment structures (Source: adapted from Poeter et al. 2005)**




These factors need to be considered in the overall context of ecologically sustainable development. To this end, the state government and the aquaculture industry are committed to minimising the risk of environmental harm, and have worked in partnership to develop these guidelines.

## 1.2 Purpose

Regulatory agencies and individual landholders have spent much time addressing concerns about the impacts of unsatisfactory performance of containment structures on adjacent properties and groundwater aquifers. Historically, construction standards for aquaculture ponds have been determined on a case-by-case basis and have not been consistently applied across Queensland. When complaints are lodged about the impacts of unsatisfactory aquaculture containment structures, it may take significant time and money to investigate and identify the causes, and remediate adjacent properties or groundwater.

Through the multi-agency Aquaculture Inter-Departmental Committee, the Queensland Government identified the need for a consistent approach to the construction and maintenance of aquaculture containment structures. These guidelines provide technical guidance to aquaculturalists, contractors, consultants, project managers and regulators involved in the construction or assessment of aquaculture facilities. Also, they include information to assist aquaculturalists undertake environmental monitoring to verify that containment structures are performing appropriately and the potential for environmental harm is minimised.

## 1.3 Scope

These guidelines refer to the design, construction and maintenance of low height (‹4 m wall height) aquaculture containment structures to minimise the potential for environmental harm from unsatisfactory performance. In applying these guidelines, other factors need to be considered, such as access to water, flooding, separation distances to adjacent residences and disease management. These factors are critical to the successful planning and operation of aquaculture facilities. While these issues are not covered by these guidelines, it is strongly recommended that aquaculturalists attend whole-of-government meetings as early as possible to ensure that they identify significant issues.

Where the location and size of a containment structure is such that its failure might threaten human life, the structure is likely to be a referable dam under the *Water Act 2000*. In that case additional dam safety requirements will almost certainly apply. For up-to-date information on the requirements for referable dams, contact your regional Department of Natural Resources and Water office or visit the website at ‹www.nrw.qld.gov.au›.

The information in these guidelines is based on established engineering principles; however, the recommended methods may be revised from time to time, as new ones are developed. Where standards or other guidelines are referred to, consult the current version of the document.

Proposals involving alternative materials or methods may be appropriate where the recommended approach is equivalent to or exceeds the recommendations in these guidelines.

# 2. Site related factors to consider in risk assessment

Selection of an appropriate site for aquaculture development is critical to the success of the operation and ensures that the potential for environmental harm is minimised. When selecting a site, consider the following factors to minimise problems with containment structures.

## 2.1 Topography

Consider the topographic relationship between the development area and adjacent sensitive environments and land uses. There is likely to be a greater risk to properties down-slope of the proposed farm area, so the nature of the land use on these properties should be carefully considered. Where practical, provide greater separation distances to sensitive areas down-slope of the development area. While the surface slope is not necessarily indicative of the direction of groundwater flow, it provides a good 'rule of thumb'. Baseline monitoring of groundwater levels may confirm the direction of groundwater flow.

Flat coastal plains or sites where the ground level is less than approximately 5 m Australian Height Datum (AHD) may require treatment for soft organic, sandy or acid sulfate soils (see **Section 2.5**) and this could involve significant costs.

## 2.2 Geology

Site geology is an important consideration in site selection. Shallow bedrock may interfere with earthworks adding to construction costs. Also, rock outcrops intersecting with containment structures may be a major source of leaks as water can travel through cracks and fissures in the rock.

## 2.3 Soils

A low level of permeability is required to minimise the intrusion of saline and/or high nutrient water into the watertable or aquifer. Preferred sites for pond-based aquaculture would have sufficient in situ material to construct ponds to a high level of structural stability and impermeability. They would also be underlain by a consistent layer of low permeability soils. Suitable material characteristics may be obtained through one or both of the following:

- over-excavation and back-filling with suitable material obtained from borrow pits in proximity to the site
- mixing of heterogeneous materials from multiple sources or layers to produce a homogeneous material suitable for pond construction.

Further information on problematic soil types is included in Appendix 1.

In the absence of suitable material on site, or in close proximity, haulage of material from off site may be required. Otherwise, alternative pond construction techniques involving the use of impervious pond liners such as concrete or plastic may be necessary. Consider these factors carefully, as long-distance haulage of materials or using synthetic lining for ponds may impose a significant financial cost, affecting the financial viability of the farm. It could also create other hazards such as increased risk of drowning.

## 2.4 Groundwater

When selecting a site consider the following attributes of the groundwater:

- depth
- quality
- direction of fbw
- resource value (see**Section 2.7**).

Consultation with local natural resource managers can be valuable in developing an understanding of local groundwater characteristics. So can the Groundwater Vulnerability Mapping, undertaken by the Department of Natural Resources and Water, which will help evaluate the risk of groundwater contamination. This dataset integrates a number of attributes of the geology, soils and groundwater to predict the groundwater vulnerability assessment at a regional scale. (For further information contact your local Department of Natural Resources and Water office or visit ‹www.nrw.qld.gov.au›.) Other valuable sources of information include local earthworks contractors, geotechnicians and drillers who may have significant understanding of the groundwater environment and soils in the area.

## 2.5 Acid sulfate soils

Most coastal aquaculture sites are found in areas where acid sulfate soils may be present and the State Planning Policy (SPP2/02) lists all shires in Queensland with acid sulphate soil issues. The extent to which acid sulfate soils affect aquaculture operations remains the subject of industry debate. However, it is generally agreed that their presence should not be detrimental to the future viability of an operation, provided they are appropriately managed during the construction stage. The desirable range of soil as well as water pH for aquaculture is 6.5 to 8.5. A pH lower than 6 is considered too acidic for most aquatic animals, and acid sulfate soil leachate is commonly less than pH 4.

If acid sulfate soils are disturbed, the environment could be damaged and productivity could be significantly affected. Therefore, under the State Planning Policy 2/02: *Planning and managing development involving acid sulfate soils*, development proposals in coastal locations will need to demonstrate that potential acid sulfate soils issues have been adequately addressed. There are a number of related guidelines and for further information, contact your local Department of Natural Resources and Water office or visit ‹www.nrw.qld.gov.au›.

In coastal areas the State Planning Policy is applicable to all land, soil and sediment at or below 5 m Australian Height Datum (AHD) where the natural ground level is less than 20 m AHD. In these areas, the State Planning Policy will apply where the proposed development involves:

- excavating or otherwise removing 100 $m^3$ or more of soil or sediment
- filling of land using 500 $m^3$ or more of material with an average depth of 0.5 m or greater.

The presence of acid sulfate soils may require detailed management to minimise environmental harm during the construction phase and may also require a level of on-going management during the operations phase. The presence of acid sulfate soils will not in most cases preclude development, but the level of treatment required will need to be considered when assessing the economic feasibility of the proposal, as the cost of management may be significant.

## 2.6 Sensitive environments

Sites in close proximity to sensitive environments are likely to require more detailed assessment and management controls. Sensitive environments include:

- protected areas such as national parks, conservation parks and resources reserves
- significant coastal dunes
- significant coastal wetlands
- remnant vegetation
- freshwater wetlands.

Unsound containment structures may affect adjacent sensitive environments by causing problems such as:

- alterations to the hydrological cycle (wetting and drying) or water quality of freshwater wetlands
- vegetation dieback through waterlogging or salinisation
- changes in vegetation characteristics in response to changed soil properties.

## 2.7 Local and regional land use

When determining the level of risk posed by containment structures, aquaculturalists need to consider the characteristics of adjacent environments and the nature of land uses in neighbouring areas including:

- activities such as cropping and grazing
- local and regional use of the groundwater resource – the consequences of an unsound containment structure will be more significant in sites where the local or regional groundwater is used as a resource for agricultural, domestic or stock watering purposes or is within a declared groundwater management area.

## 2.8 Separation distances

The proximity of a containment structure to sensitive environments or land uses will affect the risk of environmental harm occurring should there be a problem with the structure. Where practical, the containment structure should be separated from sensitive environments by a reasonable distance. Determining separation distances (buffers) is discussed in more detail in **Section 5.5**.

# 3. Risk assessment

## 3.1 Risk assessment framework

Generally, this framework can be applied to a variety of circumstances; however, in this context it provides:

- a qualitative method for evaluating a number of sites and design options
- a process for evaluating the nature and magnitude of the threat (or series of threats) posed to other resources by a poorly constructed aquaculture operation.

It is important to use a clear and relevant framework to assess risk. Risk assessments examine the likelihood of an environmental impact and the consequences of that impact, and should include the certainty with which the level of risk can be assigned to a particular development. Once the level of likelihood and consequence for an action has been identified, an assessment matrix such as the one below can be used to determine the level of risk.

**Table 1 Risk assessment matrix**

| | | **Consequence** | | | | |
|---|---|---|---|---|---|---|
| | | Insignificant | Minor | Moderate | Major | Catastrophic |
| Likelihood | Almost certain | Medium | High | Extreme | Extreme | Extreme |
| | Likely | Medium | Medium | High | Extreme | Extreme |
| | Possible | Low | Medium | High | Extreme | Extreme |
| | Unlikely | Low | Low | Medium | High | Extreme |
| | Rare | Low | Low | Medium | High | Extreme |

The environmental consequences may be qualitatively described as follows.

**Table 2 Environmental consequences**

| **Descriptor** | **Environmental consequence** |
|---|---|
| Insignificant | No measurable adverse impact. |
| Minor | Small adverse impact on environment with no long-term effects. Insignificant and reversible change to local environment e.g. groundwater salinity or nutrient load. |
| Moderate | Some adverse impact on environment with no long-term effect. The impact is reversible. Measurable but reversible change to local environment e.g. groundwater salinity or nutrient load. |
| Major | Some adverse impact on environment with long-term effect. Measurable and irreversible change to local environment e.g. groundwater salinity or nutrient load or damage to offsite flora or fauna. |
| Catastrophic | Major adverse impact on environment with long-term, irreversible effects. Major off site effects or major damage to or death of off-site flora or fauna. |

The likelihood may be qualitatively described as follows.

**Table 3 Probability of impact**

| **Descriptor** | **Likelihood** | **Probability** |
|---|---|---|
| Almost certain | Is expected to occur in most circumstances | >0.95 |
| Likely | Will probably occur in most circumstances | 0.95 to 0.50 |
| Possible | Might occur at some time | 0.50 to 0.05 |
| Unlikely | Could occur at some time | 0.05 to 0.01 |
| Rare | Is highly unlikely to occur | <0.01 |

## 3.2 Undertaking the risk assessment

Section 2 lists characteristics of the site that should be considered in a risk assessment and included in the detailed site report (see **Section 4**). These characteristics are:

- topography
- geology
- soils
- groundwater
- acid sulfate soils
- sensitive environments
- local and regional land use
- separation distances.

In addition, the nature of the proposed operation will determine the level of risk of environmental harm. The following questions should also be considered:

- Is the production system different in salinity from the underlying groundwater?
- What is the proposed intensity of operation? (This may affect the nutrient load in the production waters.)
- What is the time period of the production season?
- What is the scale of the proposed operation? (The greater the volume, the greater the potential impact of leakage.)

A risk assessment should evaluate farm layout and options to achieve the best practicable design for the proposal and should be based on the design standards and management strategies that are to be adopted. Based on the risk assessment, actions that result in serious, large-scale or long-term consequences such as serious contamination of regional groundwater or complete alteration of ecosystem functioning, would normally be considered to involve a high or extreme risk, even if it is unlikely that the action will occur. In contrast, actions with minor, transient or localised impacts, such as temporary or reversible damage to ecosystem functioning would generally involve low or medium risk.

The following generalised examples further detail how the categories may apply to various consequences in the risk assessment process:

**Low risk**

- Containment area ‹50ha
- Freshwater aquaculture
- Soils suitable (e.g. clayey sands (SC), inorganic clays (CL))
- Regional groundwater unsuitable for other uses
- Sufficient separation distance to sensitive environments

**Medium risk**

- Containment area ›10ha
- Marine aquaculture
- Soils suitable (e.g. clayey sands [SC], inorganic clays [CL])
- Regional groundwater saline or unsuitable for other uses
- Sufficient separation distance to sensitive environments
- Containment area ‹50ha
- Freshwater aquaculture
- Soils suitable (e.g. clayey sands [SC], inorganic clays [CL])
- Regional groundwater used for irrigation or potable water
- Sufficient separation distance to sensitive environments

**High risk**

- Containment area >5ha
- Marine aquaculture
- Soils suitable (e.g. clayey sands [SC], inorganic clays [CL])
- Regional groundwater used for irrigation or potable water
- Sufficient separation distance to sensitive environments

**Extreme risk**

- Containment area >5ha
- Marine aquaculture
- Soils unsuitable (e.g. poor-grade gravel [GP])
- Regional groundwater used for irrigation or potable water
- Sensitive environments in close proximity

## 3.3 Applying the outcomes of the risk assessment

Use the outcome of the risk assessment to determine the acceptable permeability performance of the pond liner. See **Appendix 4** for a discussion of calculations for permeability, time of passage through the liner, and loss from a pond.

The criteria for acceptable risk are as follows:

**Extreme risk**[1] – zero loss[2]

**High risk** – zero loss over the maximum likely filled period of the containment structure

**Medium risk** – <1 ML/ha loss over the maximum likely filled period of the containment structure

**Low risk** – <5 ML/ha loss over the maximum likely filled period of the containment structure

**Table 4 Predicted time for pond water to pass through liners with different thickness and permeability* and relation to acceptable risk**

| Risk category | k (m/s)[1] | Minimum thickness required for 180-day fill period (mm) | Minimum thickness required for 150-day fill period (mm) |
|---|---|---|---|
| High | 2e-8 | 1760 | 1560 |
| | 1e-8 | 1120 | 990 |
| | 5e-9 | 730 | 650 |
| | 2e-9 | 430 | 390 |
| | 1e-9 | 290 | 260 |
| Medium (<1 ML/ha) | 2e-8 | 1560 | 1360 |
| | 1e-8 | 930 | 820 |
| | 5e-9 | 560 | 490 |
| | 2e-9 | 290 | 250 |
| | 1e-9 | 170[2] | 140[2] |
| Low (<5 ML/ha) | 2e-8 | 940 | 780 |
| | 1e-8 | 470 | 390 |
| | 5e-9 | 230 | 190[2] |
| | 2e-9 | 90[2] | 80[2] |

* Assumes water depth of 1.5 m and growout period of 180 days.

1 1 mm/day equals 1.16 x $10^{-8}$ m/s

2 Minimum liner thickness of 200 mm is to be used.

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1 Additional measures to those outlined in these guidelines are likely to be necessary for secure containment. An earth lined structure is unlikely to be acceptable.

2 Loss in this context is water used to fill any containment structure for the growing/holding of any aquaculture product during any normal production cycle.

# 4. Detailed site investigation

## 4.1 Site topographic survey

It is recommended that a suitably qualified person be engaged to undertake a detailed site survey. This should be based on an appropriate grid with an additional survey in areas of significant variation. Typical vertical accuracy should be ±0.01 m to enable the preparation of materials budgets and engineering drawings.

## 4.2 Site geology

Geological conditions form an important part of a site investigation as the presence of shallow bedrock can interfere with construction. Rock outcroppings are also a major source of leaks in containment structures, as water can travel through cracks and fissures in the rock, rapidly lowering water levels and potentially causing rises in local groundwater levels. The following geological information should be provided as part of site investigations:

- regional geology and structure
- geological conditions at the site, highlighting any geological structure, hazards or potential problem areas
- geological sections that allow an interpretation of the stratigraphy
- geological mapping where rock structure or geological features are evident.

## 4.3 Site soil survey

### 4.3.1 Purpose

If aquaculturalists do not have detailed information on the engineering properties of the site soils, a suitably qualified engineer or soil scientist should be engaged to undertake a detailed survey of the site soils as part of the risk assessment process. The investigations should establish whether:

- the soils on site are suitable for the construction of containment structures
- soils will need to be imported
- artificial materials will be required to control or manage the quality of leachate, groundwater levels, seepage, erosion, settlement or stability.

It is often cost-effective to simultaneously undertake an acid sulfate soil assessment in accordance with the Queensland guidelines. For more information, contact your local Department of Natural Resources and Water office or visit ‹www.nrw.qld.gov.au›.

### 4.3.2 Minimum soil testing requirements

The investigation program should identify the soil profile and strata, the particle grading relevant to each of the strata, the classification of the soils in the strata plus other relevant physio-chemical parameters. Except as otherwise indicated in AS 1726 *Geotechnical site investigations*, the minimum investigation requirements should include:

- the properties of the foundation materials in containment areas.
  (Each major soil type and distinctive soil layer should be sampled. Depth of sampling should be a minimum of 1.0 m below the deepest intended excavation in the project area to assess for changes in lithology. Soil data should identify soil stratification throughout the containment area, beneath the embankments, along the routes of any channels, storage areas and at the site of any other proposed containment structures)
- the properties of the materials to be used in the embankment fill
- the permeability of the fill materials to be used in containment structures
- the settlement properties of the foundation materials if there is a risk of settlement during or after construction
- the strength properties of the foundation and fill materials.

The survey should be undertaken based on an appropriate grid with additional survey holes in areas of significant variation. The minimum recommended sampling frequency is included in **Appendix 2**.

Appropriate soil sampling, collection and preservation techniques are important in ensuring the soil analysis results are representative. Factors that should be considered are:

- sampling locations, pattern, density and depths
- tests on any soils imported to the site
- sampling devices and equipment (e.g. auger type)
- method of sample preservation.

All soil testing should be undertaken in accordance with AS 1289 *Methods of testing soils for engineering purposes*. Acid sulfate soil testing should be in accordance with the *Acid sulfate soils laboratory methods guidelines* (see ‹www.nrw.qld.gov.au›). Soil testing requirements are outlined in **Appendix 2**.

#### 4.3.3 Soil classification

Each soil type listed in AS 1726 *Geotechnical site investigations* is associated with an engineering property range. These soil types may be correlated roughly with engineering properties for the soils. These correlations are approximate only and should be used with extreme care. Soil engineering properties should be assessed by a suitably qualified engineer. The *Queensland small embankment dams guidelines* (Draft) may be used to guide the assessment of the potential engineering behaviours of the various soil types and their beneficial use (see extract in Appendix 3).

### 4.4 Groundwater survey

The objective of the groundwater survey is to develop an understanding of the existing groundwater characteristics including the depth of groundwater aquifers, quality of the groundwater and direction of flow. Regional groundwater is often complex and, in a large site, may include perched and confined aquifers and other complex variations. It is strongly recommended that expert advice is sought on the groundwater investigations and the design and installation of monitoring bores.

Where practical, undertake baseline groundwater monitoring to establish the natural variation in groundwater characteristics including:

- daily variation in groundwater level (e.g. due to gravitational or tidal influence)
- seasonal variation in groundwater level or quality
- response of groundwater to local or regional rainfall (recharge).

For further information see **Section 6**.

The limited knowledge and variability of sub-surface materials means a lengthy period of observation is often needed for an understanding of groundwater behaviour. Therefore, groundwater monitoring should start as early as possible in the life of the project. This will ensure that, if allegations are made about the unsatisfactory performance of containment structures, the information about groundwater behaviour is as comprehensive as possible.

## 4.5 Site assessment report

Site assessment reports should be supported by maps, site plans and aerial photographs where practical and include the following information:

- Site description – a description of the site and surrounds including topography, land use, watercourses and drainage and the location of sensitive environments.
- Soil survey – a description of the site soils including the location of soil sampling and the properties of the soil including an assessment of whether soils on site are suitable for the construction of containment structures.
- Groundwater survey – a description of the regional and site groundwater characteristics including the location of groundwater monitoring bores, the depth to groundwater and the characteristics of the groundwater (chemical properties, daily and seasonal variation).

The level of detail required for the mandatory site assessment report will vary according to the risk assessment and may include advice not to proceed if the risk is extreme or high. Sites with a low or medium risk will require a less detailed report than those with a high or extreme risk.

# 5. Design

## 5.1 Farm layout

The design of aquaculture developments should consider the characteristics of the site and surrounding environment to minimise the risk of environmental harm from unsatisfactory performance of containment structures. Evaluate a number of configurations to achieve the layout with the lowest risk (in conjunction with other design considerations, such as water flow, noise, odour, flooding, stormwater runoff and acid sulfate soils). For example, site topography and the relationship to surrounding land use is an important consideration in the risk assessment. Where practical, design of containment structures should account for the risk of horizontal flow or overflow into adjacent properties.

## 5.2 Containment structures

### 5.2.1 Foundations

A number of design solutions are available for the formation of linings with low permeability, including:

- ripping and re-compaction of in situ clays
- engineered imported clay liners
- mixing with bentonite
- synthetic geo-membranes
- composite liner and leakage detection systems.

The type of low permeability lining required will depend on site properties, the sensitivity of the underlying aquifer and surrounding environment, and the level of risk reduction required to meet acceptable risk levels. Liners should be designed by a suitably qualified and experienced engineer, taking into account the seepage risks associated with the particular aquaculture and the site characteristics. In large or complex sites, a range of design solutions may be required for different areas. Further detail on these design solutions are provided below.

**Ripping and re-compaction of in situ clays**

In situ clays should be ploughed and ripped to the required depth, and moisture conditioned and compacted in accordance with the design specifications. Suitable lining soils should extend deeply enough to ensure that construction, harvest activity or routine pond maintenance will not cut into a water permeable layer, resulting in leakage.

It is critical to establish a positive cut-off between the embankment walls and the floor of the ponds. Typical design solutions involve ‘keying’ the walls into the compacted floor.

**Clay lining**

Containment structures can be built in soils that have high percolation rates over the full area or part of the area, provided that some type of modification is undertaken, such as a layer of compacted clay, to reduce seepage. The liner thickness needs to have sufficient depth and impermeability to achieve the required performance standard. Provide sufficient depth to allow for possible desiccation cracking, which can significantly increase permeability.

The ongoing maintenance of the liner in growout ponds must also be considered, particularly when the ponds need to be drained, tilled and cleaned. This clay should be carefully chosen as some clays contain heavy metals, which can be toxic to cultured organisms.

**Mixing with bentonite**

Where containment structures are to be built in soils with high percolation rates, permeability may be reduced by mixing bentonite into the soil. The criteria for this approach would be similar to that required for a clay liner, i.e. the depth and permeability of the conditioned material should be sufficient to achieve the required performance standard. Building a containment structure where properly engineered bentonite modified soils are used is generally expensive. The ongoing maintenance of these in growout ponds should also be considered, particularly when the ponds need to be drained, tilled and cleaned. Take care not to damage the bentonite lining.

**Impervious geotextile liners**

Containment structures can also be built in soils with high percolation rates if impervious geotextile lining is used. Building containment structures where properly engineered impervious liners are used is generally expensive. Consider the following characteristics of geotextiles prior to use in an aquaculture setting.

- Those containment structures with thin lining material should be protected against birds that may puncture the liner with their bills while pursuing their prey. To avoid punctures, liners should be covered with soil.
- Thin liners may be punctured by plant sprouts along edges and embankment walls.
- Liners are slippery particularly when wet. This can create a safety hazard particularly where embankment slopes are steep.
- Pond liners may not work in some situations. Water pressure under the liner can force it completely or even partially away from the bottom or banks of lined structures. This problem can occur in areas where watertables rise near the surface or if springs are located near containment areas.
- Burrowing animals may tear plastic liners. Liners may also tear through normal activities within growout ponds (e.g. harvesting and aerator placement). Consequently, they may need regular repair or replacement.
- Some geotextile liners contain chemical additives that are easily leached and are toxic to cultured organisms and nitrifying bacteria. When selecting a liner for aquaculture facilities, it is important to evaluate its toxicity prior to use. If it appears to be toxic, washing methods can usually be applied to remove toxins from the liner.
- Liners also reduce soil respiration so they can affect nutrient dynamics and can lead to the creation of anaerobic zones underneath liners, causing the build up of toxic gases and reduced compounds.
- Rusting of anchors within liners can pose a safety issue.

Where geotextile liners are used, they should be assessed for their longevity in accordance with the requirements of AS HB 154 – *Geosynthetics guideline on durability*. Periodic electrical testing of synthetic liners may be required after liners have been installed if your farm threatens sensitive aquifers or shallow groundwaters, or if acid sulfate soils are present.

### 5.2.2 Embankments

Aquaculture containment structures are usually trafficable surfaces, and it is recommended that walls are wide enough to ensure strength, stability and safe vehicular access. Walls should be surfaced with an appropriate material to reduce erosion and dust, scour, and improve trafficability during wet weather.

Protect external batters against erosion by establishing vegetation (native or crop species) and/or natural regeneration. This can be encouraged through the application of topsoil (which may be stockpiled for this purpose at the commencement of construction) and irrigation. The only plant suitable for helping to hold banks together is grass or small succulents because of their small size and shallow root systems. Deep-rooted vegetation on banks should not be planted or encouraged as this destroys structure and increases the potential for leakage. In the case of salt-water aquaculture projects, select appropriate species of salt-tolerant grasses.

Internal batters are typically not steeper than 1H:2V and are not actively revegetated. Erosion of pond walls can be minimised by using rock lining (rip-rap), synthetic liners or other materials such as geotextile fabric. Erosion control systems such as geotextile fabric or synthetic lining that may degrade and/or float free need to be securely fastened and routinely inspected to minimise the risk of entanglement in equipment.

If erosion control systems are likely to prevent a person from safely exiting the containment structure (in the event that someone accidentally enters it), ensure that safe exit points are provided.

Where rock armouring is undertaken some problematic rock types are known including shales and mudstones – which may break down with time and not perform as expected – and rocks containing harmful minerals or that generate acid. It is advised that these types of armouring materials should not be used.

### 5.2.3 Freeboard

An appropriate freeboard is required to minimise the risk of overtopping of containment structures. Refer to the Department of Primary Industries and Fisheries policy FAMOP001 – *Management arrangements for potentially high-risk activities in the context of Ecologically Sustainable Development (ESD) for approved aquaculture operations*. When this report was prepared, the policy stated:

> **A freeboard height (distance from the water level to the lowest point on top of the wall) that is adequate to prevent overflow must be maintained in ponds used for aquaculture (Fig 2.2). DPI&F recommends a freeboard of at least 0.5 m.**

For current information, contact your local Department of Primary Industries and Fisheries office or visit ‹www.dpi.qld.gov.au›.

### 5.2.4 Inlet/outlet works

Farm inlet and outlet works may involve a pump or gravity-based system that will allow ponds to be filled and drained. Conduits passing through ponds have the potential to result in piping failure within embankments. Therefore, the design and construction of any inlet and outlet works will need to consider:

- erosion and scour around inlet
- compaction around pipes and the installation of collars
- protection from scour and erosion
- piping through walls in small embankments.

## 5.3 Intake and discharge points

Aquaculture operations may require the movement of large volumes of water around the farm. Intake and discharge points are therefore highly susceptible to erosion and scour, which may result in the loss of integrity of liners, undercutting of embankments and the suspension of sediments. A number of design solutions are available to minimise scouring and dissipate velocity. These include the use of baffles, concrete blocks, rock armouring and gabion baskets. Pay attention to the area around intake and discharge weirs, and pipes and culverts through walls where increased erosion may occur due to shear.

## 5.4 Buffer zones

This section presents a framework for assessing the potential for mounding and lateral mound movement, in the context of setting-appropriate buffer zones around land-based aquaculture farms. (Note: other factors such as noise, light and odour also need to be considered in the assessment of appropriate separation distances and are beyond the scope of this document.) Buffer zones provide separation between the containment structures and environmentally sensitive areas and beneficial land uses. Their purpose is to minimise the harm that unsatisfactory performance of containment structures may cause.

Hydrogeological evaluation of aquaculture containment structures is important because it establishes whether a site has sufficient capacity to assimilate water in excess of natural infiltration. Insufficient capacity may result in significant groundwater mounding on low hydraulic conductivity lenses and/or elevation of the underlying watertable. This may alter saturated flow directions. Aquaculture containment structures may cause the following adverse environmental effects:

- significant groundwater mounding or high elevation of the watertable, in relation to the ground surface (which may alter saturated flow direction or reach the ground surface, causing waterlogging or salinisation)
- lateral movement of water, which may result in off-site migration of dissolved contaminants – affecting nearby properties, water supplies or water bodies – or water breakout on slopes in the vicinity.

In general, mound formation that results in groundwater levels rising to within 2 m of natural ground surface beyond any buffer zone would indicate a design failure.

A number of methods are available for assessing the magnitude of mounding, vertically and laterally, and therefore the size and extent of buffer zones that should be set around aquaculture farms. In evaluating mounding and subsequent buffer zones, it is important to take into account that mounding is largely due to hydrostatic pressure effects, provided that losses from the ponds meet the guidelines associated with the risk level determined for each development. Methods used for determining buffer zones appropriate for recharge and seepage pits may not be appropriate for aquaculture containment structures. Seek the advice of a suitably qualified hydrogeologist or engineer to complete the proper investigations and evaluations required to determine the size and extent of buffer zones around farms. Buffer zones should be designed to protect groundwater resources and neighbouring land-users. Undertake assessment of appropriate buffer zones for all aquaculture developments where the risk is assessed as medium, high or extreme.

## 5.5 Engineering plans and drawings

In designing aquaculture facilities, the potential for unsatisfactory performance of containment structures and the advantages and disadvantages of a number of design options to minimise this risk should be considered. It is strongly recommended that a suitably qualified person is engaged to design the farm and prepare detailed engineering drawings. While this may represent a considerable up-front expense for smaller proposals, experience has shown that significant savings on construction and operating costs, and improved environmental management can be achieved by seeking professional advice on:

- earthworks staging
- material budgets (cut and fill)
- optimising the performance of the farm (water flow)
- construction standards for contracting purposes.

The engineering report should include:

- a description and evaluation of the proposed works giving due consideration to site constraints
- drawings and designs of the proposed works
- specifications of the proposed works that indicate the properties of the materials to be used in the construction of containment structures, and the standards to be met in the construction.

Prior to construction, submit the site assessment report (see **Section 4**) and engineering drawings to the administering authority (usually the local government authority) for approval.

# 6. Construction

## 6.1 Notification

It is recommended that the administering authorities (usually local government, Environmental Protection Agency, Department of Natural Resources and Water and Department of Primary Industries and Fisheries) are notified in writing before construction begins. Include the date on which construction will begin and the contact details of the earthworks contractor/project manager.

## 6.2 Site preparation

Before pond construction begins, the site should be cleared of trees, logs, tree roots, and brush. All woody materials should be cleared to avoid leaks in foundations or embankments that could arise as this material decomposes. Roots also provide easy tracks for some biota to tunnel along, which breaks down the integrity of the bank and should be removed, were possible. (**Note**: approvals may be required for the clearing of native vegetation or marine plants. Contact your regional Department of Natural Resources and Water and Department of Primary Industries and Fisheries offices ‹www.dpi.qld.gov.au› for further information). These latter steps will be a requirement of any development approval issued under the *Integrated Planning Act 1997*.

All organic material (topsoil), loose or low density fill material, or material that may be compressible, weak or not consistent with the general soils being used to construct containment structures should be removed from foundation areas before the fill is placed. The material may be stockpiled for later use where topsoil is required for erosion control, landscaping or rehabilitation, or used for other components of the earthworks, such as core fill. In some cases, the material may be moved to a borrow pit for conditioning by blending with other materials to achieve appropriate material suitability.

## 6.3 Material suitability

The material used for lining the structures should be well-graded, impervious material, classified as either CL, CI, CH, SC or GC in accordance with the soil classification system described in Appendix A (Table A1) of AS 1726 *Geotechnical site investigations*.

**Note:** The classification symbols represent inorganic clays having low, intermediate and high plasticity; and clayey sands and clayey gravels, including gravel-clay-sand mixtures, respectively.

## 6.4 Placement of material

### 6.4.1 Earth material lining

Where lining material is suitable and of sufficient depth to meet the thickness requirements determined through the risk assessment described above, the lining should be ploughed and ripped to a minimum depth of 200 millimetres (mm) and moisture conditioned and compacted in accordance with the requirements below.

Where in situ material is unsuitable (see **Section 5**), the material should be either ameliorated in situ or excavated and removed. Where earth lining materials are to be imported, the lining should be constructed in even layers. The thickness of each layer of soil being compacted should be spread to an even thickness and the compacted thickness of each layer, comprising the lining, should not exceed 200 mm. The formation of the lining by layering will improve compaction and minimise the potential a weakness in the lining to be created.

In forming the lining, it is strongly recommended that allowance be made in the depth of the compacted layer for the tilling of pond floors between crops and the scouring by water movement, such as aeration. It is recommended that the depth of the compacted layer is sufficient to provide a minimum depth of 200 mm of compacted material **that will not be disturbed by future operation and maintenance of the containment structures**. (This does not refer to minor activities such as posts. stakes, and pipes.) In some circumstances this can be achieved by covering the compacted layer with material such as sand. It is important that this layer is maintained at all times during the life of the pond.

### 6.4.2 Embankments

Pond embankments should be constructed in even layers. The thickness of each layer of soil should be spread to an even thickness and the compacted thickness of each layer should not exceed 200 mm. The formation of the embankments by layering will improve compaction and minimise the potential for weakness in the compacted layer.

In forming embankments it is critical to ensure that a positive cut-off of low permeability material is created between the base of the embankment and the foundation of the containment structure. This is usually achieved by 'keying' the embankment into the floor of the containment structure to minimise the risk of structural failure or of water flowing between the join in the foundation and embankment.

### 6.4.3 Erosion control

In most cases, local councils have developed specific guidelines for sediment and erosion control with which construction activities will need to comply. In the absence of such guidelines, use *Soil erosion and sediment control: Engineering guidelines for Queensland construction sites*, a publication of the Institute of Engineers, Australia (Queensland Div.) for guidance on minimising the risk of environmental harm from stormwater runoff during construction.

### 6.4.4 Pipes, culverts and weirs

Particular attention should be paid to pipes, culverts and weirs during construction. These structures should be installed to ensure they do not create a weakness in the foundation or embankment. Compaction using small machinery may be required to ensure that appropriate standards of compaction are achieved in the vicinity of the structure. The installation of baffles or bentonite collars can further minimise the potential for water flow (piping) along the outside of the structure. Rock armouring or similar erosion and scour protection should be used to minimise erosion and scour around the inlets and outlets.

## 6.5 Correct moisture content

Correct moisture content is critical to achieving compaction and low permeability. Prior to compaction, all material used for lining purposes should be conditioned. This is so that its moisture content will fall within two per cent of the optimum moisture content required to produce the maximum dry density when compacted in accordance with AS 1289 *Methods of testing soils for engineering purposes* (Standard Proctor Compaction). Any deviation from this value will require approval from a certified engineer. The fill should be placed in continuous operation so that drying out of the surface or wetting of the surface is limited to no more than two per cent variation in moisture content. If a delay in construction occurs and drying or wetting occurs, the layer should be reconditioned to the required moisture content prior to compaction.

**Note:** as a guide, the required moisture content is as wet as can be rolled without clogging a sheep's-foot roller. Make a preliminary assessment of the required moisture content by rolling a sample of the material between your hands. If it can be rolled to pencil thickness without breaking, it should be satisfactory.

## 6.6 Compaction

Each layer of material should be compacted to a density greater than 95 per cent of the standard compaction density when tested in accordance with AS 1289 *Methods of testing soils for engineering purposes* (Standard Proctor Compaction).

**Note:** this degree of compaction may generally be achieved by rolling each layer of material, placed at the correct moisture content, with at least eight passes of an appropriate sheep's-foot or tamping roller. As a guide, compaction will generally be sufficient when there is a clearance of 100 mm between the drum of the roller and the compacted material.

Note that it is generally easier to compact and handle material which is a little below the standard optimum moisture content; however, the consequences of doing this are likely to lead to a marked increase in the leakage potential of the finished product.

## 6.7 Documentation

Construction supervision is an important part of building an aquaculture containment structure. Supervision ensures that the specification requirements have actually been included in the final product.

On the project's completion, a suitably qualified person should prepare a report confirming that the structure has been built to an appropriate engineering standard. (Generally, this will be consistent with the approved engineering drawings with reasons for variations from the approved drawings documented).

In order to demonstrate compliance with the construction requirements of these guidelines, the placed material will need to be tested, particularly its in situ density. This testing should be carried out in accordance with the appropriate sections of AS1289, *Methods of testing soils for engineering purposes*.

It is also strongly recommended that all earthworks are audit tested and certified by a suitably qualified person. During construction, all excavations forming part of the permanent works should be geologically mapped. All foundation levels should be recorded, so that the location of any part of the foundations is permanently known. Extensive photography of the earthworks including foundations should be retained permanently.

# 7. Monitoring

## 7.1 Purpose

Environmental monitoring should be carried out in order to:

- Assess potential impacts from aquaculture containment structures on the environment or nearby groundwater users. This can include contamination of groundwater, waterlogging or salinisation of surrounding soils or accelerating discharge of existing poor-quality groundwater to environmentally sensitive areas.
- Assess the potential for shallow groundwater or seepage to affect embankment stability. As embankments and foundations become wet they can weaken. Where groundwater levels rise above the base of lined containment structures, the liner may rupture when structures are drained for maintenance.
- Assess the potential for surrounding groundwater quality to affect containment water quality. Containment structures built in areas of shallow, poor-quality groundwater can become contaminated by groundwater inflow when water levels drop below groundwater levels.
- Identify, prior to construction, any groundwater issues, including nutrient contamination, shallow watertables, acidity or salinity that might otherwise be attributed to aquaculture operations if detected in the future.

## 7.2 Visual inspections

Problems with containment structures may be discovered via the following visual indications:

- waterlogging
- salinisation e.g. salt scalds
- vegetation dieback or changes in vegetation characteristics e.g. to more salt or waterlogging-tolerant species
- evidence of exposure of acid sulfate soil (e.g. iron stains)
- embankment failure, slumpage or bulging
- overtopping
- erosion.

It is strongly recommended that routine inspections are carried out, and permanent photographic monitoring points are established. This will provide a record of visual changes in surrounding environments and at representative points at the perimeter of the containment structures. Particular emphasis should be placed on sensitive environments and the property boundary adjacent to sensitive land uses. Photographs should be taken at least annually at the same time of year as a permanent record of visual changes.

## 7.3 Groundwater monitoring

### 7.3.1 Purpose

Groundwater monitoring helps to identify any significant problems with containment structures. Experience has shown that installing groundwater monitoring bores and commencing groundwater monitoring **should be undertaken as soon as possible in the life of the project**. In the event of allegations of environmental impacts, baseline monitoring data will provide valuable information for those investigating and assessing the allegations. It is likely to be cost effective to install the monitoring bores at the same time as the geotechnical and acid sulfate soil investigations are undertaken. Both tasks should be carried out by skilled and competent people.

While leakage from synthetic lined ponds (concrete, HDPE lined) is not expected, it is recommended that monitoring bores be installed to account for potential impacts from hydrostatic mounding or liner damage.

### 7.3.2 Location and number of monitoring bores

The initial bores installed to collect baseline data should be located outside the proposed construction area but must be suitably positioned so they can be used for future monitoring. This will minimise any risk of damage during construction and will enable the same monitoring bores to be used for baseline and post-construction data acquisition, providing a clear comparison of pre- and post-construction data.

Groundwater monitoring bores should be located so that baseline conditions, including seasonal and tidal variation in water quality and potentiometric levels are defined. This will enable early detection of any impacts from aquaculture farm construction or operation, and identify the difference between impacts from farm operations from those due to other sources.

Before choosing the locations of monitoring bores at the site, the following conditions should be considered:

- likely direction and velocity of the groundwater flow
- potential off-site contaminant sources
- geology of the site and the region
- location and proximity of the site to surface water resources
- location and proximity of the site to groundwater bores used for extraction of potable water
- surface topography of the site and likely underlying topography of any aquifer.

The number and location of monitoring bores will depend on geological assessment and the characteristics of the aquifers, depth to groundwater, direction and rate of flow, hydraulic gradient and distance to sensitive receptors. The number and location should allow for monitoring of both spatial and temporal trends. It is recommended that at least two bores are placed between the containments structures and sensitive receptors or neighbouring properties to identify changes in depth and quality of any groundwater over time. These may need to be nested bores depending on the aquifers. If trends are recognised, other bores may need to be installed to gain a better understanding; this may require a bore within the containment area. Trend information is important in assessing seepage problems.

### 7.3.3 Control bores

Where practical, it is strongly recommended that a control bore or bores be installed at a location distant to the development area (e.g. >250m) to provide a reference against which to evaluate the magnitude of any impacts detected in the monitoring bores. For example, a control bore should be installed in an adjacent property to monitor the same groundwater aquifer as the impact monitoring bores (permission should be sought when installing bores on other properties).

### 7.3.4 Depth of monitoring bores

The shallowest aquifer is the most critical to monitor, as it will be the most sensitive to any problems with the containment structures. Groundwater monitoring bores should be installed so they can take samples across the full depth of the aquifer. The ultimate depth of each bore will depend on the depth to the watertable as well as the saturated thickness of the aquifer. At sites with multiple aquifers it may be necessary to install nested bores, comprising a separate bore screened in each aquifer. **Under no circumstances** should bores be constructed with screens, filter packs or permeable backfill extending across multiple aquifers.

### 7.3.5 Monitoring bore construction standards

All monitoring bores must be drilled and constructed by a licensed water bore driller, with copies of bore logs submitted to the Department of Natural Resources and Water, as required by the *Water Act 2000*. The monitoring bores should be constructed in accordance with the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) *Minimum construction requirements for water bores in Australia*. A suitably qualified engineer or hydrogeologist should collect soil samples and log the lithology on-site.

For security, bores should have lockable, heavily-galvanised, steel bore shields or standpipes. The standpipe should protrude above potential flood or tidal inundation, or at least 0.5 m above the ground surface, and be bedded in concrete to a depth of approximately 0.3 m. The annulus between the PVC casing and the standpipe should be backfilled with filter pack material or grout to minimise the risk of fire damage to the casing. The standpipe should be painted in a high-visibility colour, with the well ID (e.g. BH01) marked on the top of the standpipe. In cases where vegetation may obscure the bore headworks, a star picket, painted in a high-visibility colour, should be installed, extending above the expected height of the vegetation where feasible.

The location, natural surface level and casing level of the monitoring bores should be accurately surveyed (location to ±0.1m and height to ±0.005m). The location and natural dry season surface level of nearby surface water bodies should also be surveyed where applicable.

### 7.3.6 Development of monitoring bores

On completion, bores should be developed to remove excess fine sediments in and surrounding the filter pack, to increase near-bore permeability and minimise the turbidity of future water samples. New bores should not be developed within 24 hours of construction, to allow for concrete and bentonite seals to stabilise. Purging should continue until the purge water is visually clear or for a maximum period of two hours. Field water quality parameters should be measured and recorded to confirm removal of any added water.

### 7.3.7 Groundwater flow assessment

Groundwater flow assessments apply to high and extreme risk proposals only.

In order to gauge the direction and rate of flow of water in aquifers, the hydraulic conductivity of the aquifer and the slope of the watertable (hydraulic gradient) should be determined where practical.

To calculate the hydraulic gradient, measure the depth to groundwater and convert this to Australian Height Datum (AHD). Measurements can be made physically using a float, string and tape measure or with an electronic water level probe.

The hydraulic conductivity of the aquifers should be determined by constant-rate pumping tests, falling head (confined aquifers only) or rising head permeability test methods, depending on bore construction and aquifer permeability. If necessary, drilling logs and groundwater sampling measurements can supplement these calculated values.

The hydraulic gradient, hydraulic conductivity and estimated effective porosity can then be used to estimate groundwater flow velocities. These measurements will help to assess the potential lead time for contamination or impact on environmentally sensitive areas.

### 7.3.8 Monitoring program

Groundwater samples should be collected from each monitoring bore on site to gain information on pre-construction groundwater conditions. The recommended parameters and sampling frequency is included as **Appendix 5**.

Groundwater monitoring (sample collection, preservation and analysis) should be undertaken in accordance with the Australian Standards (AS/NZS 5667 'Water Quality Sampling' series with particular reference to Part 11: Guidance on sampling of groundwater).

Baseline groundwater monitoring should be carried out to establish the natural variation in groundwater characteristics including:

- daily variation in groundwater level (e.g. due to gravitational or tidal influence)
- seasonal variation in groundwater level or quality
- response of groundwater to local or regional rainfall (recharge).

Groundwater sampling should not be carried out within one week of bore development, to allow for water levels and groundwater chemistry to stabilise.

Prior to sampling, water levels in each bore should be measured over the shortest possible period of time, to minimise tidal and barometric variations. Water levels should be converted to AHD. Bores should then be purged so that representative groundwater samples are obtained. To confirm the completion of purging and to obtain a preliminary assessment of groundwater quality, appropriate water quality parameters (e.g. pH, electrical conductivity, temperature) should be measured during purging operations. Purging should continue until readings have stabilised (within 0.1 pH units, 5 per cent of reading and 0.2°C respectively). Purging data, including field parameters, general colour, turbidity and odour should be recorded. As a guide, a minimum of three to five casing and filter pack volumes (casing volume + ~0.2 x filter pack volume) will need to be removed to adequately purge a bore using conventional sampling methods.

Groundwater monitoring can be carried out by farm employees with appropriate training. Equipment used to monitor groundwater needs to be properly maintained and calibrated. If monitoring is undertaken by farm employees, it is strongly recommended that at least annually, the proponent engage a suitably qualified independent person to carry out the sampling to validate the data collection methodology. Any significant inconsistencies between the routine sampling and the independent sampling should be investigated and appropriate corrective actions taken.

In addition to groundwater monitoring, it is strongly recommended that monitoring and recording of key environmental and operational conditions should be undertaken. Key parameters include rainfall, pond water levels and pond water quality (e.g. electrical conductivity). This data will assist in the detection or evaluation of allegations of environmental harm caused by containment structures.

#### 7.3.9 Performance indicators

It is beyond the scope of these guidelines to specify performance indicators that can be applied generally. Performance indicators will need to be determined on a site-specific basis according to the baseline monitoring, which will assist in establishing the natural variations in groundwater depth and quality. Performance indicators may also be defined by reference to control bores where these are available. Indicators for problems may include:

- A close link between pond status (filled/empty) and groundwater level and quality (e.g. electrical conductivity) that is not detectable in the control bores. However, hydrostatic mounding of groundwater does not, by itself, indicate a problem.
- A trend for increasing groundwater level and/or field parameters over time that is independent of regional recharge and is not detectable in the control bores.

#### 7.3.10 Decommissioning of monitoring bores

If monitoring bores need to be decommissioned (e.g. due to a modification to the farm layout), the bores need to be safely removed to ensure that the potential for future environmental harm is minimised. Decommissioning monitoring bores should comply with the Australian guidelines or equivalent standard specified in *Minimum Construction Requirements for Water Bores in Australia*, Agriculture and Resource Management Council of Australia and New Zealand.

# 8. Maintenance

A program of routine maintenance of containment structures is important. Typical maintenance activities include:

- repairs to erosion and beaching of embankments
- repairs to pond floors where erosion and scour from aerators has occurred
- repairs to erosion and scour around inlet and outlet structures
- removal of woody vegetation (trees and shrubs) in pond embankments.

In addition to these routine maintenance activities, typical pond management disturbs a shallow layer on the pond bottom (0.05–0.10m) at the end of the production cycle when the pond floor is tilled and limed.

During all maintenance activities, it is critical to maintain the integrity of the engineering of the containment structures. Repeated disturbance may result in the integrity of the lining being compromised and result in subsequent problems. Therefore it is important that maintenance activities do not disturb the impermeable layer.

Where significant maintenance works or alteration of farm layout are undertaken, it is strongly recommended that the works be designed, supervised and certified by a suitably qualified person and undertaken in accordance with these guidelines.

# 9. Corrective actions

Industry experience has shown that investigating allegations of unsatisfactory performance of containment structures and correcting these problems can be expensive. Costs may include engaging technical and legal professionals and undertaking detailed analysis. Significant cost savings can be made by following the critical steps in these guidelines.

☑ appropriate site selection

☑ appropriate design including the provision of adequate buffers

☑ construction to appropriate standards

☑ certification of construction

☑ baseline and routine monitoring

If performance indicators are not complied with, it is strongly recommended that a suitably qualified person investigates the reason for the non-compliance and determines appropriate corrective actions. It is also strongly recommended that the relevant authorities are notified of potential problems with the containment structures, and are consulted about further investigations, and appropriate corrective actions.

Corrective actions will generally proceed through the following stages:

1. Verifying non-compliance through data analysis, additional monitoring and detailed site investigations including detailed groundwater monitoring.
2. Assessing, in consultation with the administering authorities, the potential risk to sensitive environments, groundwater or adjacent land uses from non-compliance with performance indicators. This may include a cost benefit analysis to assess the potential cost of remediation of environmental harm against the cost of remedial actions.
3. Identifying probable and/or critical causes for non-compliance and possible solutions e.g. laboratory testing of samples or in situ testing using groundwater tracers, modelling etc. to evaluate permeability.
4. Implementing corrective actions – options may be arbitrarily defined as engineering or management solutions. Examples of possible solutions are summarised below:

   **Management solutions**
   Modifying the rate at which ponds are filled
   Relief wells
   Interception bores/ trenches
   Infiltration trenches
   Recharge bores

   **Engineering solutions:**
   Repairing low permeability lining
   Retrofitting of low permeability lining
   Modifying the farm design e.g. decommissioning ponds or relocating supply and/or discharge channels

   Further information on engineering and management solutions is provided in Appendix 6.

# 10. References and further reading


ARMCANZ 1997, *Minimum construction requirements for water bores in Australia*, Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

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State Planning Policy 2/02: 'Planning and managing development involving acid sulfate soils', *Integrated Planning Act 1997* (Qld)

# Appendix 1: Problematic soil types

### General

Stony soils are problematic. The presence of rocks and stones interfere with foundations and it can be expensive to source fill materials and treat the foundation. Sites in areas that are known to contain sand or sand lenses, silt or dispersive clays, or are susceptible to erosion may require specialised treatment to prevent piping failure through the foundation or containment structure, and prevent erosion along the toes of the embankments or in other areas where water flow may occur.

### Silty or sandy soils

Coastal aquaculture containment structures are required to hold saline/brackish water that may contain nutrients from fertiliser and the feeding of stock. Therefore, the primary objective of the soil used to build the containment structures is to minimise the rate of seepage from the farm. Soils with a high silt or sand content are often too permeable, except when used for the embankment shell, armour or drains as outlined in **Appendix 3**. Containment structures should be lined if they are to be built in relatively permeable soils.

### Expansive soils

Although expansive soils have a very low permeability, they can shrink and swell with changes in moisture as experienced in growout ponds subjected to filling – drying cycles. This shrinking and swelling can cause large cracks to form in embankments and foundations. Where these soils demonstrate high dispersivity, tunnelling failure of the structures and embankments is also a risk. Where possible expansive soils should not be used to build embankments particularly in zones where they can be subject to changes in moisture. High plasticity clays are often sticky and difficult to dry and till.

### Structured soils, slickenslided soils

These soils contain visible structuring, which becomes obvious in the soil fabric as cracks upon drying or parting planes upon disturbance. Many of these clay soils tend to form strong aggregates that can lead to high soil porosities. Some of these (slickenslides) may appear shiny when moist. This structure is associated with a history of movement or working of the soil, and is often seen in expansive soils. The structure is associated with high secondary permeability and significant weakening of the soil.

### Dispersive soils

These clayey soils generally possess a high percentage of exchangeable sodium, and have a tendency to go into solution and stay suspended within the water column. Ponds affected by dispersive soils have high turbidity and therefore are subject to reduced light penetration and primary production. Dispersion, while often suppressed in coastal areas due to the high solute levels in seawater, can occur within containment structures during dry-out periods if dispersive soils are exposed to heavy rainfall. When excavated, these soils can form tough and impermeable clods that require considerable force to be broken down. Dispersive soils can lead to wall failure due to erosion and tunnelling, and erosion of pond bottoms when ponds are drained.

### Organic soils

Soils with high concentrations of organic matter (generally greater than 20 per cent) should not be used in the embankments or foundations of aquaculture containment structures because they have the potential to:

- create high oxygen demands when decomposing
- be highly permeable
- be acid generating
- be difficult to compact
- have excessive settlement.

Laboratory tests will determine the level of organics present in the soils.

**Alkaline soils**

Alkaline soils can harm culture production by causing the pond water pH to increase. The desirable range of soil as well as water pH for aquaculture is 6.5 to 8.5. pH. Greater than 9 is considered too alkaline for most aquatic animals. Alkaline soils are usually found in the driest parts (central and west) of the state, and are therefore generally not considered an issue in coastal areas where the majority of aquaculture farms are located. However, alkaline soils may arise in coastal areas if lands have been exposed to certain types of industrial contamination. These soils should be avoided as they are likely to be also affected by other contaminants associated with industrial activity.

**Acid sulfate soils**

Acid sulfate soils in pond construction can harm culture production by causing pond water pH to decrease. The desirable range of soil as well as water pH for aquaculture is 6.5 to 8.5. pH. Lower than 6 is considered too acidic for most aquatic animals, and acid sulfate soil leachate is commonly less than pH 4. Acid sulfate soils are usually found in low lying coastal areas, and are therefore considered an important issue for the majority of aquaculture farms. The topic is dealt with in **Section 2.5**

# Appendix 2: Minimum soil testing requirements

| Soil property to be tested | Testing methodology | Testing frequency | Discussion | Guide to assessing soil suitability for construction |
|---|---|---|---|---|
| Soil grading using unified soil classification system (USCS) | AS 1726 | Tests should be undertaken on all strata identified in the foundations of containment structures and on each type of fill being used in embankments.<br>Material to be used for pond sealing is to be of a quality that will minimise seepage. A suitably qualified person must, for each stage, test and verify the permeability of the material for the pond sealing. | The USCS is based on the grading of constituent particles (soil particle size distribution), the plasticity of the fines fraction and organic matter content. It gives information on the ability of the soil to resist seepage, its attainable compaction, and its load bearing capacity. | Refer to **Appendix 3**. |
| Atterberg limits and linear shrinkage | AS 1289.3.1.1. to 3.4.1 | Tests should be undertaken on all strata identified in the foundations of containment structures and on each type of fill being used in embankments.<br>Material which is to be used for pond sealing is to be of a quality that will minimise seepage. A suitably qualified person must, for each stage, test and verify the permeability of the material for the pond sealing. | Tests to determine the expansive and shrinkage behaviour of soils include the Liquid Limit together with the Plastic Limit and Linear Shrinkage. The Liquid Limit is proportional to the compressibility of a soil and therefore its load bearing capacity and trafficability when wet. | Non-dispersive soils with a low shrink/swell potential (‹12%) are generally considered suitable for construction.<br>Dispersive soils with a low shrink/swell potential (‹12%) can undergo settlement. This may result in tunnel failure.<br>Soils with medium shrink/swell potential (linear shrinkage 12–17%) are susceptible to minor shrinkage and swelling but are amendable.<br>Dispersive soils with a high shrink/swell potential (linear shrinkage ›17%) may be subject to tunnelling.<br>Soils with a very high shrink/swell potential (linear shrinkage ›22%) undergo extensive cracking upon drying but usually seal well when saturated.<br>Refer to **Appendix 3**. |

| Soil property to be tested | Testing methodology | Testing frequency | Discussion | Guide to assessing soil suitability for construction |
|---|---|---|---|---|
| Proctor standard compaction | AS 1289.5.1.1 | Material to be used for pond sealing is to be of a quality that will minimise seepage. A suitably qualified person must, for each stage, test and verify the permeability of the material for the pond sealing.<br>All soils used to construct an embankment to confine an aquaculture containment structure should be tested to determine the optimum moisture content and the maximum dry density of the soil. | This test determines the optimal soil moisture content for compaction.<br>Soil compacted below this optimum moisture content has a tendency to resist compaction, while soil compacted above this optimum moisture content has a tendency to flow away from compaction zones. | The soil should be placed in the embankments to reach a density greater than 95% of the maximum dry density and placed at the optimum moisture content (usually within +/-2%) unless otherwise determined by a suitably qualified engineer based on site geotechnical conditions and embankment materials. |
| Dispersivity | AS 1289.3.8.1–3.8.3 | Tests should be undertaken on all strata identified in the foundations of containment structures and on each type of fill being used in embankments.<br>Material to be used for pond sealing is to be of a quality that will minimise seepage. A suitably qualified person must, for each stage, test and verify the permeability of the material for the pond sealing. | Pinhole dispersion (AS 1289 3.8.3) and sodium absorption ratio of the soil together with the concentration of salts in the water can also be used to measure dispersive behaviour of the soils.<br>Note: If it is likely containment structures will intersect the watertable, the testing procedure can be varied to assess the soils behaviour under farm conditions by substituting de-ionised water used in standard testing procedures with the water to be used in ponds for culturing and local groundwater. | In general, soils in excess of 50–65% dispersion and/or an Emerson Dispersion class value of 1, 2(2) or 2(3) are considered to be high risk soils as they are unstable and susceptible to tunnelling in embankments and therefore should be avoided unless compacted or ameliorated.<br>Soils with low dispersion (<10%) are usually too pervious to be used for water storage.<br>Soils with an Emerson Dispersion class value of 6 are likely to have leakage problems and should be avoided unless highly compacted or ameliorated. |

| Soil property to be tested | Testing methodology | Testing frequency | Discussion | Guide to assessing soil suitability for construction |
|---|---|---|---|---|
| pH and net acidity | See *Acid sulfate soil guidelines* (http://www.nrw.qld.gov.au) | See *Acid sulfate soil guidelines* (http://www.nrw.qld.gov.au) | See *Acid sulfate soil guidelines* (http://www.nrw.qld.gov.au) | Soil pH between 6.5 and 8.0 is considered ideal for aquaculture production. Soil pH lower than 6 or greater than 9 is considered potentially toxic to most aquatic animals. |
| Permeability | Constant head permeability test (AS 1289.6.7.1) should be used to determine hydraulic conductivity. | Testing should be undertaken at a minimum of one test per 10,000 $m^3$ of material to be used as lining.<br>Testing will also include one location per ha of completed lined pond for all containment structures. Where this testing will be ongoing the sites should be selected at random within the ponds. | Where the soils on site will result in seepage causing an increase in the groundwater level or contamination of the groundwater or seepage water passing over adjoining properties, engineering solutions will be required to prevent the seepage.<br>Consider the geology between the ground surface and the aquifer to determine subsurface permeability, particularly the effects of heterogeneity on soil permeability. | Foundations and embankments should have suitable physical characteristics to achieve permeability in accordance with **Section 3**. |
| Organic matter | AS 1289.4.1.1 | Tests should be undertaken on all strata identified in the foundations of containment structures and on each type of fill being used in embankments.<br>Testing should be undertaken at a minimum frequency of one locations per ha of foundation for all containment structures, and a minimum of one test per 10,000 $m^3$ of fill. | Prior to testing, organic matter should be removed e.g. all visible vegetation, including roots.<br>Often organic-rich soils are also high in acidity due to a build up of organic acids. | Soils with greater than 20% organic matter are generally considered unsuitable for use in foundations and embankments.<br>Refer to **Appendix 3** |

# Appendix 3: Potential engineering behaviours of various soil types

| Group symbol | Typical name | Properties | Beneficial use | Danger area |
|---|---|---|---|---|
| GW* | Well-graded gravel, gravel sand mixture, little or no fines | High strength, stable, permeable | Shell fill, drains and filters, armour | Beaching[1] |
| GP* | Poorly-graded gravel, gravel sand mixture, little or no fines | High strength, stable, very permeable | Shell armour, drains | Beaching, bad filter, piping |
| GM* | Silty gravels, poorly graded gravel-sand-silt mixtures | Not so high strength, stable, lower permeability | Shell fill, drains and filters, armour | Internal erosion |
| GC | Clayey gravels, poorly graded gravel-sand-clay mixture | Not so high strength, stable, lower permeability | Shell fill, core | Bad filter, piping[2] |
| SW* | Well graded sands, gravely sands, little or no fines | High strength, stable, moderate permeability | Shell fill, filters, leaky core | Surface erodible[3] |
| SP* | Poorly graded sands, gravely sands, little or no fines | High strength, stable, more permeable | Shell fill, drains, leaky core | Surface erodible |
| SM* | Silty sands, poorly graded sand-silt mixtures | Lower strength, compressible, less permeable | Shell fill, drains, leaky core | Easily erodible, liquefiable |
| SC | Clayey sands, poorly graded sand-clay mixtures | Lower strength, stable, compressible, low permeable | Shell fill, leaky core | Erodible |
| ML* | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity | Low strength, stable, compressible, low permeability | Leaky core | Easily erodible, liquefiable |
| CL | Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays | Low strength, stable, compressible, low permeability | Core | Erodible |
| OL* | Organic silts and organic silt-clays of low plasticity | Low strength, unstable, compressible, low permeability | No use | Piping |
| MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts | Low strength, stable, compressible, low permeability | Core | Erodible, piping |
| CH | Inorganic clays of high plasticity, fat clays | Very low strength Stable, compressible, very low permeability | Inner core[4] | Shrink swell Cracking, Piping, Dispersive |
| OH* | Organic clays of medium to high plasticity | Very low strength, unstable, compressible, very low permeability | No use | Piping |
| Pt* | Peat and other highly organic soils | Very low strength, unstable, compressible, unreliable permeability | No use | Piping |

[1] Beaching refers to movement of embankment material by wave action. Granular materials erode rapidly once the threshold wave height is exceeded.

[2] Piping refers to internal material movement forming self enlarging pipes.

[3] Erodible refers to surface erosion, gullying that could lead to a breach

[4] Must not be subject to moisture variation as shrink swell characteristics will open up piping paths.

* Soil types marked with * would generally result in excessive seepage from ponds. If they exist in the foundations or are to be used as fill for embankments, engineering justification would be required or the ponds should be lined.

# Appendix 4: Simple method for determining the required level of permeability

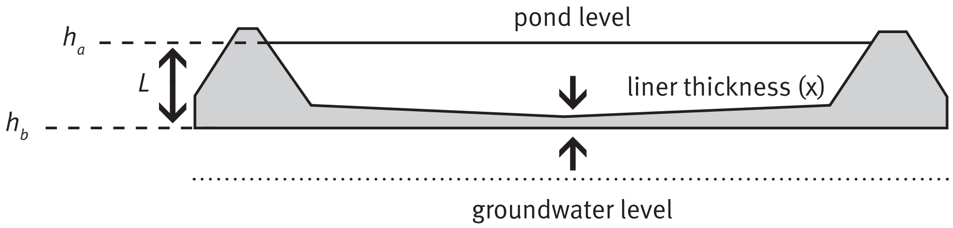
Darcy's Law defines a simple relationship that relates the instantaneous discharge rate through a porous medium to the local hydraulic gradient (change in hydraulic head over a distance) and the hydraulic conductivity (k) at that point. It is one of the basic relationships of hydrogeology.

$$Q = kA \frac{h_a - h_b}{x}$$

For the purposes of these guidelines, Darcy's law is applied in the absence of a known groundwater level, therefore:

- $Q$ is the total discharge (e.g. $m^3/s$)
- $k$ is the hydraulic conductivity based on the properties of the soils on site following compaction (e.g. m/s)
- $A$ is the cross-sectional area to flow (e.g. $m^2$)
- $h_a$ is the level of the pond surface (e.g. m)
- $h_b$ is the level of the base of the impermeable layer (e.g. m)
- $L$ is the distance between the level of the pond surface and the level of the base of the impermeable layer (m) i.e. depth of water + depth of impermeable layer
- $x$ is the thickness of the liner (impermeable layer) (e.g. m)

The parameters are schematically demonstrated below:




The equation may be simplified to:

$$Q = kA(L/x)$$

Normal application of Darcy's law (and measurement of k) uses the full cross-sectional area of the soil because it is readily measurable. The velocity ($v$) obtained then is only a notional velocity as it is calculated as if flow is occurring over the whole cross section:

Notional velocity $v = Q / A$

In reality the movement of water is restricted through the voids that are only a fraction of the total cross section. This means that to pass the flow rate, actual seepage velocities through the pores are faster than the notional velocity—effectively by the ratio of total cross-sectional area to the area of void or the inverse of porosity. A saturation moisture content of 18 per cent corresponds to a porosity of approximately 33 per cent, so for such a soil the seepage velocity (or the advance of the pond water) would be three times the velocity obtained from Darcy's law.

Based on this, a modification of Darcy's Law should be used to evaluate the required combination of liner thickness and liner permeability to ensure compliance with the risk-based level of permeability (see **Section 6.7**) –

Actual velocity $v_t = v / 0.33$

The time taken for water to pass through the liner is therefore:

Time to pass through liner: $T = x / v_t$

The steps in this process may be combined to the following final equation:

$$T = 1000\, x^2 / 3\, k\, L \qquad \text{(assumes porosity of 33 per cent)}$$

where the parameters and units of measurement are:

- $T$ is the time to pass through liner (days)
- $x$ is the depth of the impermeable layer (m)
- $k$ is the predicted saturated hydraulic conductivity (mm/day)
- $L$ is the distance between the level of the pond surface and the level of the base of the impermeable layer (m) i.e. depth of water + depth of impermeable layer

The volume leaked during the period of ponding may be calculated using the following equation:

$$V = Q\, t_a\, 86.4$$

Where V is the volume leaked during the period the pond is filled (ML/ha),

- $Q$ is the flow ($m^3$/s),
- $t_a$ is the number of days that leakage may occur (the maximum likely filled period of the containment structure (days) minus the time to pass through the liner (T)),
  and 86.4 is a unit conversion factor from $m^3$/s to ML/day.

# Appendix 5: Recommended groundwater monitoring parameters and frequency

The following parameters have been selected as indicators of contamination from aquaculture operations, or are key groundwater quality parameters for assessing the highest use of groundwater or potential environmental impacts.

**Table 5 Recommended groundwater monitoring parameters (refer to the acid sulfate soils groundwater monitoring guidelines for groundwater monitoring for acid sulfate soils** (http://www.nrw.qld.gov.au))

| Parameter group | Test | Level of reporting |
|---|---|---|
| Field parameters | Groundwater depth | 0.01m |
| | Field parameters – pH, Eh, T, EC/Salinity, DO (%sat and mg/L) | ~ 1% of range |
| Primary analytes | Total dissolved solids | 1 mg/L |
| | Total nitrogen | 0.01 mg/L |
| Secondary analytes | Major anions (Cl, $SO_4$, $CO_3$, $HCO_3$) | 1 mg/L |
| | Major cations (Ca, Mg, Na, K) | 1 mg/L |
| | Dissolved metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Zn) | 1 µg/L |
| | Dissolved metals - Hg | 0.1 µg/L |
| | Ammonia as N | 0.01 mg/L |
| | Nitrate + Nitrite as N | 0.01 mg/L |
| | Total organic carbon (TOC) | 1 mg/L |
| | Total phosphorus | 0.01 mg/L |

| Parameter | Pre-operational | First season | Thereafter |
|---|---|---|---|
| Groundwater levels | In tidal areas:<br>Checked at 15-minute intervals over at least one 72-hour period; and<br>In tidal and non-tidal areas:<br>Checked at weekly intervals for the first month, then monthly until operation commences.<br>More frequent monitoring may be required during construction if dewatering of acid sulfate soils is required.<br>**Monitoring should commence as early as possible in the project** to obtain the best possible baseline data on groundwater properties, and daily monitoring should occur following heavy rain, until such time as the relationship between rainfall and groundwater level rise can be determined. | On initial filling following construction, groundwater levels should be monitored daily for the first week, then weekly for the first month, then monthly for one year. | Monitoring should be undertaken monthly during the period that ponds are filled, commencing one month prior to filling and concluding one month after the ponds are drained.<br>Monitoring should be undertaken quarterly during the period that ponds are not filled. |
| Field parameters (farms using salt-affected or saline waters) | Samples should be collected and analysed monthly. | Monitoring of pH and EC should be undertaken monthly for 12 months, commencing one month prior to filling. | Monitoring of pH and EC should be undertaken monthly during the period that ponds are filled, commencing one month prior to filling and concluding one month after the ponds are drained.<br>Monitoring should be undertaken quarterly during the period that ponds are not filled. |
| Primary parameters | Depending on the variation of the aquifer across the site, sufficient samples should be collected to provide a representative 'baseline' sample prior to the commencement of construction works. Sets of samples should be taken late in each of the dry and wet seasons. | Subject to expert advice should further investigations be necessary. | Subject to expert advice should further investigations be necessary. |
| Secondary Parameters | Dependent on the variation of the aquifer across the site, sufficient samples should be collected to provide a representative 'baseline' sample prior to the commencement of construction works.<br>Sets of samples should be taken late in each of the Dry and Wet seasons. | Subject to expert advice should further investigations be necessary. | Subject to expert advice should further investigations be necessary. |

Please note: these are the minimum recommended monitoring requirements. Additional monitoring is strongly recommended to ensure that the variation in groundwater characteristics both spatially and temporally are fully understood and that any changes detected following construction can be appropriately investigated.

# Appendix 6: Options available to repair containment structures or mitigate impacts from unsatisfactory performance

| Option | Description | Application | Limitations |
|---|---|---|---|
| Impermeable liners | The type of liner required will depend on the sensitivity of the underlying aquifer and surrounding environment, and the level of risk reduction required to meet acceptable risk levels. Impermeable liners can range, in increasing level of protection, from:<br>• ripping and re-compaction of in-situ clays<br>• synthetic geo-membranes<br>• engineered imported clay liners<br>• composite liner and leakage detection systems. | Geotechnical assessments should be undertaken to confirm the suitability of liner material and should include, as a minimum:<br>• testing for moisture content<br>• Atterberg limits<br>• dispersion potential<br>• linear shrinkage<br>• particle size distribution<br>• percentage clay fraction and moisture contents<br>• standard compaction testing to define maximum dry density<br>• optimum moisture content.<br>Liners should be designed by a suitably qualified and experienced engineer, taking into account the seepage risks associated with:<br>• particular aquaculture<br>• availability of suitable materials and necessary treatments<br>• appropriate testing programs<br>• liner thickness and construction specifications<br>• uplift potential. | Lining costs are usually high, so care needs to be taken to prevent damage to liners.<br>Liners should also be carefully chosen, as some liners can be toxic to cultured organisms.<br>Synthetic liners will not work in all situations, as a build up of water pressure behind liners can force them partially or completely away from the bottom or banks of structures.<br>Some liners may also reduce soil respiration so can effect nutrient dynamics within growout ponds.<br>Some liners can present safety concerns (such as slippery banks and rusting anchors). |
| Interception bores | Interception bores involve the installation of a series of active extraction bores around the containment areas to intercept any seepage and maintain groundwater levels below the level required for embankment stability or waterlogging considerations. | The design of dewatering systems, including depth of dewatering bores, extraction method (gravity discharge to buried main, submersible pump, airlifting, or suction), and bore spacing, will vary from site to site and should be assessed by a suitably qualified and experienced hydrogeologist or groundwater engineer. | Associated running costs are relatively high.<br>Collection by gravity drainage to a buried main, discharging to a common low-level sump can be feasible for long-term operation, subject to suitable site topography.<br>Any collected water may need treatment prior to re-use or release.<br>Any dewatering in coastal areas should be adequately assessed and managed to ensure acid sulfate soils are not drained and oxidised. |

| | | | |
|---|---|---|---|
| Interception trench or ring trench | Interception trenches can be installed between the farm and environmentally sensitive areas, or installed surrounding the entire containment area perimeter. Trenches can either be open, although this induces additional risks, or can comprise a properly designed and constructed, graded gravel-filled trench, with a perforated collection pipe. | Trenches can be used where groundwater is naturally shallow, or to limit the extent of any groundwater mounding. As with embankment design, any trenches should be designed by a suitably qualified and experienced person and constructed to maintain bank stability and prevent piping erosion or blockage of the gravel backfill. | Intrusion of surface waters may increase discharge water volume and quality.<br>Any collected water may need treatment prior to re-use or release.<br>Any dewatering in coastal areas should be adequately assessed and managed to ensure acid sulfate soils are not drained and oxidised. |
| In-situ treatment of contamination | In some cases, where water used in growout ponds is compatible with surrounding groundwater except for a limited number of chemical parameters, such as pH or nitrate, in-situ treatment of seepage plumes is possible. | This treatment option is generally only used where some other containment option has failed and remediation of groundwater contamination is required. In-situ treatment systems should be designed by a suitably qualified groundwater engineer or hydrogeologist. | This technique is generally expensive to establish and maintain.<br>Unlikely to be feasible for routine aquaculture operations. |
| Monitored natural attenuation | This option uses natural processes to attenuate any seepage and contamination prior to affecting environmentally sensitive areas. Attenuation can occur through dilution by advection and dispersion, dilution by intervening recharge, biochemical decay, or adsorption. | This treatment option is generally only used where some other containment option has failed and remediation of groundwater contamination is required. Monitored natural attenuation is a possible option only where aquifer and growout pond water's physical and chemical properties are suitable, and sufficient buffer distances are available. In order to satisfy licensing agencies that this method is appropriate, highly detailed site-specific assessment and detailed ongoing monitoring and validation is normally required. | Monitored natural attenuation can be expensive.<br>Unlikely to be feasible for routine aquaculture operations. |