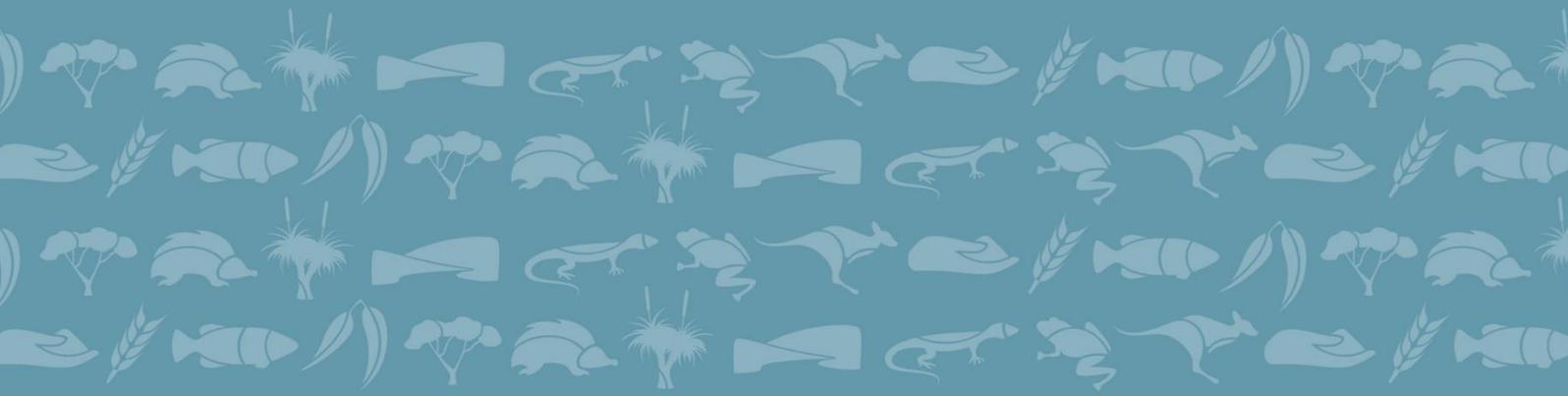


**FARM DAMS – A GUIDE TO SITING, DESIGN,
CONSTRUCTION AND MANAGEMENT ON EYRE
PENINSULA**





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1. INTRODUCTION

Water has always been an important factor for farming on Eyre Peninsula. This fact has been reinforced by the recent run of dry years, 2006 - 2009. With generally low rainfall (under 500mm), high evaporation rates, permeable soils and flat landscapes – there is a lack of abundant runoff and surface water resources on EP (EPNRMB 2009b).

Despite this relative water scarcity, a substantial proportion of Eyre Peninsula farms rely on dams and catchment drains to provide both critical livestock water supplies and water for domestic uses.



Photo: Peter Ciganovic

The majority of dams occur in the southern and eastern ranges, where surface water flows are generally ephemeral and responsive to dominant winter rainfall. Salinity has become a major threat in the region (EPNRMB 2009b), a result of inherent factors (rainfall, evaporation and flat landscapes) and compounded by vegetation clearance for agriculture, which has altered the hydrology and salt movement in the landscape.

Increasing adoption of minimum and no-till farming practices (for production and environmental benefits), and a run of dry years, have resulted in many farm dams struggling to capture enough water to sustain existing stock and domestic requirements. Water is now very often limiting the current and potential expansion of livestock enterprises.

Areas for improvement in the establishment and management of farm dams on Eyre Peninsula have been identified. Dams are often poorly constructed due to inadequate compaction or are built using unsuitable soil types. Siting of dams in low lying areas prone to salinisation has also been an issue of concern on Eyre Peninsula. Many farms have an abundance of small stock dams which invariably go dry or saline. Water lost to evaporation could often support significant additional stock numbers.

Issues of water supply and delivery to livestock on Eyre Peninsula are being addressed through the Sustainable Stock Water Supply Project run by the Eyre Peninsula Natural Resources Management Board (EPNRMB or ‘the Board’). This document (*Farm Dams – A Guide to siting, design, construction and management on Eyre Peninsula*) aims to provide technical information to support landholders in key areas of dam **siting, design, construction and management**.

The wide variety of issues that need to be considered will be covered through discussion of both generally applicable and situation-specific best practice principles.

A list of references and further reading is provided for the reader to find more detailed information on particular topics of interest.



1.1. SCOPE OF THIS DOCUMENT

This document provides guidelines and introduces key concepts associated with farm dams. Its intended audience includes farmers, advisors, dam builders, earthmoving contractors and natural resource management (NRM) workers.

This Guide can be seen as a combination of:

- principles to ensure equitable sharing of the water resource and protection of environmental assets
- design features to provide stable, safe and effective dam structures
- further information to optimise water supplies for farmers

This document is not intended to replace the need for appropriate professional engineering advice, particularly in areas concerning dam construction where the failure of built structures may endanger life, property or important environmental assets.

Professional consulting engineers should be engaged in such circumstances.

Figure 1 below depicts some of the terminology used when discussing dams. Figure 2 provides an outline of the content of this document.

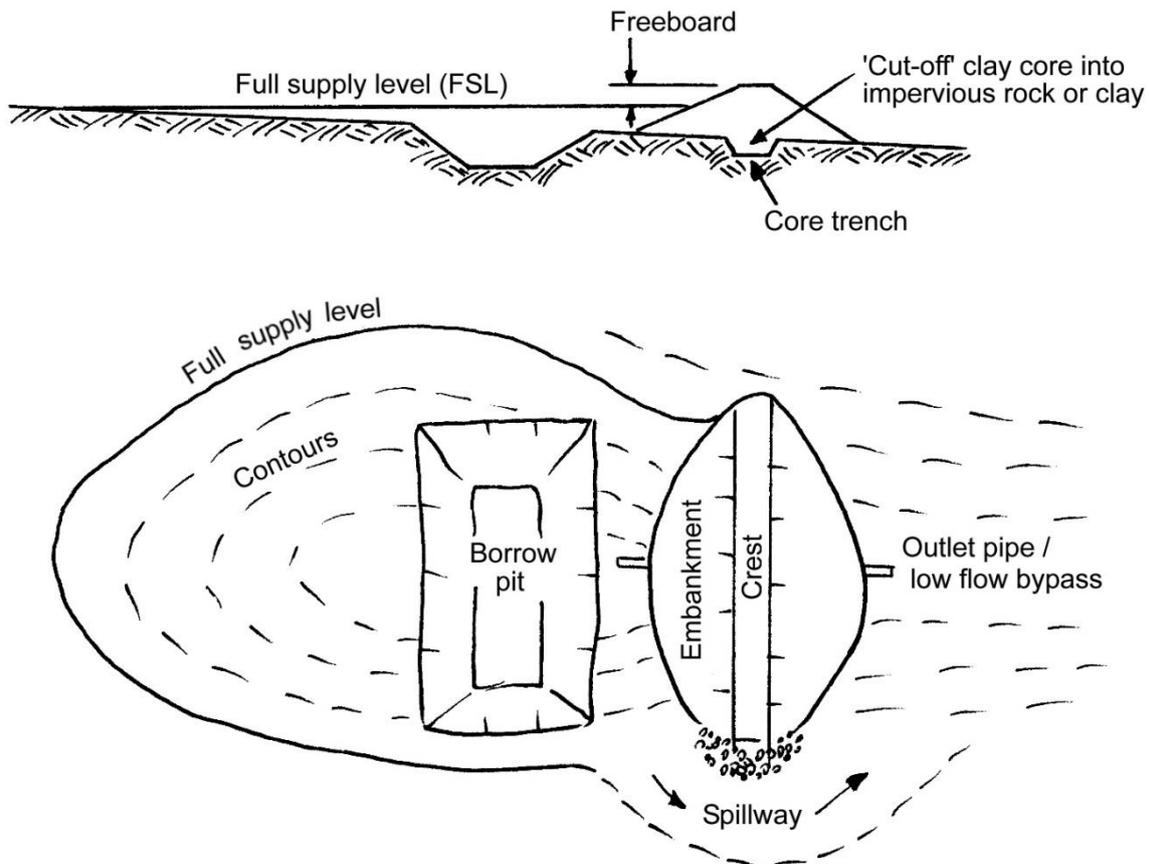


Figure 1. Dam terminology

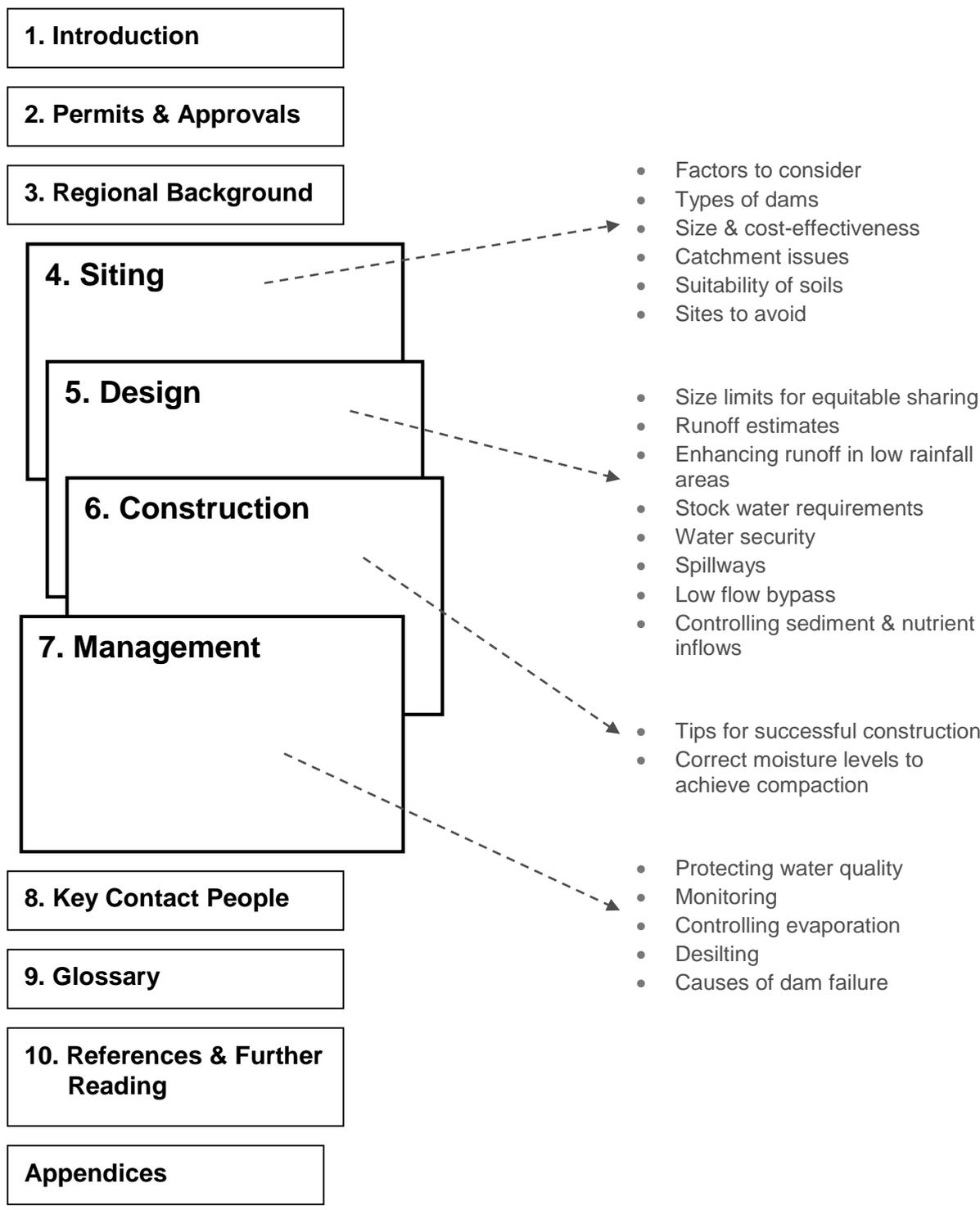


Figure 2. Outline of content in this *Farm Dams: – A Guide to siting, design, construction and management on Eyre Peninsula*)



2. PERMITS AND APPROVALS

Key points

- EPNRMB staff can provide advice on permits and approvals.
- In priority (southern EP) catchments new dams, and modifications to existing dams, require permits, capacities are restricted and principles of construction need to be followed (see Figure 22, page 26).
- Across South Australia, dams above 5ML in capacity or with a dam wall height of 3 metres or above will require development approval from the local council.

2.1. WHY CONTROL DAM DEVELOPMENT?

Rules are needed to protect downstream users and to ensure the resource is shared equitably between water users and the environment. This is particularly important where levels of dam development are high (e.g. southern Eyre Peninsula).

The approval process (through the EPNRMB) also allows critical aspects of dam design to be considered – such as preserving low flows for vulnerable water dependent ecosystems.

Larger dams are controlled under the *Development Act 1993* and regulations, due to the risks of failure to public safety, property and the environment.

2.2. ESTABLISHING NEW DAMS

Establishing a new dam is a water affecting activity (WAA), however permit requirements will vary between regions. Due to significant levels of existing development and potential impacts to sensitive water-dependent ecosystems, ‘priority catchments’ within southern Eyre Peninsula have been identified, as outlined in the Board’s latest Plan (EPNRMB 2009a). Proposed new dams in the Hundreds¹ of the priority catchments (also see Figure 22) require permit approvals through the EPNRMB and have restrictions on the allowable dam volumes (Section 5.1).

Proposed new dams in more northern regions (ie. Hundreds not listed in the footnote below), and under the ‘development size’ (see below) do not require permits.

Is development approval under the *Development Act 1993* required?

In some cases it will be. For example, if the dam wall is higher than 3 metres above the natural surface of the ground or has a capacity greater than 5 Megalitres (ML).

¹ The dam construction objectives and principles of Section 127(5)(a) [EPNRMB 2009a] – see Appendix 2 - apply only in the Hundreds of Ulippa, Cummins, Stokes, Yaranyacka, Warrow, Mortlock, Koppio, Hutchison, Wanilla, Louth, Lake Wangary, Uley, Sleaford and Lincoln (see Figure 22).



2.3. MODIFYING EXISTING DAMS AND CATCHMENTS

Do I need a permit?

WAA permits may be required for some management activities in the priority (southern EP) catchments only. The EPNRMB can be contacted for advice about your particular situation.

Native vegetation clearance applications (where exemptions are not covered under Native Vegetation Council policy) are required throughout the whole State.

Table 1 below covers some of the dam and catchment management options that landholders might consider.

Table 1. Permit requirements for dam and catchment management activities.

Management Options	*Do I need a permit?
(1) Clean out silt - in accordance with EPNRMB policies**	No
(2) Fence out stock a) With no native vegetation clearance b) Involving native vegetation clearance	a) No b) Yes
(3) Establish native plants / grasses to stabilise soil & filter nutrients	No
(4) Distribute water to an external trough	No
(5) Enhancing catchment runoff via: a) Herbicide control b) Graded or roaded catchments c) Plastic sheeted catchments	a) No b) Yes c) Yes
(6) Changes to capacity, dam wall height or low flow bypass	Yes

Notes: 1. * Water affecting activity (WAA) permits are required in the priority catchments (southern EP) only. WAA permit applications need to be submitted for assessment by the EPNRMB. Unless exemptions apply, native vegetation clearance applications are required for the whole State.

2. ** See Appendix 2 'Dam maintenance' (EPNRMB 2009a)

Even though permits are not required for dams outside the priority catchments it should be pointed out that landholders still have a general statutory duty to protect the environment.



3. REGIONAL BACKGROUND

Key points

- On-site information is essential
- However ... regional mapping information can highlight important issues for dam siting and construction (see Appendix 1).

Climate

The climate of EP varies from mild, moist, coastal conditions in the south and southwest to a warmer, drier climate inland to the north. Mean annual rainfall varies from 250mm in the north and northwest to more than 500mm in the south.

Evaporation is high throughout the region with mean monthly Class A pan evaporation exceeding median monthly rainfall throughout the year, except in the south during winter. Mean annual evaporation varies between 1550mm at the Tod River reservoir and 2300mm at Ceduna (EPNRMB 2009b).

Farm dam settings

Farm dams occur across a broad range of climatic and on ground conditions.

The majority occur within surface water catchments of the eastern and southern ranges. Elsewhere, localised suitable conditions and/or the necessities of livestock production will influence the distribution of farm dams.

On-ground conditions are important for various aspects of farm dam establishment and management, and usually dictate:

- the suitability of on-site materials
- the levels of technology and catchment management needed to establish a useful water supply
- the economic viability of farm dam development.

The maps shown in Appendix 1 highlight important factors for consideration when planning new dams. These factors include rainfall, evaporation, dominant soils, geology, soil sodicity (indicating dispersion), acid sulphate soils, saline seepage, proportions of clay in soils, among other information. The historic distribution of dams (taken from 1:50,000 topographic mapping), is shown in Appendix 1. Higher dam densities indicate areas that have suitable clays and topography for dam building (however runoff may be limited due to high numbers of existing dams).

These maps are not intended to substitute for specific on-site investigations when it comes to identifying potential problems or factors to consider!

On-site information needs are discussed in more detail in the following sections – and will include the likes of: checking the quantity and quality of clay with a backhoe or soil auger holes, performing soil and water tests and checking local flooding histories.



4. SITING

Key points

- A number of factors need to be considered simultaneously when looking for dam sites.
- The type and size of dam, quantity and quality of clay soils and catchment runoff characteristics are critical factors.
- Soil testing and professional advice will help with decisions.

4.1. GENERAL PRINCIPLES

Factors to consider when seeking a site for a dam include:

- type of dam
- size and storage ratio
- catchment or source of water
- soils for foundation and bank materials
- proximity of dams should be as close as possible to where water will be used
- spillway or by-pass site
- protection of sensitive environments

4.1.1. Types of farm dams

The siting, type and purpose of a farm dam will all be inter-related. Different factors will play a greater role depending on the specific situation. Stock dams must be deep enough to allow for losses through evaporation, so a site with deep suitable clayey soils is best. It is often beneficial, where possible, to take advantage of natural topography to maximise the water storage, compared to excavation volume (storage ratio).

Farm dams can be broadly divided into on-stream or off-stream:

On-stream dam

A dam, wall or other structure placed on, or constructed across a watercourse or drainage path for the purpose of holding back and storing the natural flow of that watercourse or the surface water runoff flowing along that drainage path.

Off-stream dam

A dam used to store water that is diverted from a watercourse or surface water run-off, by a wall or other structure. Off-stream dams will normally capture a limited volume of surface water from the catchment above the dam.



Gully dam

This is an on-stream dam commonly used in undulating country. Runoff and watercourse flows back up behind the embankment for some distance, particularly in lower catchment areas where drainage line gradients are flatter. This type of dam is favoured for its good storage to excavation ratio (large water storage for minimal cost of excavation/ earth works).

These sites can be associated with good clay deposits (within floodplains and flatter sloping country).

Potential problems can occur:

- where saline seepage is present.
- In hot, dry inland regions if the storage is shallow with a large surface area, potential for evaporation losses is greatly increased.

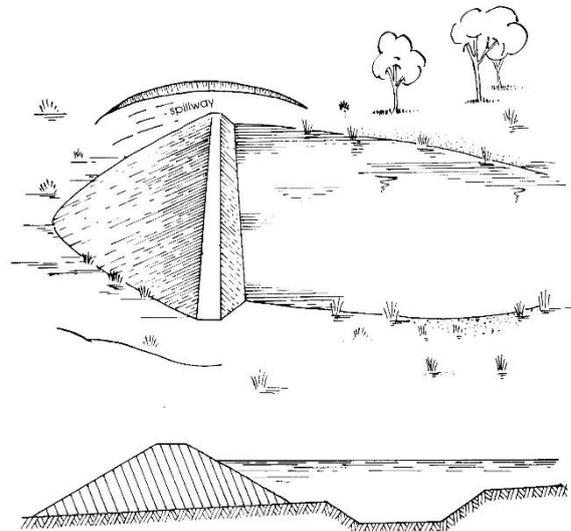


Figure 3. Gully dam (Nelson 1985)

In priority catchments there are restrictions on placing new dams in lower (downstream) catchment areas – ie. dams should not be placed on third order or higher level watercourses (see Appendix 2).

Hillside dam

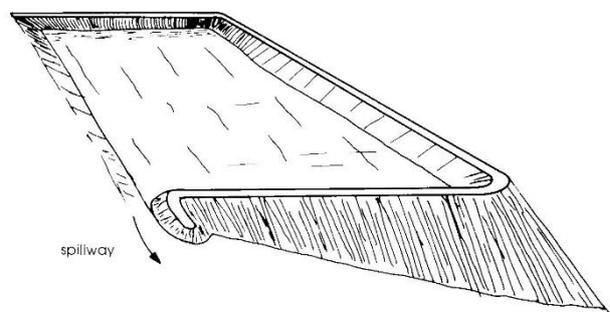
This is an off-stream dam often comprising a low three sided bank or long, curved bank straight across the across the hillside slope (on the contour). They are usually filled by diversion drains or graded catch drains. Suitable sites may rely on the presence of hillside clay deposits (perhaps due to in-situ weathering of the underlying rock).

Potential advantages include:

- diversion drains can extend the catchment area significantly, enabling siting high in the catchment to avoid saline seepage and damaging floods which may occur down slope.
- elevated positions can provide a source of gravity supplied water.

Potential disadvantages include:

- lower storage (to excavation) ratios





- difficult or impractical to excavate in shallow soil / rocky sites.

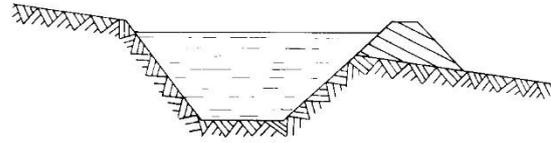


Figure 4. Hillside dam (Nelson 1985)

Excavated tanks

These are suitable for flat sites where pumping is impractical or undesirable. The excavation becomes the water storage, below the surface level.

Earth removed is stockpiled nearby, unless extra dam walls are constructed for additional storage above ground level.

Potential for intercepting shallow saline groundwater can be a disadvantage with these tanks

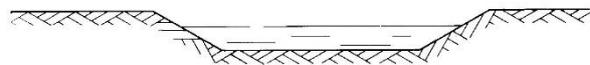
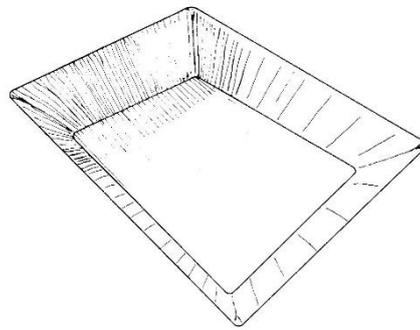


Figure 5. Excavated tank (Nelson 1985)

The following are less common types of off-stream storages for South Australia. These are generally considered unsuitable for South Australian conditions being prone to leakage and high evaporation.

Ring tank / dam

This off-stream storage is constructed on relatively low sloping ground by using earth from inside the ring (circular or shaped to suit topography) to build the surrounding embankment. Water is mostly stored above the natural surface. They may have external sumps to temporarily store diverted surface flows prior to pumping into the dam.

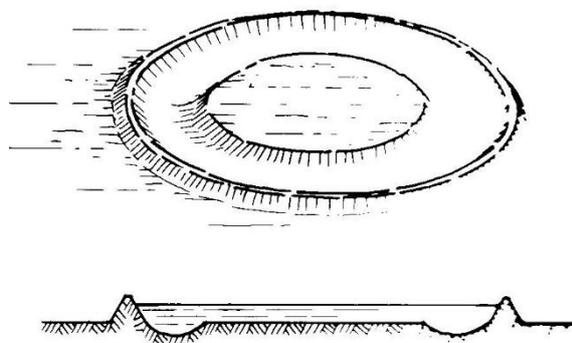


Figure 6. Ring tank (Nelson 1985)

'Turkey's nest' dam



These are a variation of the ring tank where the borrow pit is located outside the embankment. As with ring tanks they need to be filled from external sources as they cannot capture runoff. Water is stored above ground level, allowing gravity flows through an outlet pipe from the dam's lowest point. These are not used in SA due to excessive leakage.

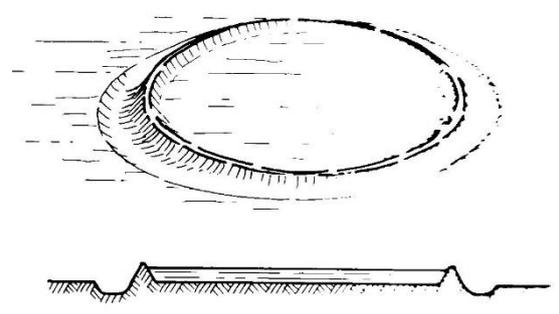


Figure 7. Turkey's nest dam (Nelson 1985)

View of dam inlet where drains discharge



Air photo: DEH

View from downslope



Hillside dams can provide a gravity-fed supply and use diversion drains to expand the catchment. The diversion drains (or banks) also protect the downslope paddocks from soil erosion.



Off-stream dams sited adjacent to roads can take advantage of reliable runoff events from the bare, compacted road (which acts as a catchment).



Gully dams have the potential for large water storage from minimal earthworks. However on-stream dams must cater for environmental flows and large dams need extra care with design and construction.



Excavated earthen tanks, sited in relatively low parts of the landscape are a common form of farm storage on EP. New dams of this type need to factor in reduced runoff rates from no-till farming practices to ensure sufficient catchment area.

Photos: Peter Ciganovic

Figure 8. Examples of siting dams in different landscapes.

4.1.2. Size and storage ratio

Typically the most economic sites will be where the most water is stored for the least amount of soil material moved. That is where storage to excavation ratios (also known as ‘storage ratios’) are low. This means minimal excavation and low dam wall heights. Highly desirable sites may have a storage ratio of 10 or higher (Cummings 1999b).

Gully dams

Gully dams can offer high storage to excavation ratios and are typically the most cost-effective. A narrow valley with a flat area widening out upstream from the bank is ideal for storing large volumes. If the floor slope is less than 1:20 (~3°) a relatively low bank will store water over the natural surface for a considerable distance upstream (Cummings 1999c).

Difficulties with this approach may occur in priority catchments where dams are not allowed to be placed on third order or higher level watercourses (Appendix 2). This restricts dam placement further downstream where catchment slopes tend to flatten out.

Another potential issue will be in higher evaporation (inland, northern) regions, where flatter sites, with shallow water storages will have higher potential evaporation losses and higher rates of salinity build up. In these situations deep excavations are used to overcome evaporation, through higher volume to surface area ratios.

Estimates for storage volumes in gully sites can be made using the following formula:

Storage size potential (Gully site):

$$V_g = (d \times w \times l)/3000 + V_e$$

Where:



V_g =	Total volume of water stored behind bank (Megalitres, ML)
d =	depth of water adjacent to bank (m) but not including excavation depth
w =	width of water body at full supply level adjacent to bank (m)
l =	length of water body from bank to inflow point (m)
V_e =	Volume of excavation below full supply level (ML)*

(Cummings 1999b)

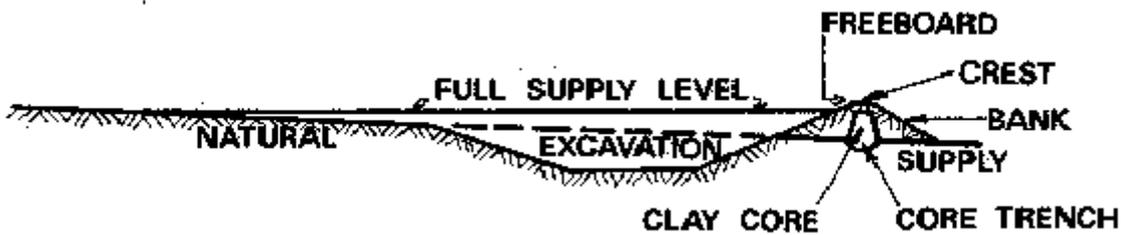


Figure 9. Sketch of cross section of a gully dam (Cummings 1999c).

*The volume of a rectangular battered excavation can be estimated using:

Volume of rectangular sided excavation:

$$V_e (\text{rect pit}) = L_{\text{half height}} \times W_{\text{half height}} \times D$$

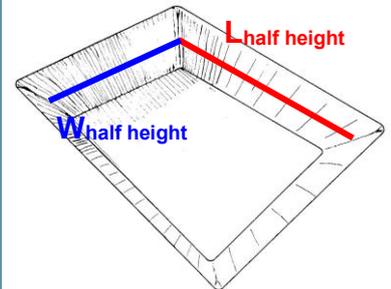
Where:

$V_e (\text{rect pit})$ = Volume of a rectangular sided pit (kL)

$L_{\text{half height}}$ = Pit length at half height of the pit (m)

$W_{\text{half height}}$ = Pit width at half height of the pit (m)

D = depth of the pit (m)



Hillside dams

With higher slopes associated with hillside dams, the storage to excavation ratio can be quite low (1.5 is common). A site that is as flat as possible should be sought, taking into account soil suitability and catchment yield. With small storages of less than 1 ML (commonly used for stock water), storage to excavation ratios of less than 1.0 are likely if slopes are steeper than 1:10 (~6°) (Cummings 1999c).





Figure 10. Sketch of cross section of a hillside dam (Cummings 1999c).

Estimates for storage volumes for a hillside site can be made using the following formula:

Storage size potential (Hillside site):

$$V_h = (d \times A)/3000 + V_e$$

Where:

V_h = Total volume of water stored behind bank (ML)

d = depth of water adjacent to bank (m) but not including excavation depth

A = surface area of water body when full

V_e = Volume of excavation below full supply level (ML)*

(Cummings 1999b)



4.1.3. Catchment or source of water

A good dam site needs sufficient run-off, of a suitable quality.

Decisions on catchment suitability will be assisted by knowledge of local history, monitoring data or other indicators of:

- quantity and quality of small to large runoff events
- catchment erosion and sedimentation issues
- potential pollutants or contaminants from agricultural land use (e.g. fertilisers, pesticides, disturbed soils) or land degradation issues (salinity, acidity)
- potential for enhancing catchment runoff

Potential runoff

Do upslope soils run water well? Runoff will be reduced by permeable soils, areas of minimum or no till cropping and large tracts of native vegetation. It is normal that soil moisture will need to build up – before catchments will wet up and run water – following drought or extended dry periods.



Runoff is determined by the rate of infiltration and interception by plants. Generally pastures do not run water. Antecedent moisture levels need to be high for runoff to occur!

Figure 11. New farming practices which promote crop water use efficiency (e.g. no-till cropping, increased perennials, etc.) will reduce run-off rates. Land use needs to be factored in when considering new dams and catchments.

Runoff coefficients have already been estimated for priority catchments (EPNRMB 2009a), as shown in Appendix 1. The EPNRMB has taken the further step of limiting the total allowable capacity of allotment based on a Megalitres per Hectare ratio in priority catchments (Section 5.1).



In drier (inland, northern) catchments runoff yields can be estimated using Table 4 (page 28). Estimates of average annual catchment yield (allowing for a variable climate) can be made using the formula on page 28.

But note: In areas with less than 400mm annual rainfall, runoff can be extremely variable!

Enhancing catchment runoff

A range of methods can be used to enhance catchment runoff:

- **Roaded and graded catchments** – these rely on exposing and rolling less permeable clay layers to enhance runoff. The feasibility of these options is determined by the presence of suitable soils and the cost of earthworks. It is suggested that sub-soil clay needs to be within around 20 cm of the surface in order to be cost effective.
- **Roads and existing farm tracks** – Historically roads as catchments have been used to collect and divert water into dams. Both public and farm roads, can be utilised to enhance water catchment.
- **Use of diversion drains**– this can extend the catchment area, and sometimes enable dams to be placed high in the catchment (avoiding potential saline seepage).
- **Spraying catchments (herbicide control)** – may be used in conjunction with other options discussed here, as well as controlled grazing. Site-specific soil and seasonal conditions need to be taken into account – spraying at the optimum time of year to reduce water use and interception by plant canopies while retaining enough protective cover to offset erosion risk. Maintaining plant cover to avoid erosion may be less of an issue in some highly engineered / compacted catchment areas and on soils less prone to erosion.

WARNING: When using Pesticides adjacent to water-bodies, natural lakes or dams, watercourses, and wetlands do not spray when weather conditions may cause drift, leaching or run-off. The Board advises, that before using pesticides, read the product label and that the products are always applied as per label instructions.

- **Plastic sheeted catchments** – welded plastic sheets provide maximum runoff and good quality water, at higher cost.

Examples of improved catchments are shown in Section 5.7. WAA permit and approval requirements should be discussed with the EPNRMB. The cost-effectiveness of these options needs to be assessed by the landholder.

Salinity and acidity

The site should be free from saline seepage and avoid acidic runoff associated with acid-sulfate / saline-sulfidic soils. Problems to look for include:

- **Saline inflows** – are typically associated with groundwater discharge zones / springs / stream baseflow, or salts deposited in the surface soils which can leach into dams following rainfall.



Look for signs of: springs and saline baseflow, areas of poor crop emergence, seasonally or permanently wet areas, salt efflorescence in summer, indicator plant species (e.g. sea barley grass, samphire, etc.). The depth to watertable should also be investigated – e.g. if a backhoe pit fills with saline groundwater.

The foundation of the dam should be above the highest seasonal watertable height.

Low flow bypasses for on-stream dams will help to divert saline inflows (see page 38, Appendix 2 and Appendix 4 for more details).

- **Acidity** – low pH waters can cause health problems in stock by making toxic heavy metals more available. While acidity is increasing in many agricultural soils (associated with the use of nitrogen based fertilisers and the removal of plant and animal products) this can be offset by the inherent alkalinity of much of Eyre Peninsula’s calcareous soils.

Acid sulfate (also called saline sulfidic) soils are an issue that land managers are becoming increasingly aware of. These occur where waterlogging and biological activity has induced permanent changes in sulphur-containing sediments. When these typically waterlogged areas dry out, or undergo periods of wetting and drying, the sediments are oxidised forming sulfuric acid and hard setting layers. Runoff events then cause the acid to be mobilised in surface water flows.

Look for normally wet areas that undergo drying cycles and are characterised by one or more of the following: black boggy soil, slimy red ooze, reddish-yellow iron rich deposits, hard impermeable iron-rich crusts, shiny oil-like surface layers, scalded and infertile patches of earth, acidic topsoil and subsoil (Fitzpatrick 1999). These areas should be further tested by a suitably qualified consultant and managed carefully. They should not be drained!





Photos: Craig Liddicoat

Figure 12. What to look out for: Saline discharge is characterised by poor crop growth, bare ground and indicator plants such as sea barley grass. This example shows saline discharge on low lying areas adjacent to Yeldulknie Reservoir.



Photos: Andrew Harding, Craig Liddicoat



Figure 13. What to look out for: Acid sulphate soils (and potential acid sulphate soils) are characterised by waterlogging (and drying cycles), poor crop and pasture growth, hard pans, red and black boggy soils, shiny oil-like surface layers and of course acidic soils and runoff.



Flood history

Consider (or seek out) local historic knowledge of reliability of flows, flood heights, etc. Speak to neighbours if you are new to the area.

Knowledge of flooding heights, severity and frequency may help with siting and design, particularly spillway design. Siting off-stream out of flood prone areas (with a sacrificial diversion bank) may avoid potential flood-induced damage to the main dam wall.

Sediment, nutrient and contaminants

Sites will typically need to make allowance for features such as sediment traps and grassed filter zones. Additional actions may be needed in the upstream catchment to manage the quality of harvested runoff.

4.1.4. Soils for foundation and bank materials

Dig test soil pits – to detect the quality, quantity and range of suitable clayey soils, down to around 0.6 to 1 m below the required foundation level for the embankment and storage using a back hoe and/or auger holes. If a back hoe is available on site this can excavate to depth quicker, without much extra cost, and will give a better view of materials than auger holes.

Digging test pits will also test for the presence of saline groundwater seepage and sand/gravel seams (which may cause leakage).

A minimum set of test holes should be dug beneath the centreline of the embankment and in the foundation of the excavation / borrow pit. For large dams, some experts recommend test holes should be dug on a 15m grid (Bourchier 1998).

The foundation materials should comprise impermeable clay or rock². Where impermeable materials are not found at depth, the site will not be suitable unless a liner is constructed, e.g. from imported clay or plastic.

The volume of available clay should be estimated. If there is insufficient clay at the preferred construction site, test for sources of good clay as close as possible to it. Construction costs will increase dramatically with distance to the clay source.

² Rock foundations are not ideal as the rock/ soil interface may provide a potential seepage path.

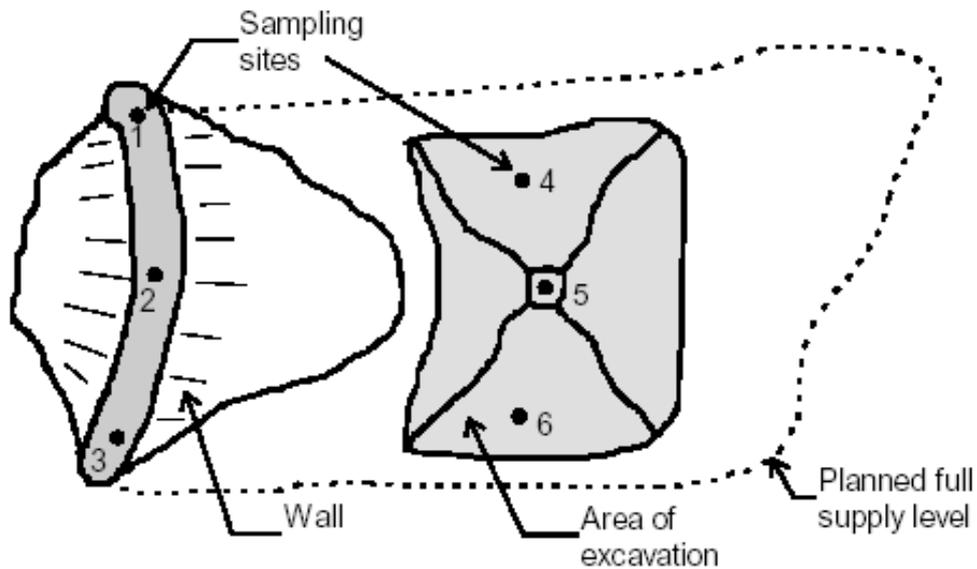


Figure 14. Example of a test digging pattern (Cummings 1999a).

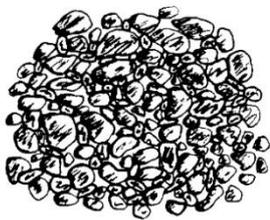
Testing the suitability of clay soils

Achieving a 'watertight' seal in dams requires soil porosity (ie. soil pores / air voids) to be minimised (see Figure 15a). Fine materials (clay particles) will help block up soil pores, and this is aided by low to moderate dispersion³ and compaction. Compaction is required at the correct moisture content such that clay clods are crushed and air voids squeezed out.

Only clays can hold water – but some clays require special treatment and others should not be used. Desirable qualities for clay soils used in dam construction are summarised in Table 2.

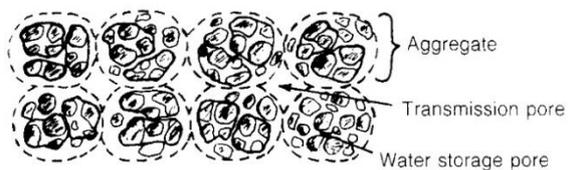
Some coarse material (e.g. sand) in the soil is desirable for structural strength.

(a) Structureless condition



Particles are packed as close together as possible. High density, low porosity

(b) Structured or aggregated condition



Particles are formed into aggregates and are loosely packed. Low density, high porosity

³ Some common soil terminology is explained in Box 1, on the following page.



Figure 15. Watertight dams need high density/ low porosity soils – this requires the right mix of fines (clay) content, some dispersion and sufficient compaction (Charman and Murphy 1991).



Box 1. Soil structural stability – definitions (Emerson 2002, Charman & Murphy 1991):

- **Slaking** – is the immediate break-up of dry aggregates into small fragments when dropped into water.

As a dry aggregate of soil is wetted, water enters from all sides and encloses the air within the aggregate. If the mechanical strength of the aggregate is low, the compressed air shatters it, generally into smaller aggregates.

- **Dispersion** – is the spontaneous deflocculation (dis-aggregation) of the clay fraction of a soil in water.

This is a characteristic of sodic soils (where there is an excess of Sodium ions on the ion exchange surfaces between clay particle layers). When water is added, water molecules are attracted to the Sodium ions, surrounding them and driving apart the clay layers – to the point where clay to clay bonds break down. Dispersion is exacerbated with low salinity water (e.g. rain water), where high osmotic pressures drive water molecules towards the Sodium ions on the clay exchange.

Conversely dispersion is alleviated with high salinity water. Dams containing saline water may be more prone to leakage due to reduced dispersion.

- **Flocculation** – is the reverse process of dispersion involving the aggregation (or coagulation) of clay in solution.

Slaking and dispersive soils are prone to erosion (see Figure 16). Highly dispersive soils are prone to ‘tunneling’ or tunnel erosion. This is where a dam wall may suddenly (and often dangerously) blow out after the development of an erosion tunnel starting at the wet side of the dam wall. A dispersive soil and a subsoil seepage path (e.g. fine cracks) are considered prerequisites for tunnel erosion.

Sodic, dispersive soils are common on Eyre Peninsula as indicated by Figure (9) in Appendix 1. A limited survey of dam embankment clays undertaken for the *Audit of farm dam issues on Eyre Peninsula* (Ciganovic et al. 2009) also found a high proportion of dispersive soils.



Figure 16. Examples of rill and gully erosion on dam walls and inlets. Dispersive clays can hold water well but are highly erodible if flows are concentrated and soil surfaces are unprotected. (Figure 25 shows some options to control the risk of erosion on dam inlets and walls.)



Table 2. Testing clay suitability for dam construction (adapted from Cummings 1999a).

Factor	Desirable	Undesirable	What is the potential problem?	How do I test this?
Clay %	A minimum clay content of 30% is recommended Some experts recommend 40% or more clay content (Matthews & Moore 1993)	Low clay content High gravel content	Without sufficient fine (clayey) material soil pores will leak.	Hand texture ribbon length: <ul style="list-style-type: none"> • More than 40mm (for approx > 30% clay) • More than 50mm (for approx > 40% clay) See Box 2 (next page)
Slaking	Low slaking		Erosion and bank stability	<ul style="list-style-type: none"> • Observe a dry soil crumb placed in water (see Box 1)
Dispersion	Low to moderate dispersion - some dispersion enables fine clay particles to mobilise when wet to block up and seal soil pores.	Too much or too little dispersion. Highly flocculated clay (ie. non-dispersive, well structured aggregates) can behave like gravel with high permeability (Figure 15b). Too much dispersion will lead to dam wall failure (e.g Figure 20).	Highly dispersive soils are prone to tunnelling (ESP > 15, but potentially ESP > 6 in some soils with pure dam water) The presence of carbonates can make clay assessment more tricky! Some moderate to highly dispersive soils can be treated by compaction at the correct moisture content – so that clay clods are crushed and air voids squeezed out. Suspect clays should be referred for expert advice!	<ul style="list-style-type: none"> • Dry soils which have no or low spontaneous dispersion – but disperse after working when moist (shaken in water in a glass jar) should be suitable • Dry soils that spontaneously disperse in a glass of fresh water (within 2 hours) are prone to failure – treat carefully! • Soils that will not disperse even after working when saturated (vigorously shaken in a glass jar then left for 10 minutes) – will be difficult to make watertight. If uncertain, lab tests and expert interpretation are recommended: <ul style="list-style-type: none"> • *Emerson's Aggregate Test • *Exchangeable Sodium Percentage (ESP)
Linear shrinkage	Less than 15%	More than 15%	Low shrink / swell capacity with wet and dry cycles reduces potential for shrinkage cracks	<ul style="list-style-type: none"> • See method in Cummings (1999a) and Figure 21 • *Lab testing
Organic matter	Negligible organic matter - except for top soil used to protect exposed faces of dam walls	> 0.5% organic matter	Organic material is considered unstable for dam construction	Top soil is only used to cover dam embankments. Tree roots should be removed and holes plugged with impervious clay
Permeability	This refers to the speed of water movement through soil. Ideally less than 1×10^{-9} metres/sec (< 0.0036 mm/hr)		Lab testing can confirm the suitability of a specific soil	<ul style="list-style-type: none"> • Mould a handful of the clay soil into a cup, fill with water and leave overnight. If the cup remains intact and no water has leaked it should be watertight. • *Lab testing will give the accurate measure.



Other laboratory testing	Further soil engineering tests can be used to determine suitability for dams, including those above(*) and: <ul style="list-style-type: none">• Particle size distribution• Plasticity limits
---------------------------------	--

Box 2. Testing soil suitability (Bourchier 1998)

Testing for soil suitability

Form a flat ribbon of soil between the thumb and forefinger. A ribbon more than 30 millimetres long indicates sufficient clay in the soil to allow for successful dam construction. Ideally, particle size distribution will be uniformly graded from clay to gravel, with a minimum clay content of 15–20 per cent although some designers prefer 20–30%.



- If the flat ribbon of soil formed in this way is more than 30mm in length the soil will contain at least 20% clay plus silt.
- A moist bolus which is hard to deform indicates a soil of high shearing strength, which is a desirable characteristic for wall construction. Organic content should be low (less than 0.5%).
- The soil should have low shrink-swell characteristics, and have low-to-moderate dispersion.
- The rate at which water is lost from a backhoe pit can give a guide to the likely performance of an excavated tank or the borrow pit for a gully wall dam.
- Strong resistance to auger penetration of clay subsoils, and high bulk density will generally indicate relatively low pore space and low soil permeability.
- It is suggested expert opinion is sought in regard to specific materials and specific projects.

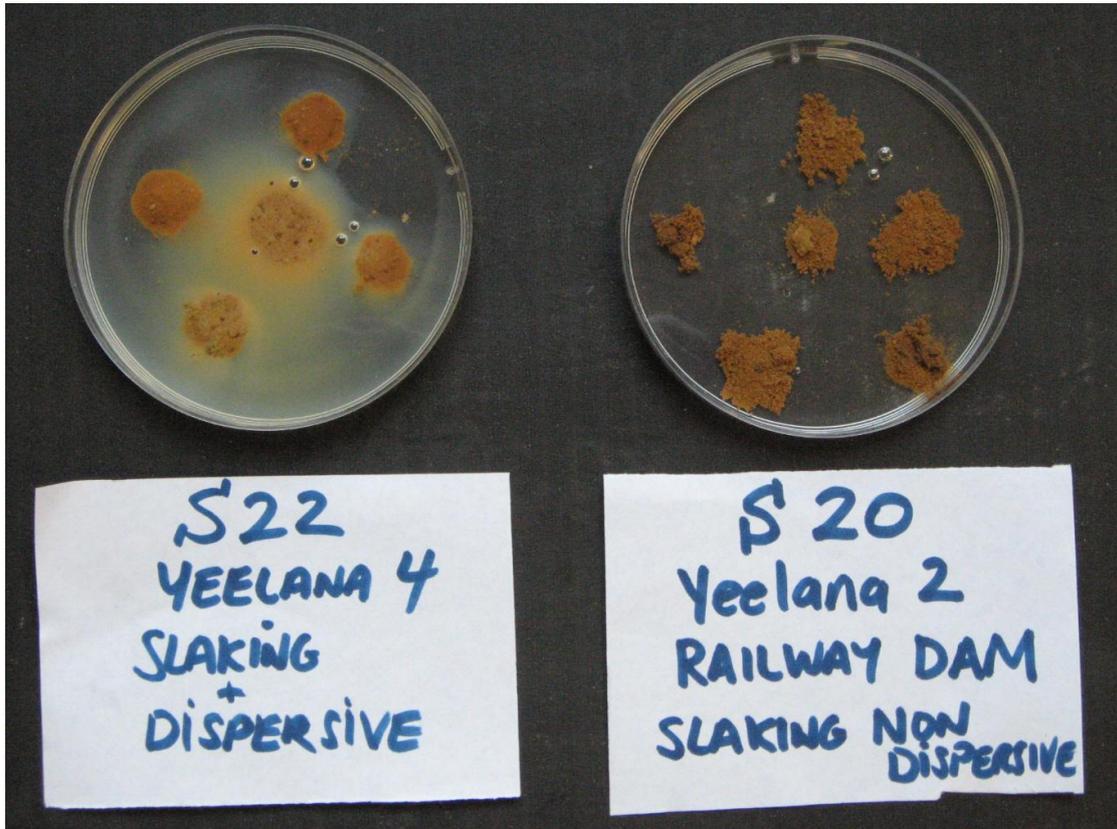


Figure 17. Soil crumb tests showing low to moderately dispersive (left) and non-dispersive (right) soils. Both of these samples show slaking.



Figure 18. A slaking and highly dispersive clay sample from Cummins shown at 5, 30 and 120 minutes after placing in distilled water. Highly dispersive soils need to be treated with caution. Gain expert advice!



Photo: Peter Ciganovic

Figure 19. After being shaken and left to stand for 10 minutes, the soil on the left is showing strong flocculation (re-aggregation). This particular soil shows low dispersive properties and would be difficult to make watertight.



Photos: Steve Moore

Figure 20. Top photo: dam built in dry soil by bulldozer at Wharminda in 1974. Bottom photo: dam bank breached at first filling due to insufficient compaction during construction.



Also note the minimal freeboard level visible by the high-water mark on dam wall, this could also have contributed to the dam wall failure.

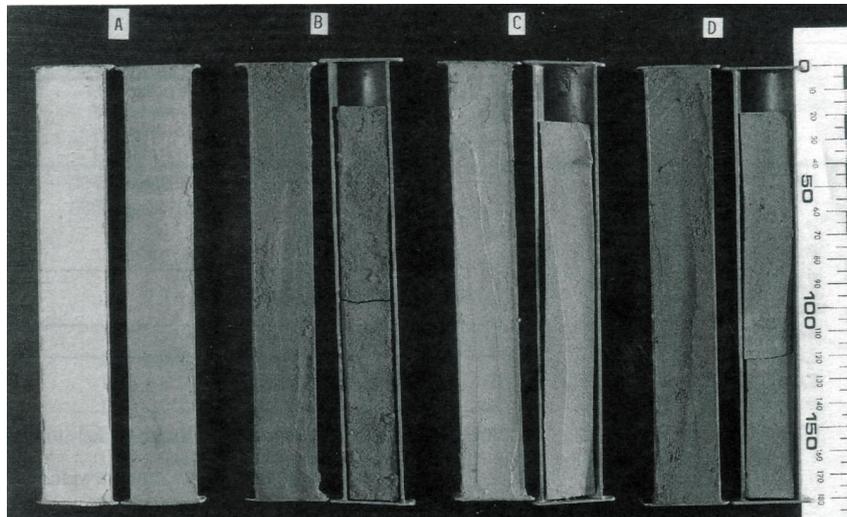


Figure 21. Linear shrinkage tests (Charman and Murphy 1991).

4.1.5. Site dams as close as possible to where water is used

Where possible dams should be located as close as possible to where water will be required. Pipeline length and friction associated with pumping can contribute a substantial amount to running costs.

4.1.6. Spillway or by-pass site

Dams, particularly gully dams in large catchments, have significant risks of failure during large floods. Large flows can cause spillway erosion and failure, and overtopping and failure of banks. Site selection should consider the availability of sufficient space, or opportunistic natural structures, to provide an adequate spillway.

The site must be topographically suitable to enable the spillway to be constructed as an integral part of the dam. (Spillway design is discussed in Section 5.5.)

Spillway flows should be returned to the normal drainage route before they leave a property.

4.1.7. Protecting sensitive environments

Dams should not be located in areas prone to erosion or areas that are ecologically sensitive. The following are examples of ecologically sensitive areas:

- remnant vegetation
- wetlands, permanent pools and aquatic ecosystems
- habitat for rare and threatened flora and fauna species⁴

⁴ Rare and threatened flora and fauna species (identified under the Commonwealth's Environment Protection and Biodiversity Conservation [EPBC] Act and South Australia's National Parks and Wildlife Act) and their



- conservation areas
- heritage agreement areas

5. DESIGN

Key points

- Principles of equitable sharing will place an upper limit on dam sizes.
- Site topography and soils, stock requirements, water security through dry years and the need to minimise evaporation – will also determine dam dimensions.
- Dam design also needs to consider floods, spillway erosion and low flow bypass requirements.
- Landholders will need to find the right balance between sound engineering principles and cost of construction.

5.1. DAM CAPACITIES – UPPER LIMITS TO ENSURE EQUITABLE SHARING

Priority (southern) catchments

In ‘priority’ surface water catchments of southern Eyre Peninsula, restrictions are placed on allowable dam volumes. This has occurred due to historic high levels of dam development and the need to ensure future equitable sharing of the water resource between downstream users including the environment.

In order to administer policies relating to farm dams, permits are required for new dam developments in the Hundreds within which the priority catchments are located (see Figure 22, or the list at the bottom of page 4). In these catchments the principles outlined in Appendix 2 should be adhered to (EPNRMB 2009a).

For the construction of new dams in the priority catchments, the following applies (EPNRMB 2009a):

Allowable dam volume:

$$V_{\text{pri}} = A \times V_{\text{allow}}$$

Where:

V_{pri} = Allowable dam volume in priority catchments (ML)

A = Area of *allotment (ha)

V_{allow} = Allowable volume (ML/ha) defined in Table 3

recorded locations can be investigated via the Department for Environment and Heritage [DEH] “EnvMaps” website: <http://maps.deh.sa.gov.au/>



Note: *Allotment means section, lots or allotment identified on a certificate of title, including two or more adjacent allotments owned or occupied by the same person and operated as a single unit for the purpose of primary production.



Example calculation (priority catchment):
 For a 100ha allotment in the Upper Tod subcatchment, the allowable dam capacity = $100 \times 0.054 = 5.4$ ML

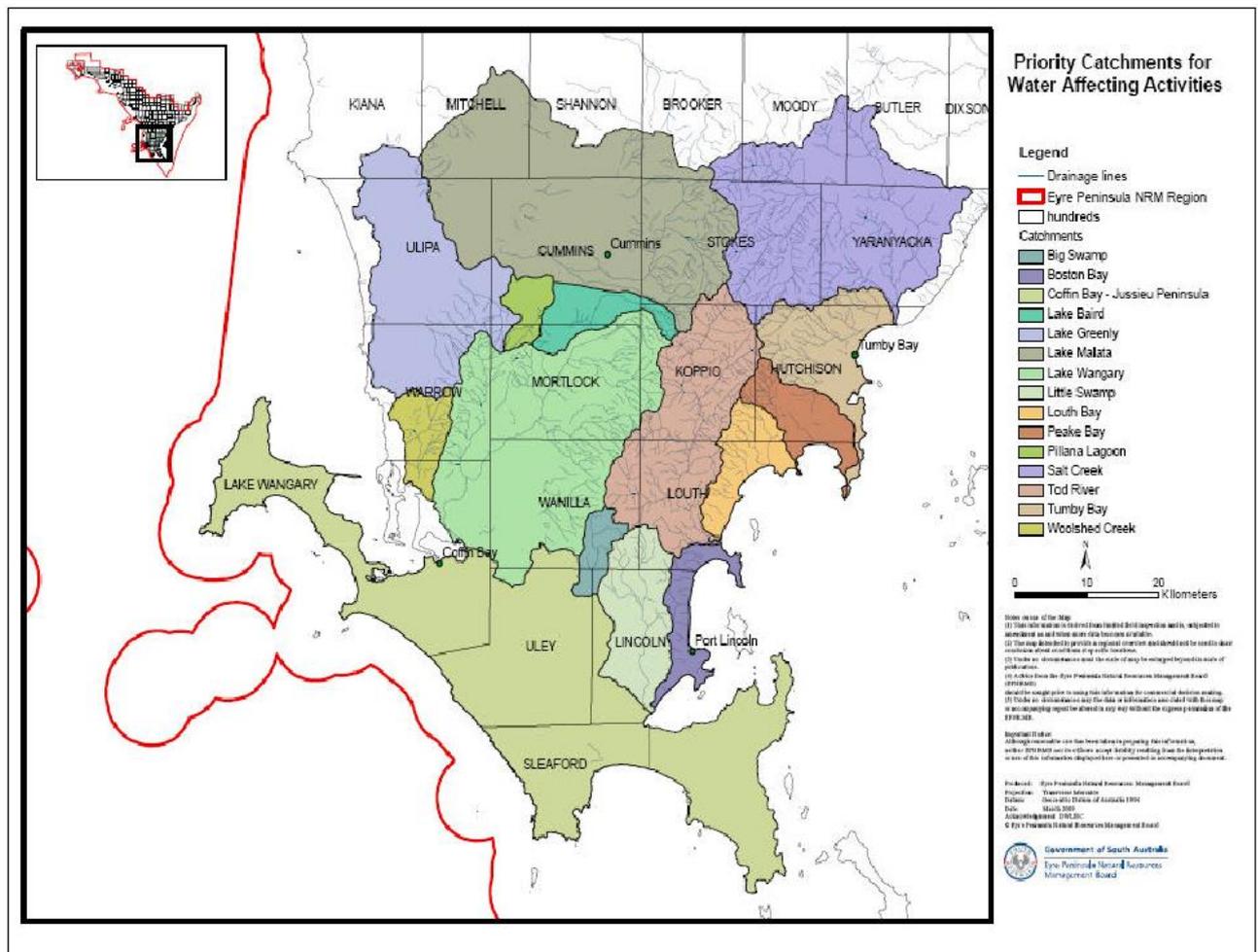


Figure 22. Priority catchments for water affecting activities (EPNRMB 2009a).



Table 3. Total catchment capacity and allowable dam volumes – for priority catchments (EPNRMB 2009a).

A Priority catchments (Figure 22)	B Catchment area (ha)	C Mean average rainfall (mm)	D Estimated surface runoff (ML/ha)	E Allowable dam volume (ML/ha)	F Total catchment capacity (ML)	G Unit threshold flow rate (L/s/ha)	Runoff ratio (Dx100/C)
Pillowarta	4000	475	0.14	0.042	168	0.004	0.029
Upper Tod	10800	500	0.18	0.054	583	0.008	0.036
Toolillie	3900	515	0.21	0.063	246	0.100	0.041
Charlton	6600	535	0.25	0.075	495	0.014	0.047
Lower Tod	14100	485	0.16	0.048	677	0.005	0.033
Lake Wangary	71900	530	0.24	0.072	5177	0.013	0.045
Big Swamp	4600	585	0.36	0.108	497	0.022	0.062
Little Swamp	7900	545	0.27	0.081	1450	0.015	0.050
Lake Malata	84900	445	0.10	0.03	2547	0.003	0.022
Salt Creek	63100	400	0.06	0.018	1136	0.002	0.015
Lake Greenly	42000	490	0.16	0.048	2016	0.006	0.033
Pillana Lagoon	4700	495	0.17	0.051	240	0.007	0.034
Lake Baird	8800	490	0.16	0.048	422	0.006	0.033
Tumby Bay	19400	385	0.04	0.012	233	0.002	0.010
Peake Bay	10400	410	0.06	0.018	187	0.002	0.015
Woolshed Creek	7500	527	0.23	0.069	518	0.012	0.044
Louth Bay	10200	450	0.11	0.033	337	0.003	0.024
Coffin Bay – Jussieu Peninsula	120000	555	0.29	0.087	10440	0.017	0.052
Boston Bay	8100	435	0.16	0.048	389	0.005	0.037



Outside of 'priority' catchments

Design considerations for environmental purposes and equitable sharing of water resources outside the priority catchments are discussed in Appendix 3.

Calculating catchment yields

The following formula can be used to estimate catchment yield:

Catchment Yield:

$$Y_{\text{catch}} = A \times \text{Rain} \times \text{Runoff} \times 10$$

Where:

Y_{catch} = Catchment yield (kL)
 A = Area of your property in the catchment (ha)
 Rain = Average annual rainfall (mm)
 Runoff = Runoff coefficient*

- Notes:
1. Catchment areas can be delineated on topographic maps by sketching around the topographic high points (hill tops, spur lines) from which water should flow to your dam site. 1 hectare (ha) = 100 metres x 100 metres = 0.01 km².
 2. *The following table contains example runoff coefficients (or seek local advice from the Department of Water, Land and Biodiversity Conservation, Science Monitoring and Information Division – Surface Water Unit, or the EPNRMB).
 3. Runoff coefficients for sheeted, roaded and graded catchments are shown in Table 13, Section 5.7.

Runoff in areas where rainfall is < 400mm is extremely variable.

Table 4. Runoff estimates from different soil types (Nelson 1985).

Annual average rainfall (mm)	Total annual evaporation (mm)	Runoff as a percentage of average annual rainfall			
		Shallow sand or loam soils (%)	Sandy clays (%)	Elastic clays (%) [#]	Clay pans, inelastic clays or shales (%) ^{##}
Over 500	1300 to 1800	3 to 5	3 to 8	3 to 6.5	6.5 to 10
401 to 500	1300 to 1800	1.5 to 3	3 to 6.5	1.5 to 3	5 to 8
250 to 400	less than 1800	0 to 1.5	0 to 3	0 to 1.5	1.5 to 5
	more than 1800	0	0 to 1.5	0	1.5 to 3

- Notes:
1. Percentage runoff is expected to be equalled or exceeded in 9 out of 10 years. In wetter than average years, % runoff is expected to be higher.
 2. Percentage runoff values will vary with land use. Values at the lower end of ranges given are expected for native vegetation blocks, forested, cultivated and pasture-improved areas. Upper limits should be used with caution.
 3. [#]Elastic clays when dry develop pronounced surface cracking, which reduces runoff
 4. ^{##}Inelastic clays are identified when dry by a fine dust cover; this dust prevents seepage into the ground and so increases runoff.

Example calculation (non priority catchment):



For 200ha of hillslope catchment with loamy soils (comprising 80ha native vegetation and 120ha of cleared land), mean annual rainfall of 350mm, and estimated runoff coefficient from cleared areas of 0.01 (1%) – annual average catchment yield is estimated = $(80 \times 0 + 120 \times 0.01) \times 350 \times 10 = 4200 \text{ kL} = 4.2 \text{ ML}$

5.2. STOCK WATER REQUIREMENTS

The next important question is ‘how much water do I need for my stock?’

Consumption rates

Figures taken from a three year study (Wright & Ashton 1978) conducted in a hot environment by the Minnipa Research Centre indicated that:

- Merino ewes drank an average of 1.6L a day over three years.
- The highest month of consumption was 3.7L a day in January and the lowest was 0.1L a day in August.
- The highest rate consumed over a week was 6.1L a day.
- Cattle used twice as much water as sheep on a dry-sheep-equivalent (dse) basis.

Average rates of consumption are useful for designing storage capacity

Peak rates of consumption are useful for designing delivery systems (pipes, pumps & troughs)

Increased consumption will occur (at times):

- On saltbush (up to 14L a day but sheep very rarely graze pure saltbush all year)
- With British Bred sheep (20% more)
- On lupin stubbles (young sheep will drink up to 50% more)
- At various times (extreme hot weather, leakages, etc)

Security of water supply

Due to the unreliable nature of stream flows, Nelson (1985) recommends different storage periods based on average annual rainfall. The thinking here is that dam capacities should be adequate to meet water supply needs, evaporation and seepage losses over the storage period.

Table 5. Storage periods for different rainfall zones (Nelson 1985).

Average annual rainfall (mm)	Storage period (months)
Less than 250	30 to 36
250 to 450	24
451 to 650	18
More than 650	12



Assuming average consumption rates of 1.6 litres per dse per day and evaporation losses of 50%, the table below summarises different dam volume requirements for different combinations of livestock numbers and storage periods.



Table 6. Dam capacities to meet stock water requirements* (units in Megalitres, ML).

Storage Years	Number of livestock (dse)				
	250	500	1000	1500	2000
1	0.29	0.58	1.17	1.75	2.34
1.5	0.44	0.88	1.75	2.63	3.50
2	0.58	1.17	2.34	3.50	4.67
2.5	0.73	1.46	2.92	4.38	5.84
3	0.88	1.75	3.50	5.26	7.01

*Figures are based on average yearly water consumption of 1.6 litres / dse/ day and evaporation and seepage losses of 50%.

Water quality

Salinity and other aspects of water quality are also a concern for livestock performance. This is discussed further in relation to dam and catchment management later in the document.

Water distribution systems

The fundamentals of pipeline design can be obtained from references such as *Liquid Assets* (Bourchier 1998) or through advice from local water industry consultants (refer to Section 8).

One important point is that water distribution systems need to cope with peak demands – not average rates of consumption. Also some form of back-up system or buffer storage should be present to cater for breakdowns and repairs.

5.3. MINIMISING EVAPORATION

The following are common methods for estimating annual evaporation losses from dams:

Annual Evaporation Loss (method 1- rough guide only):

$$E_{\text{loss}} = \frac{1}{2} V$$

Where: E_{loss} = Evaporation loss (ML)
 V = Dam volume at full capacity (ML)

Annual Evaporation Loss (method 2 – more accurate):

$$E_{\text{loss}} = 0.67 \times E \times A_{\text{FSL}} \quad (\text{Lewis 2002})$$

Where: E_{loss} = Evaporation loss (Litres) per year
 E = Local annual evaporation (mm)
 A_{FSL} = Dam surface area at full supply level (m²)

ML = Litres ÷ 1,000,000

Method 2 example:

Farmer has a dam at Koppio which has a surface area of 570m² when it is full. The annual evaporation is about 1200mm.

$$E_{\text{loss}} = 0.67 \times 1200 \times 570$$

$$= 458280 \text{ Litres per year}$$

Or

$$E_{\text{loss}} = 0.46 \text{ ML per year}$$



These estimates may be similar depending on the specific local climate and dam shape. Both can be easily estimated to give an idea of potential evaporation losses.



Minimising evaporation loss can be achieved by:

- increasing dam depth and minimising surface area
- management actions – as discussed in Section 7.2

5.4. DAM EMBANKMENT DESIGN

For gully dams, there are three major types of construction techniques (Bourchier 1998):

- **Homogeneous dams** – are constructed from one material (usually 20-30% clay)
- **Zoned dams** – use a clay core surrounded by a more pervious shell. These are more stable, and have reduced construction costs with steeper slopes.
- **Diaphragm dams** – are used when suitable clay is limited. A compacted clay layer acts as an impervious blanket over more pervious sand or gravel.

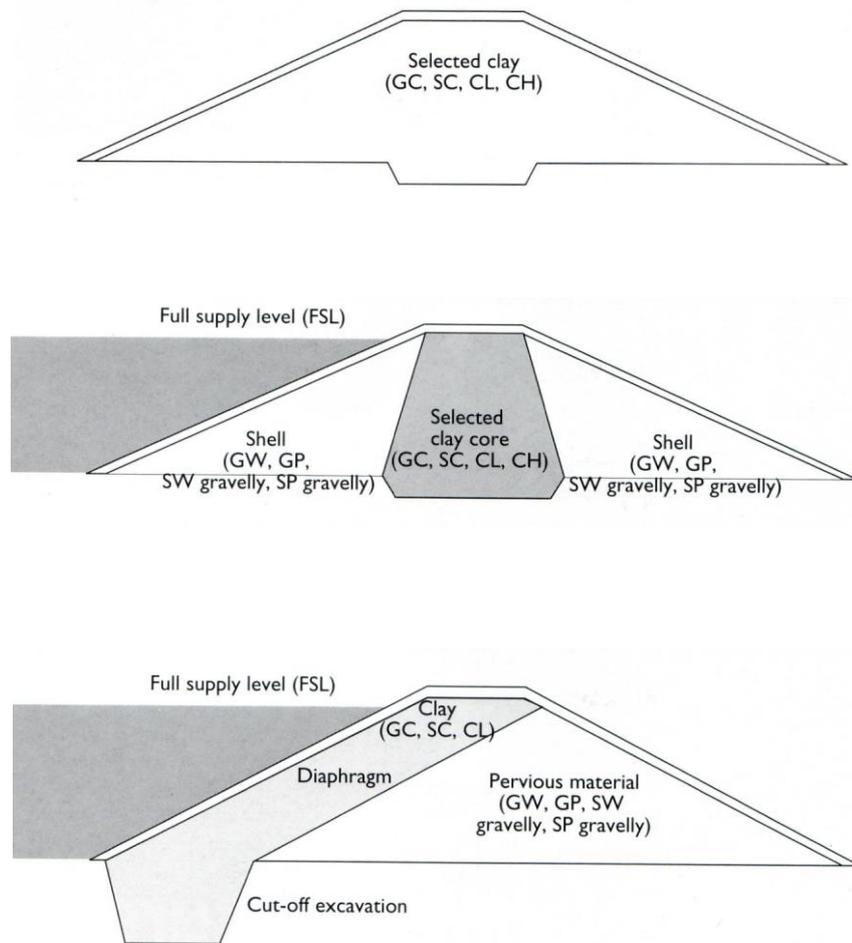


Figure 23. Dam construction techniques (Bourchier 1998)

Soil classification codes used in Figure 23 are outlined in Box 3.

Box 3. 'Unified soil classification' groups (Bourchier 1998)

SC	Clayey sand
SW	Well-graded sand
SP	Poorly-graded sand
CL	Low-liquid-limit clay
CH	High-liquid-limit clay
GW	Well-graded gravel



GC	Clayey gravel
GP	Poorly-graded gravel

Cut off excavations

A cut off excavation is used to improve the watertight seal where the base of the embankment meets the impervious dam foundations. In clay foundations cutoff excavations should have a minimum width of 2.5m, 0.6 m deep and side batters of 1:2 or 1:1 (horizontal: vertical). In well-cleaned (non-weathered) rock foundations, a cutoff excavation 0.3m wide and 0.3m deep is recommended (Nelson 1985). However dams on rock foundations are not ideal as the interface between rock and soil can form a seepage path.

Embankment structural risks due to seepage

When dams are kept full inevitably some water will seep through the embankment to the downstream, dry side (Figure 24). This can potentially affect the structural stability of the wall. Saturated soil has a much lower strength than dry soil (due to the lubricating effect of excess water) and it can be liable to collapse. By keeping the dam wall as low as possible at the point where the seepage exits, the risk of structural collapse is minimised (Bourchier 1998). Building low slopes and ensuring proper soil compaction (see Construction section) reduces the height of the seepage line. Higher dam walls will require flatter slopes to reduce the risk of soil instability.

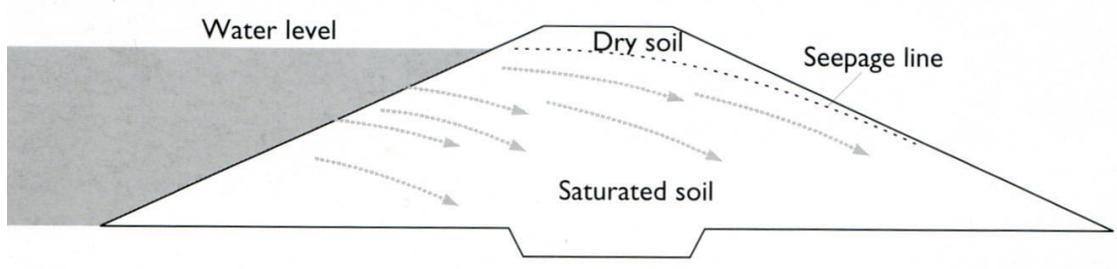


Figure 24. Seepage lines in earth embankments (Bourchier 1998).

Crest width

The width of crest should increase with dam wall height, as per the examples below.

Table 7. Suggested minimum crest widths (from Nelson 1985)

Height of dam wall (m)	Crest width (m)
Up to 2	2.5
2.1 to 3	2.8
3.1 to 4	3.0
4.1 to 5	3.3
5.1 to 6	3.5



Diaphragm (clay blanket) thickness

For diaphragm dams, the recommended thickness of the diaphragm (measured at right angles to the upstream face) will vary with dam wall height, as per examples below. Design of large dams will require consultation with a suitably qualified consultant.

Table 8. Suggested diaphragm (clay blanket) thickness (from Nelson 1985)

Height of dam wall (m)	Diaphragm / clay blanket thickness (m)
Up to 5	0.6
5.1 to 6	0.75

5.5. OTHER FEATURES OF DAM DESIGN

Batter slopes

Slopes in contact with water should be no steeper than 3 horizontal:1 vertical. Slopes steeper than this are prone to eroding and difficult to compact with machinery.

As mentioned above, downstream batter slopes on dam walls should be flat enough, so that the seepage line emerges as low as possible.

Protection from drying

Shrinkage cracks in dam walls are a concern when heavy clays are subjected to wetting and drying cycles. Covering the crest of the dam with 150-225 mm of sandy soil will provide a mulch to help prevent the clay drying out (Nelson 1984).

This approach (a sandy mulch layer) can also be applied throughout the base of the dam, where drying out and shrinkage cracks are a likely issue.

Protection for erodible (dispersive / slaking) soils

Dispersive and slaking soils are prone to erosion under the impact of rainfall, water inflows or wave action. Measures to control this may include:

- Applying a layer of topsoil over the dam wall and batter slopes.
- Establishing drought-proof grasses (not trees!) on dam banks and diversion drains.
- Protecting batters and the embankment from wave action with tyres or additional width of crest (to allow for some collapse).
- Install plastic or a rock or concrete chute to prevent erosion on dam inflow slopes. Unprotected steep inflow slopes are prone to gully erosion which can move up the hillslope, and mobilise sediment into dams.



Well grassed diversion drains reduce the risk of erosion and further sediment entering the dam



Maintenance of grass cover can protect the diversion drain and dam inlet.



Old tyres can be used to protect the dam walls and embankment crest from wave erosion.



Spreading topsoil and establishing grass can be another cost-effective way to protect dam walls.



A concrete structure provides protection from inlet erosion, but at high cost.



Cheap plastic sheeting also provides effective protection from inlet erosion.

Photos: Peter Ciganovic and Steve Moore

Figure 25. Options for controlling erosion in dams and drains.

Dam inlet erosion is a common problem with EP dams. Plastic sheeting (buried at the top edge) can provide a cost effective solution.



Freeboard

A height difference of 1m is recommended between the crest of the dam and full supply level (ie. to the spillway/ bywash height) for large dams to ensure stability of the dam wall against wave action and during floods. In smaller stock and hillside dams 600mm is sufficient.

Spillways and flood flows

Spillways need to be designed to carry peak flood flows following heavy rainfall, typically based on a 1 in 100 chance flooding event and be resistant against erosion. A good spillway will carry peak flows, working with adequate freeboard to protect the dam wall from 'over-topping' which can cause serious failure and wash out of the dam wall (see figure 41a). Costs and potential impacts of failure will be greater for larger dams and expert engineering advice should be sought⁵. For small catchments, which have small dams, designing for 1 in 100 year events is not applicable. An example of a well constructed spillway is shown in Figure 40.

The following dot points provide a 'first cut' approach to spillway design (otherwise see the footnote below):

- Nelson (1985) provides estimates of 1 in 100 year flood flow rates (in cubic metres per second) for different catchment areas using Figure 26 and Table 9. The values assume a worst case scenario conducive to maximum flood flow rates (ie. stony or shallow soils, steep slopes and sparse vegetation).
- Taking these estimates of peak flood flow rates (= spillway discharge), a guide to appropriate spillway dimensions can be obtained from Tables 10 and 11 (and refer to Figure 26).
- Bouchier (1998) suggests spillways be designed to pass the 1 in 100 year event with a flow depth of about 0.5m.

⁵ For a more detailed design approach, information for estimating flood flows can be obtained using the 'Moore method' (Moore 1979) for catchments up to 20ha, or the 'rational method' for bigger catchments - from *Australian Rainfall & Runoff - A Guide to Flood Estimation* (Pilgrim 1987).



South Australia

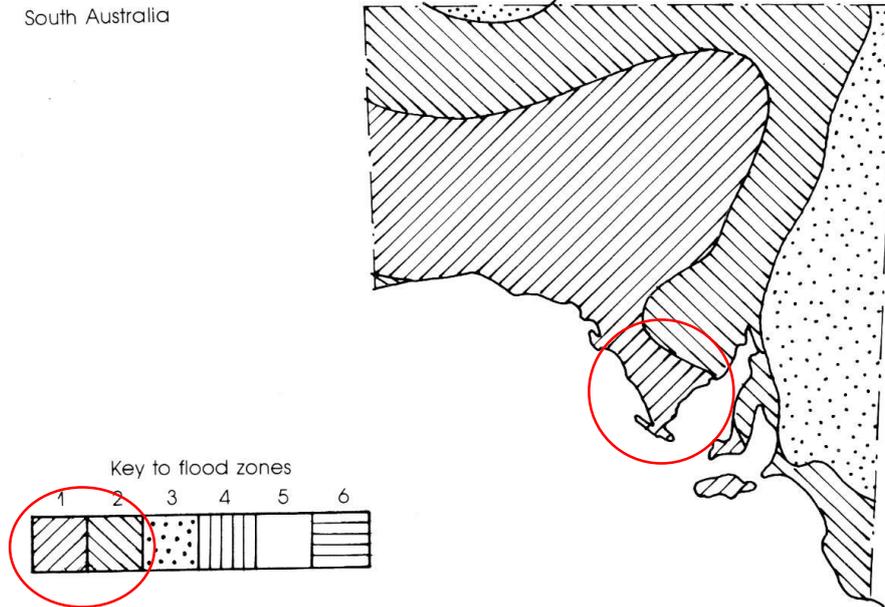


Figure 26. Flood flow zones (Nelson 1985).

Table 9. Estimated peak flood flows in different zones (Nelson 1985).

Catchment area (ha)	Flood flow in zone 1 (cubic metres per second)	Flood flow in zone 2 (cubic metres per second)
10	0.9	1.7
20	1.2	2.3
30	1.4	2.9
40	1.7	3.4
50	1.9	3.7
60	2.1	4.1
70	2.2	4.4
80	2.4	4.7
90	2.5	5.0
100	2.6	5.3

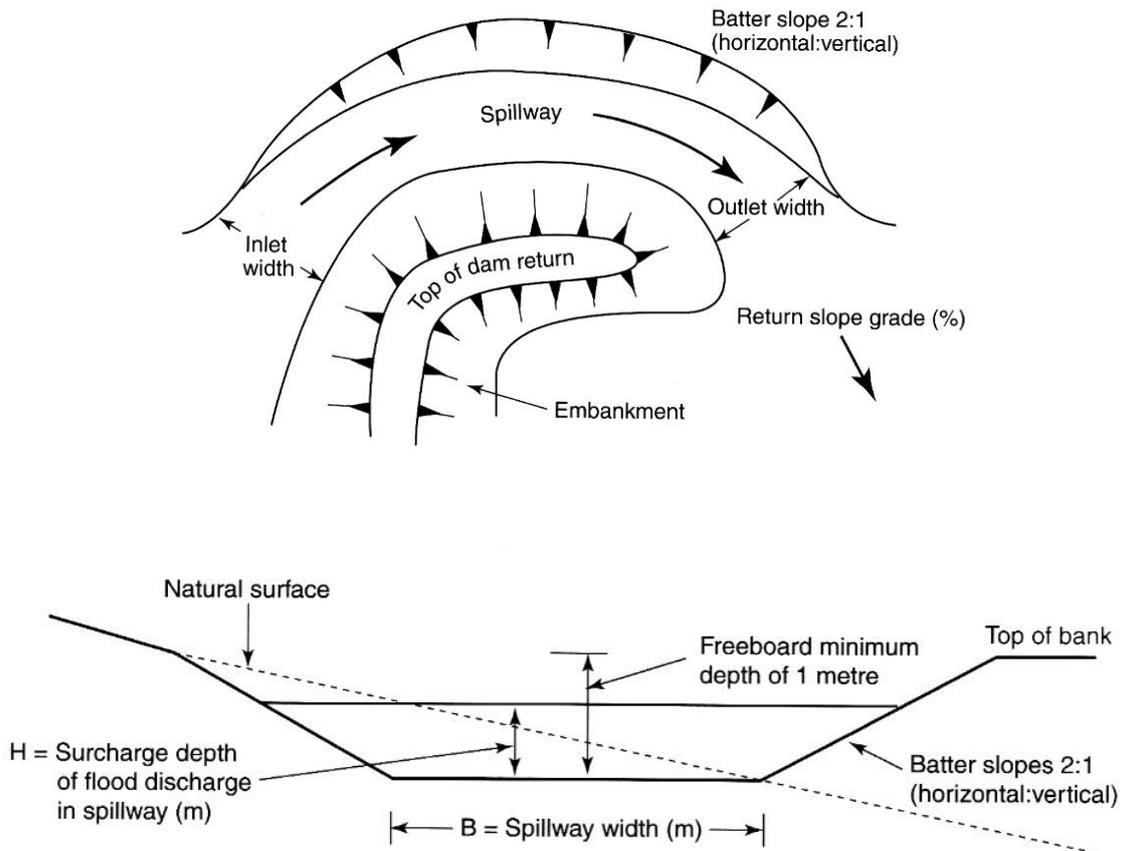


Figure 27. Sketch of earth spillway, plan view and cross section (Lewis 2002).



Table 10. Minimum inlet width of spillway (excerpt from Lewis 2002).

Spillway discharge / peak flood flow (m ³ /s)	Depth of flow (m)				
	0.3	0.4	0.5	0.6	0.7
	Inlet width (m)				
1	4	4	4	4	4
2	7	5	4	4	4
3	11	7	5	4	4
4	15	10	7	4	4
5	19	12	8	6	5
6	23	15	10	7	6

*Assumes well grassed spillways. Poorly grassed spillways should be wider.

Table 11. Minimum outlet width of spillway (excerpt from Lewis 2002)

Spillway discharge / peak flood flow (m ³ /s)	Return slope (%)				
	3%	4%	5%	7%	10%
	Outlet width (m)				
1	6	6	6	6	6
2	6	6	6	6	6
3	6	6	6	8	10
4	6	6	8	10	14
5	6	8	10	13	17
6	8	10	12	16	20

*Assumes well grassed spillways. Poorly grassed spillways should be wider.

Example calculation (i):

Assuming a 50 ha catchment in flood zone 1, peak flood flow rates = 1.9m m³/s (approx 2 m³/s).

Designing for a depth of flow of 0.5m, and a return slope of 5%: spillway inlet width = 4m and spillway outlet width = 6m.

An alternative and much simpler rule of thumb – which is good for small catchments – is to design the width of spillway = square root of the catchment area in hectares (Cummings 1999b).

Example calculation (ii):



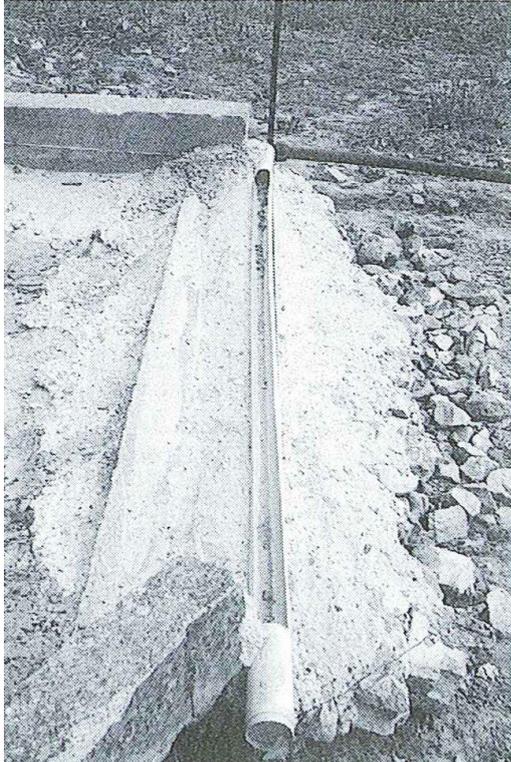
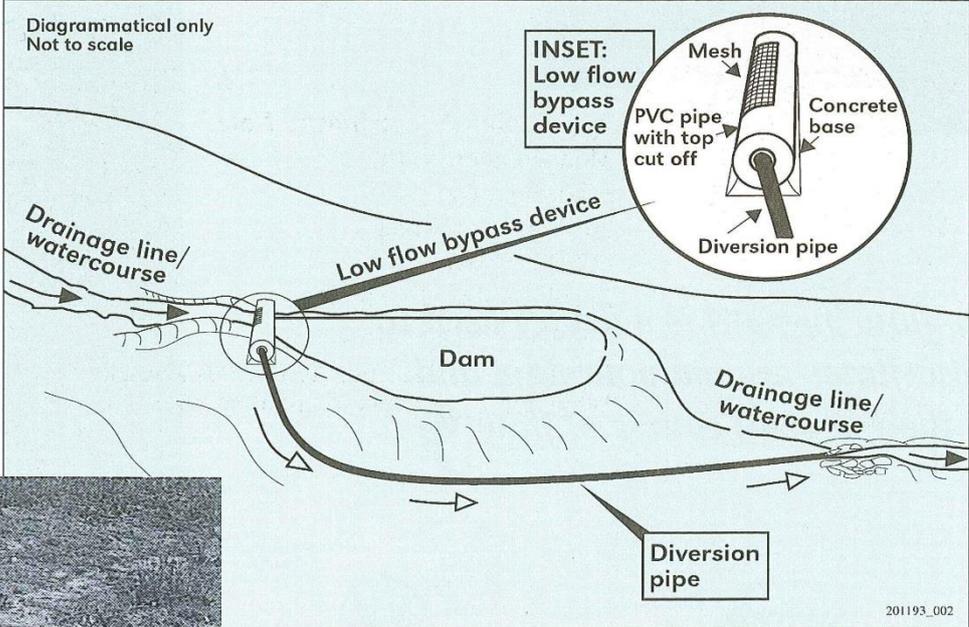
Assuming a 50 ha catchment, width of spillway = $\sqrt{50} = 7\text{m}$.

Trickle pipes

Trickle pipes are high water level outflow pipes that discharge dam water before the earth spillway comes into operation (Lewis 2002). These are useful where consistent small overflows may cause spillway erosion. Professional advice should be sought regarding their design to allow for incorporation during construction of the dam wall.

Low-flow bypass

In priority catchments, the EPNRMB Plan (EPNRMB 2009a) requires that dams or structures that collect or divert water from a watercourse must incorporate a low flow by-pass mechanism. This is a structure (e.g. drain or pipework) that diverts low flows around or through the dam embankment.



This example consists of a 6 inch PVC diversion pipe set in concrete across the diversion channel to the dam. The top is cut off and covered with mesh to ensure it is kept free from blockages. Pipework diverts flows at or below the threshold flow rate to return them to the watercourse below the dam. The outlet of the pipework needs to be located so as to avoid scouring and may require the placement of rocks. Engineering design is required (assessing the pipework diameter, length and head difference) to ensure that the pipework and friction losses do not impede threshold flows (DWLBC 2003).

DWLBC's fact sheets on low flow bypasses are currently being reviewed but will be available from their website:
http://www.dwlbc.sa.gov.au/publications/fs_brochures.html



Figure 28. Example of a low flow bypass (DWLBC 2003).



This structure should divert flows up to the ‘threshold flow rate’, which are seen as environmental flows essential for sustaining water dependent ecosystems (including sub-surface flows). This means that the first flows after summer can not be captured and a dam can only start to fill when watercourse flows exceed the threshold flow rate – defined as the greater of 0.002 litres/ second/ ha or the 10th percentile of normal catchment flows (see Appendix 2 for more detail).

The type and design of low flow by-pass mechanisms can vary and advice should be sought from the EPNRMB or a suitably qualified consultant. Designs are usually site specific.

Example designs are shown in Figure 28 and Appendix 4.

Controlling sediment and nutrient inflows

Sediment traps which encourage uniform, slow flows (so that water-borne sediments slow and settle out) can be constructed upstream of dams. Advice from a suitably qualified consultant should be sought.

Plastic lined dams

Lined dams are an option where impervious materials are not found close to the site. Polyethylene liners have been used in a number of locations across EP and are one of a number of dam-lining options (see table below).

Lined dams may be combined with options to enhance catchment runoff (e.g. plastic sheeted catchments) – as shown later.

Landholders will need to make their own assessments on the cost-effectiveness of different lining options.

Important safety note: plastic lined dams are very slippery! They should be fenced off and a safety rope installed to help people climb out if needed in emergencies.



Figure 29. These 5 photos show the construction of a plastic-lined dam and catchment. Once installed, the plastic lining will maximise runoff rates and create a reliable, good quality water supply of 1.3ML for stock and domestic use. The plastic sheeting is rolled out, welded together and buried at the edges (in trenches) to keep it in position. The low point in the catchment area acts as a collection point, allowing time for water to flow into the dam, and also as a sieve to remove leaves and other debris.

Photos: Andrea Hannemann (Cleve)





Table 12. Comparison costs for lining dams, from 1995 data (Lewis 2002).

Materials	Typical material cost (\$/m ²)	Typical labour costs		Price range in total cost (\$/m ²)
		Machinery cost (\$/m ²)	Manual labour (\$/m ²)	
Liners				
Black Polyethylene Membrane	2	–	0.5	2–5
Woven (reinforced) Polyethylene Membrane	3	–	0.5	4–8
Vinyl (PVC) Membrane	5	–	0.5	4–8
Hypalon	14	–	1	10–20
Hertalan (EPDM)	10	–	1	10–20
Butyl Rubber	12	–	1	10–20
Chlorinated Polyethylene (CPE)	10	–	1	10–20
Compacted Asphalt	7	2	5	8–16
Reinforced Concrete	10	2	6	12–24
Gunite (Air Blown Concrete)	10	20	–	10–40
Steel	10+	–	10+	20+
Compacted Soil	–	3	–	2–15
Chemical treatment				
Bentonite	7	4	1	2–10
Sodium Tripolyphosphate or Sodium Carbonate	1	2	0.5	2–20
Bitumen/Soil Mix	3	3	–	4–10
Cement Stabilised Soil	0.5	3	1	4–10
Gypsum Stabilised Soil	0.01	2	0.5	2–8
SS-13 Waterborne Dispersion	4	–	0.5	3–10
Underlays for drainage or protection				
Geotextiles	2	–	1	3–20
Sand	0.5	0.5	–	1–3

Notes:

- 1 Total costs of polyethylene and vinyl liners include a secondary cover of heavy duty sheeting around the top half of the dam, to protect the liner from sunlight and other causes of damage. Protective covers of soil may be applicable where gradients are no steeper than 3.5:1 (horizontal:vertical).
- 2 The range in total costs for bentonite, sodium tripolyphosphate, sodium carbonate and gypsum-stabilised soil includes allowance for a protective cover of untreated soil 100 mm to 1000 mm thick over the treated layers. Different thicknesses are necessary in different situations to protect treated layers from varying degrees of erosion, drying and cracking.
- 3 Costs do not include the provision of a firm compact base onto which liners or other treatments are placed. Dam construction costs are also additional and are valid at time of writing this book.
- 4 Not all types of liners or chemicals are listed in this table. Information about other treatments can be obtained from the suppliers.
- 5 Material costs do not include allowances for transport or delivery.



5.6. MULTIPLE USE / WILDLIFE CONSERVATION & VEGETATION

Some landholders see wildlife conservation as an important secondary use for farm dams. With some thought it is usually possible to incorporate dam design features that allow multiple uses, e.g. stock water, habitat for waterbirds and/or fish, and refuge for native animals during dry times (Lewis 2002, Victoria DNRE 2002, Bouchier 1998).

Vegetation, including trees planted at sufficient distance from the dam, can provide windbreaks which reduce wave action (and hence bank erosion) as well as reducing evaporation. At the same time they provide shelter for wildlife.

Shrubs, trees or other deep rooted plants should not be allowed to establish within 5 meters, or the anticipated height of the mature growth of the dam embankments or spillway. The roots of this type of vegetation can provide pathways for leakage through the dam wall and may result in dam failure (VGDSE 2007)

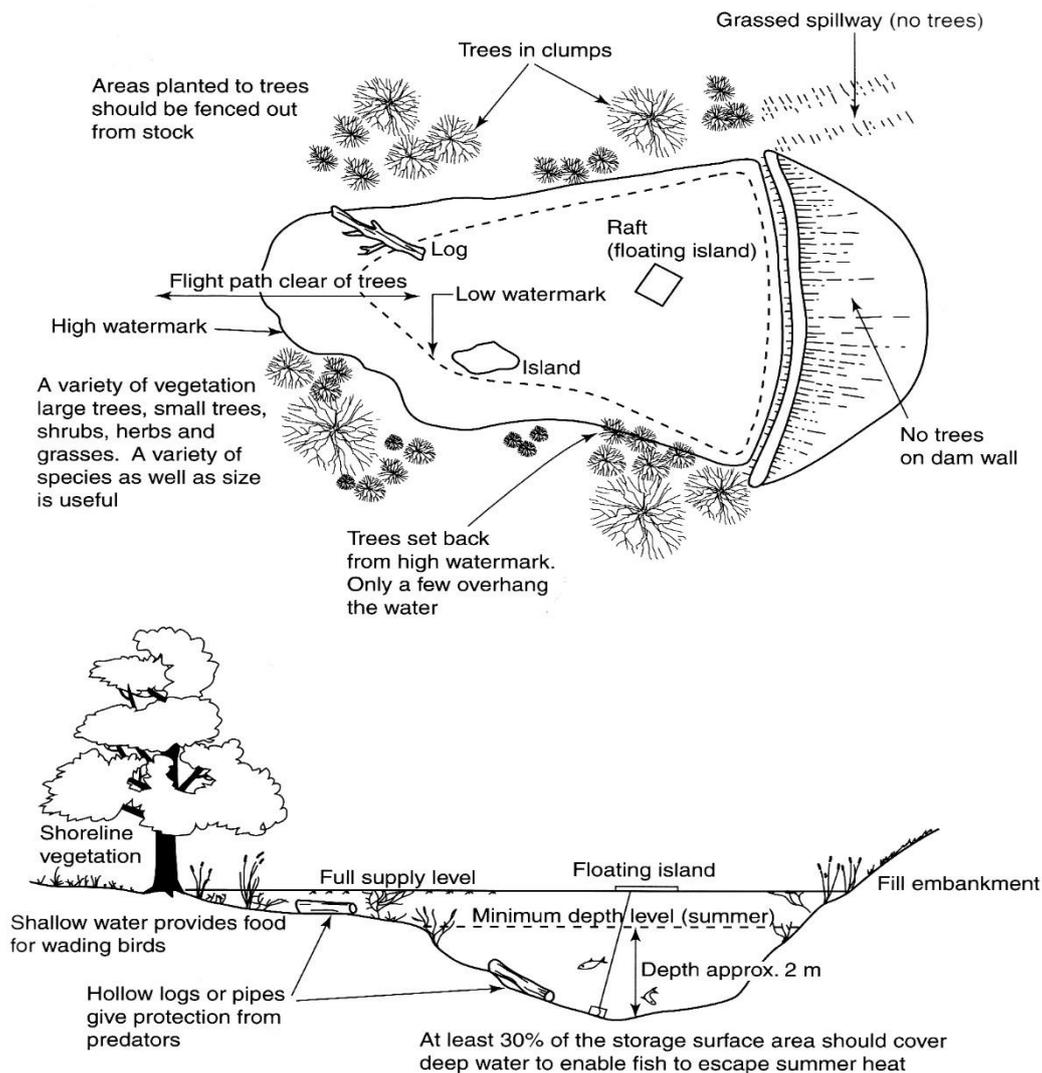




Figure 30. Example dam layout for wildlife conservation (Lewis 2002).

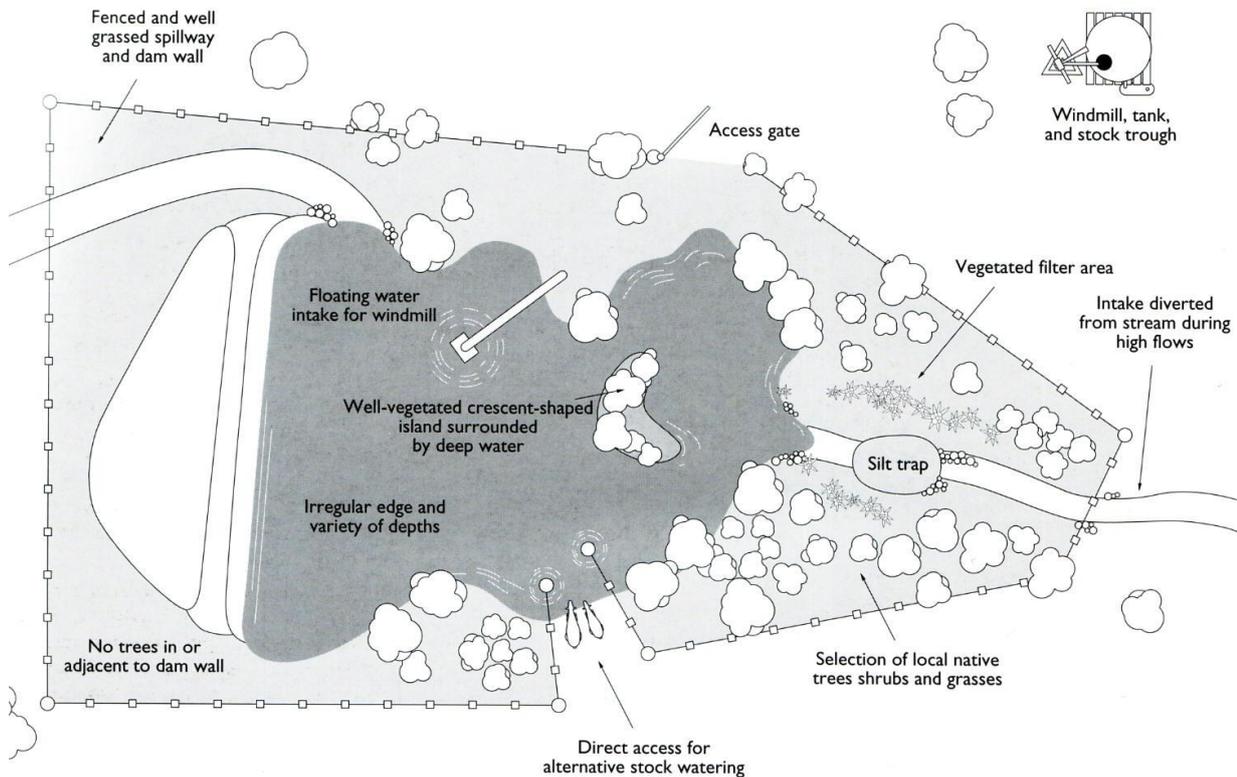


Figure 31. Wildlife prefer a range of water depths and vegetation types (Source: Upper River Torrens Landcare Group) (Bourchier 1998).

Fencing can be used to protect banks and limit grazing of vegetated filter areas, while also providing an alternative limited (direct access) watering point. At the limited watering point:

- lack of shade and shelter can prevent stock camping or loitering near the site
- compacted soil, gravel or concrete can be used to protect the bank from erosion

(Bourchier 1998).

5.7. ENHANCING RUNOFF IN LOW RAINFALL AREAS

A number of different options are potentially available for enhancing catchment runoff and these should be discussed with the EPNRMB or a suitably qualified consultant. Table 13 provides a guide to the range of runoff coefficients possible from different catchment enhancement options. Runoff coefficients towards the higher end of the ranges provided are expected in higher rainfall areas.



Cost, annual rainfall, soils and relevant approval requirements will be factors influencing the potential success and applicability of different options.

Some example photos of different catchment treatments are shown below.



Table 13. Runoff estimates from different catchment types (adapted from Bourchier 1998).

Catchment type	Runoff (%)
• Uncleared	0-0.5
• Farmland	0-8
• Sprayed (with herbicide)	2-10
• Roaded / Graded / Scraped / Contour banks	5-20 (in low rainfall) 25-40 (in high rainfall)
• Rock outcrops	45-50
• Plastic or Bitumen	75-90

Plastic sheeted catchments



Photo: Brian Hughes

Figure 32. A plastic sheeted catchment for a farm water supply near Yalanda, approx 1 ha in size. The tyres help to hold down the plastic in strong winds. Holes can be cut in the tyres to avoid creating sites for water retention and mosquito breeding (P Davis 2009, pers. comm.).



Photo: Adrian Simpson

Figure 33. A recently constructed plastic sheeted catchment to supplement the community water supply at Scotdesco Aboriginal Community at Bookabie.

Roaded / graded / scraped catchments



Photo: WA Dept of Agriculture

Figure 34. Farmers and agency staff in Western Australia were the early pioneers of roaded catchments in the 1940s (Bourchier 1998).



Photos: Steve Moore



Figure 35. A roaded catchment on Sims Farm near Cleve. Topsoil is heaped into rows, then the mildly dispersive clay subsoil is spread over and compacted to make a more impervious corrugated surface drainage network.



Photo: Steve Moore

Figure 36. A scraped catchment on Sims Farm, near Cleve. This involves lightly scraping the topsoil back to expose a more impervious clay subsoil. (This photo was taken on the same day as the bottom photo of Figure 35.)



Photo: Steve Moore

Figure 37. A contour bank catchment on Sims Farm (Cleve) as part of a runoff trial for steeper slopes.



Photo: Brian Hughes

Figure 38. A scraped / graded catchment for a farm water supply near Mangalo. Topsoil is scraped away to enable better runoff along the clay subsoils. Some ground cover is necessary on erodible soils, but controlling weeds helps to optimise runoff.



Photo: Adrian Simpson

Figure 39. This catchment at Koonibba Aboriginal Community uses cold mix asphalt.



6. CONSTRUCTION

Key points

Tips for successful dam construction:

- Employ a reliable and experienced contractor.
- Ensure there is at least 2m depth of suitable clay available on site (use a backhoe for testing).
- Thoroughly prepare the foundation for the embankment.
- Don't use dry soil – it must be pliable to achieve compaction.
- Ensure adequate freeboard – for safety in floods and to cope with wave action.
- Allow for settlement (5-10% of embankment height), particularly with bulldozer construction and dams over 3m high.
- Don't plant trees on the embankment

(S Moore 2009, pers. comm.)

6.1. GENERAL PRINCIPLES

Soil moisture

Correct soil moisture is critical for construction purposes. The clay soil will layer and compact more easily, and reduce leakage and settlement after the bank has been built.

The dam embankment should be constructed from soil that is sufficiently moist to be pliable without crumbling, but not so wet as to excessively stick to, or flow away from machinery. A simple test is to roll a small ball of the soil into a 'rod' between the hand and a smooth, hard surface. If you can roll it into the thickness of a pencil (about 7mm) then the moisture content is near optimum (Lewis 2002).

Soil that is too wet will stick to your palm. A soil that is too dry will crumble.

In average rainfall seasons, soil moisture contents are often close to the optimum level (Nelson 1984). Dams should be built in Spring.

Building farm dams during droughts

Water scarcity during drought periods often causes an upsurge of interest in farm dam building, but construction under such dry conditions is fraught with problems (Nelson 1984). It is better to defer building dams until conditions are favourable because dams built in dry periods are more prone to failure.



Clay – soil differences

Prior to construction testing should identify different qualities of clay. Think out and plan the stages for excavation and placement of different soil types so that good quality clays are placed appropriately. (This may be done by the contractor, as discussed below).

Spillway construction

Spillways should be designed to carry flood flows uniformly at a speed that will minimise erosion. Designers will typically use 'Mannings Formula' which estimates water velocities allowing for different surface types. A well grassed waterway will generally be sufficient, but if velocities are too high then rocks and gabions (wire and rock-filled mattresses) will be needed to protect against erosion. Bare soils offer poor protection and are prone to erosion, particularly when sodic and dispersive in nature.

Where rock reinforcement is required, a rough rule of thumb is to have 1/3 of the rocks directly underlying the spillway channel, with 1/3 each on the side batters (to protect against high flood flows). Site specific spillway design must allow for rainfall intensity and catchment size.

Reeds and other large vegetation should not be allowed to grow in spillways as this will obstruct large flow events and place the dam embankment at increased risk of failure. Figure 40 shows an example of a well constructed spillway.



Photo: Mark Sindjic

Figure 40. An example of good spillway construction with rock reinforcement.



There is potential for rocks to cause problems in spillways when not used correctly. Landholders using front end loaders to place rocks cannot move them once they have been dropped in place. Problems occur particularly when rocks are placed directly in the path of water, with the idea that the rocks will slow the water down. Placing rocks directly in the path of flowing water will not slow the water down, rather it will speed up (becoming more erosive) as the water tries to flow at the same rate through a constricted pathway.



Photos: Mark Sindjic

Figure 41. Examples of spillway erosion and a failed repair (right) causing additional erosion as water flows around rocks placed in the flow path.



Figure 41a. Examples of dam wall failure and washout due to inadequate spillway design and lack of sufficient freeboard. Photos Dave Cunningham (L) & Seb Drewer (R)

6.2. EXAMPLE SPECIFICATIONS FOR THE CONSTRUCTION OF DAMS WITH BULLDOZERS

The following will provide a guide to considerations and activities during the construction phase. The EP NRM Plan 2009 *Caring for our resources* (EPNRMB 2009a, pages 33-39) outlines general principles for dam construction that also apply (as shown in Appendix 2).



It is recommended that specialist advice be sought for specific situations. The guide below assumes that relevant approvals have been gained for native vegetation clearance and dam construction, where needed.

(1) CONSTRUCTION MATERIALS

The contractor must satisfy himself of the nature of the material to be excavated by actual inspection of the site and testing of the materials.

(2) PREPARATORY WORK

- **(2.1)** The area to be covered by the embankment, borrow pits and spillway together with an area extending beyond the limits of each for a distance of 16m all around shall be cleared of all trees, scrub, stumps, roots, dead timber and rubbish. All these shall be removed from the vicinity of the work or otherwise disposed of in a manner approved by the landholder. Care must be taken to minimise disturbance in the vicinity of the spillway.
- **(2.2)** The area to be covered by the stored water outside the limits of the borrow pits shall be cleared of all scrub and rubbish. Trees shall be cut stump high and removed from the vicinity of the work.
- **(2.3)** All trees near the site which are likely to damage or obstruct work in any way shall be cut down stump high or root felled as directed and removed from the vicinity of the work.
- **(2.4)** Top soil from the site is to be stockpiled beyond the downstream toe of the embankment, refer to points 4.12 and 3.2. in this document.

(3) BORROW PITS

- **(3.1)** The material for the construction of the embankment shall, as far as possible, be excavated from within the area to be covered by the stored waters.
- **3.2** If the material from within the area to be covered by the stored water is insufficient or unsuitable to construct the embankment to the required dimensions, the balance of filling shall be obtained from other borrow pits, the locations and dimensions of which shall be as directed by the landholder. Any borrow area not covered by water must be restored with a cover of top soil.

(4) EMBANKMENT CONSTRUCTION

- **(4.1)** No tree branches, roots, organic or other perishable materials shall be placed in the embankment.
- **(4.2)** Excavation shall commence at the downstream toe.
- **(4.3)** Each series of excavations should extend across the full width of the dam before the next layer is commenced.
- **(4.4)** As excavation proceeds the machine will be working progressively upstream
- **(4.5)** Where, the soil from the excavation is of varying types from pervious to impervious material, the embankment shall consist of two zones. The more impervious material shall be placed in the upstream zone and the pervious material in the downstream zone (See Figure 42)



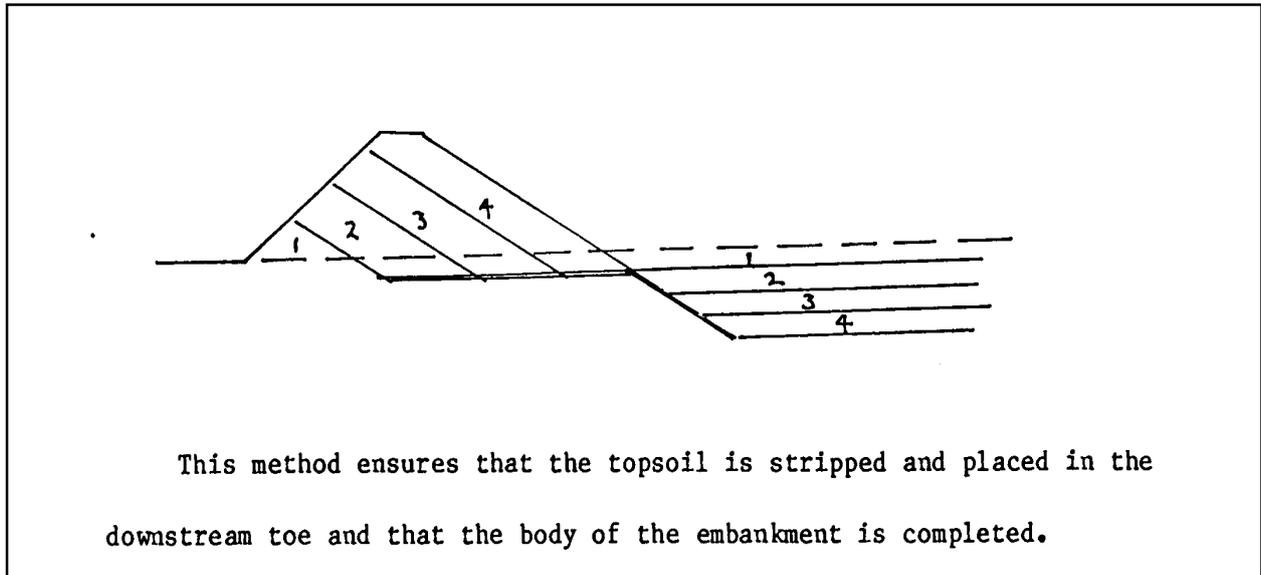


Figure 42. A simplified order of soil excavation when building a bank with a bulldozer

- **(4.6)** Material to form the bank shall be spilt from the blade on the uphill journey so that it is deposited in a layer not more than 20cm thick. No material will be tipped over the downstream batter.
- **(4.7)** Each layer must be thoroughly consolidated by rolling or traversing with suitable plant before the next layer is placed.
- **(4.8)** The distribution and gradation of the materials throughout the impermeable zone of the embankment shall be such that this zone will be free from lenses, pockets, streaks or layers of material differing materially in texture or gradation from the surrounding material.
- **(4.9)** The moisture content of the material to form the embankment shall be such that the material may be rolled by hand on a glass plate into a thread 3mm in diameter which just begins to crumble (Alternatively see page 49). If the natural moisture of the soil is less than this limit, water shall be added in borrow areas until the moisture content is raised to the limit described or to the satisfaction of the landholder.
- **(4.10)** Excavated material which, in the opinion of the landholder, is not suitable for use in the embankment shall be dumped in spoil banks clear of the works as directed.
- **(4.11)** The embankments shall be finished to the dimensions and levels as directed making due allowance for final settlement – see note below. The specified batters are to be obtained when the settlement as allowed for has taken place. Unless otherwise directed the upstream batter shall be 1 in 3 and the downstream 1 in 2.
- **(4.12)** After the embankment has been completed as specified in 4.11 sufficient top soil previously stripped from the area of the construction shall be uniformly spread over the embankment so that a grass cover can be established.

Note: Allowance for settlement



With good compaction by rolling while the dam is built, it is safe to allow 5 % extra height for settlement. For a bulldozer built dam with no compaction other than the pressure of the bulldozer tracks, 10 % extra height in the embankment should be allowed for settlement.

The allowance in an embankment built with a carry-all scoop with no compaction other than the tracks and wheels of the equipment should be about 8 %

Spillway

The spillway shall be cut to the level and dimensions as directed by the landholder or his agent. The material from the by wash shall be deposited on the embankment.

Source: Steve Moore 1986

Reference: South Australian Department of Agriculture *Soil Conservation Technical Manual 1986* (Internal Publication) Chapter 5 Engineering Aspects of Water Erosion Control



7. MANAGEMENT

Key points

- Fence and restrict stock access
- Control sources and entry of organic pollution
- Monitor water quality
- Assess the cost-effectiveness of evaporation control options
- Inspect regularly and maintain dams to avoid problems which can develop into dam failure

7.1. PROTECTING WATER QUALITY

Stock access

Controlling stock access to dams is an important aspect of maintaining water quality, through minimising contamination from dung (nutrients and pathogenic bacteria) and carcasses, damage to soil structure and banks and overgrazing of surrounding filter vegetation.

Good water quality for stock

Essentially any aspect of water quality (e.g. salinity, taste, smell, organic pollution, etc) that makes water unpalatable to stock is a problem. In some cases, poor water quality can lead to poor stock health or deaths, however poor water quality can be an important problem just in terms of reduced production and livestock profitability.

Organic pollution

During periods of low rainfall, when pasture cover falls to critical levels, wind-borne dung and other organic materials may blow into dams. Rain-storms can also wash such materials into dams.

Once in the water, the organic materials provide ideal food for bacteria and algae. These organisms grow rapidly using up all free oxygen in the water (ie. it becomes anaerobic). Symptoms are dark water, a bad smell and black scum around the edge.

Stock find the water unpalatable. Thick scum around the waters edge may also prevent stock access to the water. It is believed that the water is not poisonous to sheep, but may be harmful to the young or weak. Unpalatability can result in a period of days when stock refuse to drink, resulting in lost body weight. They may eventually drink the poor quality water but the setback period may be associated with tender wool problems (Cummings and Thomas 1999).

Recommendations (adapted from Cummings and Thomas 1999)

- Maintain vegetation (e.g. grasses and shrubs) around the dam so that it is effectively able to filter and trap wind- and water-borne organic matter. (Trees should not be planted close to dam banks!)
- Fence to restrict stock access and protect filter vegetation.



- Shelter the dam from direct movement of wind- and water-borne organic matter by temporary mechanical barriers around strategic parts of the dam.
- Skim floating organic material and scum from the dam before it sinks.
- Desludge sunken materials from the edges of the dam, and the bottom if possible.
- Aerate and/or chemically treat anaerobic water if it is urgently needed for stock or domestic use.

Monitoring

Monitoring water quality (e.g. salinity, nutrient pollution and palatability to stock), along with quantity/availability, is an important management tool for farmers. Better water quality means better feed utilisation and improved profitability of livestock.

7.2. CONTROLLING EVAPORATION

Evaporation can be controlled using two main methods

- Windbreaks (Hipsey 2002) – however any trees planted need to be well away from dam walls!
- evaporation control covers – as expanded on further below

There are three major classes of evaporation control covers for water storages, including (Craig 2008):

- floating (continuous or modular)
- suspended shade structures
- chemical monolayers

Floating – continuous plastic sheet (Craig 2008)

Floating covers are impermeable barriers that float on top of the water surface, with the aim of reducing evaporation rates. Of the different materials that have been trialled (including wax, foam and polystyrene). Polyethylene plastic has been found to be the most satisfactory and durable material for floating covers.

The material of the floating covers usually consists of a multi-layered, polyethylene membrane. Buoyancy cells exist within the material (similar to bubble wrap or swimming pool cover products) which is made from a tough material to prevent degradation from sunlight. The multi-layering of the floating cover enables the cover to reflect some of the heat from the sun. The reflective top layer of the cover is white, while the under layers are black, to completely eliminate the transmission of light to the water underneath the cover.

The type of polyethylene used to manufacture floating covers is used in food packaging and storing, can be recycled, and is environmentally safe. Trials have demonstrated that a well managed cover can effectively reduce evaporation from open water storages by over 95 per cent.

A number of covers that have been installed on water storages in South-West Queensland, using specialised equipment designed and built for the installation of water storage covers. Existing test sites include, Meandarra, Stanthorpe, Barossa and North Star feedlot.





Floating – modular covers (RMIT 1999, Allen 2008, Craig 2008, DKCRC 2009)

These are similar to continuous plastic covers, however, modular covers consist of individual units which are not restrained and freely move across the water surface. Installation costs are believed to be less expensive for modular covers than continuous cover types. The evaporation reduction rates are based on how tightly the modules are packed together and may be slightly lower than continuous plastic floating cover types.

Existing prototypes include circular, hexagonal, and rectangular designs. As each module is small in size, thousands of modules may be required to cover some water storages.

Recycled waste materials have also been used as modular covers. Tyres and styrene can form a buoyant cover. This type of module is manufactured by filling the voids of the tyres with ground styrene foam. The recycled modular units are then closed and floated in the water storage. Minimal pollution may be caused by these units, with very small trace amounts of zinc released into the water storage. It is estimated evaporation can be reduced by 70-80% using this method

As modules do not cover 100% of the water surface, their evaporation reduction rates will be less than 100%.

Modular covers are free floating and will migrate with the wind movements to the downwind margins of water storages. This is usually where the warmest water of the storage lies, and where the highest evaporation rates occur.

Suspended covers (Craig 2008)

For this type of cover shade structures are usually suspended above the water surface with the use of cables.

Shade structures reduce solar radiation and wind speed, and act as a trap for humid air between the shade structure and the water surface. All of these factors affect evaporation rates.

As the suspended shade structure is not in contact with the water, storages can be emptied with the cover in place. Shade structures are not as effective in reducing evaporation rates compared to well managed plastic covers, however they are less likely to have problems.

The suspended shade cloth structures dry out quickly after rainfall preventing wind blown soil from collecting on the surface of the cloth (either it blows off or falls through). This also means that the growth of weeds or algae on the cover surface is unlikely.

Shade cloth is available in a range of percentage-of-UV-reduction ratings. Storm damage may be an issue (covers may need to be replaced), however hail shoots or valves can be installed into the cloth to reduce potential damage.

The main disadvantage of this product is the relatively high capital outlay (mainly labour cost for construction). This has now been offset by a new shade cloth knitting machine in Malaysia which produces a much wider shade cloth roll. This means that fewer cables are involved in the installation of a wider shade cloth roll.

More research also needs to be carried out into the aerodynamics of suspended structures in high wind speeds. A limiting factor may be the ability to satisfactorily anchor the cables in poor quality soils.





Photo: Peter Ciganovic

Figure 43. Controlling evaporation is an important component of water conservation, as shown here at the historic Moody Rocks Tank. A range of different options for evaporation control are available to landholders, to suit a large range of situations.

Chemical covers (Craig 2008, Aquatain 2009)

The most commonly used chemical monolayer is a long chain cetyl alcohol (C16-C18) which forms a one-molecule-thick oily layer on the surface of the water. As these layers are degradable, there is a need to reapply the chemical every two to four days. With smaller storages the chemical layer can be applied by hand from the bank as the chemical has some self-spreading ability. With larger storages a form of mechanised delivery system may be required.

Trials of chemical methods have generally proved to be not as effective as physical methods in reducing evaporation. The evaporation reduction performance of chemical covers during trials was possibly affected by wind (creating waves which disperse monolayers), UV radiation, algae and bacteria.

Despite only a low evaporation saving rate, the main advantage of chemical monolayers is the low initial setup cost. Also the product need only be applied when it is required e.g. when the dam is full and/or during periods of high evaporation. Chemical monolayers are particularly suited to low risk investment options for owners of agricultural storages that do not have water in them all year and every year.



Examples of available products

Below is a summary table of evaporation control products available.

Table 14. Example evaporation control products, indicative performance and costs (RMIT 1999; Allen 2008; Craig 2008; Aquatain 2009; DKCRC 2009)

Cover Type	Cover Name	Key Advantages	Estimated Evaporation Savings	Estimated Cost
<i>Chemical Monolayer Covers</i>	WaterSavr	Very low initial setup costs and relatively low ongoing maintenance costs.	Up to 30%	\$18.00/kg with an application rate of .5-1 kg/ha
	Hydrotect	Very low initial setup costs requiring minimal capital expenditure.	25-35% in larger storages	\$5.00/kg with an application rate of 1.5 kg/ha
	Aquatain	Very low initial setup costs and relatively low ongoing maintenance costs.	around 50%	\$18/litre with an application rate of 6 litre/ha
<i>Chemical (PAM)</i>	CIBA PAM	PAM can reduce erosion and nutrient runoff in the field and also reduce seepage from the water storage.	Unknown at this stage	It is expected to cost \$25/ML.
<i>Floating Covers</i>	Evaporation Control System E-VapCap	Reduction of salt build up, improved water quality, reduction in algal growth, reduction in wave action and reduced bank erosion.	As much as 90-95%	\$7.00/m2 but these costs are dependant on transport costs and may be site specific.
	Aquaguard Evaporation Cover	Reduces algae growth, allows rainwater to enter the storage, reduces erosion from wind and wave action, slower salt build up.	up to 90%	The estimated cost is \$6.00-\$6.60/m2 installed. Cost subject to site location.
	CURV	The product is relatively cheap and long lasting.	Unknown at this stage	The estimated cost is around \$3.50/m2 or more.
	C.W. NEAL Corp Defined Sump floating cover	Long lasting and prevents light from entering the storage and so eliminates algal growth and increases water quality.	by up to 95%	The anticipated cost is \$30/m2 but this price is subject to size of site and the site conditions.
	Evap-Mat	Heat reflective, self-protecting in high winds (up to 150 kph) whether empty or full. It is simple and easy to install, the cover is also suitable for all storage sizes, shapes and profiles up to 2 km wide.	by up to 90%	\$3.50/m2 for complete installation.
	Fabtech	Heat reflective, self-protecting in high winds (up to 150 kph) whether empty or full. It is simple and easy to install, the cover is also suitable for all storage sizes, shapes and profiles up to 2 km wide.	by up to 95%	\$3.50/m2 for complete installation.
	REVOC floating cover	The cover can be inflated for maintenance and inspection of the storage.	by up to 95%	The anticipated cost is \$30/m2 but this price is subject to size of site and the site conditions.
	RTD Enterprises	Reduces algal growth and wave action.	No information available	\$28.38-\$63.86/m2 (US \$21.53-48.44/m2). The cost of this product is site specific and therefore it may vary.

(continued next page)



<u>Shade Structures</u>	NetPro cabled shade cover	The cover does not float on the water so there are no problems with changing water levels.	around 75%	\$7.00–10.00 (US \$6.00-7.50/m ²)
	Aquaspan	The structure is long lasting and the cover is not affected by changing water levels.	by 76-84%	The cover costs approximately \$33.00/m ² .
	MuzCov	The cover allows easy access to the storage for maintenance operations.	Unknown at this stage	The anticipated costs are \$7.50/m ² .
<u>Modular Covers</u>	Raftex	Easy to install and remove from the storage.	Still in trial	The anticipated cost of this product is \$ 4.00–5.00/m ² .
	AQUACAP	Minimal bank erosion and turbidity due to reduced wave action there will also be a reduced concentration of nutrients and salts in the water and possibly a reduction in algal blooms.	an average of 70% (when dam is 80% covered)	The estimated cost is \$17/m ² installed.
	Euro-matic Bird Balls	Reduce light penetration and therefore algal growth and are virtually maintenance free. They allow rainfall to penetrate the storage and they adjust with changing water levels.	by up to 90%	The approximate cost is \$22.80/m ² .
	Layfield Modular Cover	Maintenance is easy to carry out as damaged modules may be removed independently and with ease.	Unavailable	Unavailable
	LemTec Modular Single Sheet Cover System	Reduces algae and also reduces the amount of total suspended solids in the storage and this product is relatively easy to install.	Information unavailable.	Information unavailable.
	HexDome™	It has been shown to greatly reduce the effects of wave action – easily installed by the customer.	by up to 90%	The anticipated cost is between \$4.50–8.00/m ²
	MOD-E-VAP	Easy to install by the land owner and easy to remove the cover if necessary. There is no need for an anchor trench and maintenance costs are expected to be minimal.	Unknown at this stage	The product has an estimated cost of \$3.00–3.50/m ² depending on the catchment area shape.
	POLYNET	Quick and easy to install.	Unknown at this stage	The anticipated cost is \$2.50/m ² .
	QUIT Evap Modular Floating Cover	Lightweight and easy to install.	85-95% (when dam is 90-95% covered)	The estimated cost is around \$6.00–8.00/m ² plus transport and installation.
	AgFloat (recycled tyres & styrene foam)	Made from recycled materials, durable & long lasting, little maintenance, stops wave action which can be a significant cause of bank erosion.	estimated 70-80%	purchase price reported to be considerably less than other available products

7.3. DESILTING

Dams may leak after removing silt and fines. Dam site histories should be known (or sought out) to better understand the potential impacts of cleaning out accumulated silt and sediments.

In priority catchments, desilting of a dam may be carried out following the following principles (EPNRMB 2009a):

- Desilting of a dam does not require a permit provided desilting only involves the removal of unconsolidated material deposited since construction of the dam or material deposited since the dam was previously desilted.



- Any excavated material removed (for construction and maintenance) or during the desilting of a dam must not be deposited within a watercourse, lake or floodplain of a watercourse.
- The maximum holding capacity of the dam must not be increased by deepening or enlargement of the dam without a permit.

7.4. MONITORING POTENTIAL PROBLEMS

Regular monitoring and maintenance can protect dams against some of the main causes of failure. Typical problems, which can be fixed if detected early enough include (Lewis 2002):

- erosion, rilling and piping
- seepage / leakage
- cracking
- deformation and settlement
- concrete structure defects
- spillway blockage or erosion
- animal damage

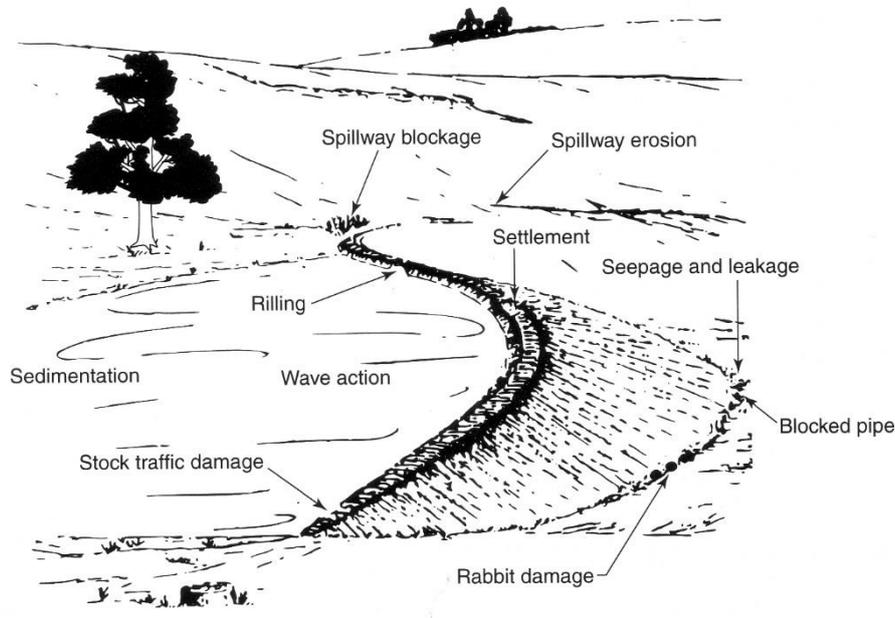


Figure 44. Problem areas with dams (Lewis 2002).

Some dam cracking and failures will require expert attention to attempt to remedy (e.g. see Figure 45). Some remedial works may have limited success, or be time consuming and expensive. The important message here is to get it right during construction.



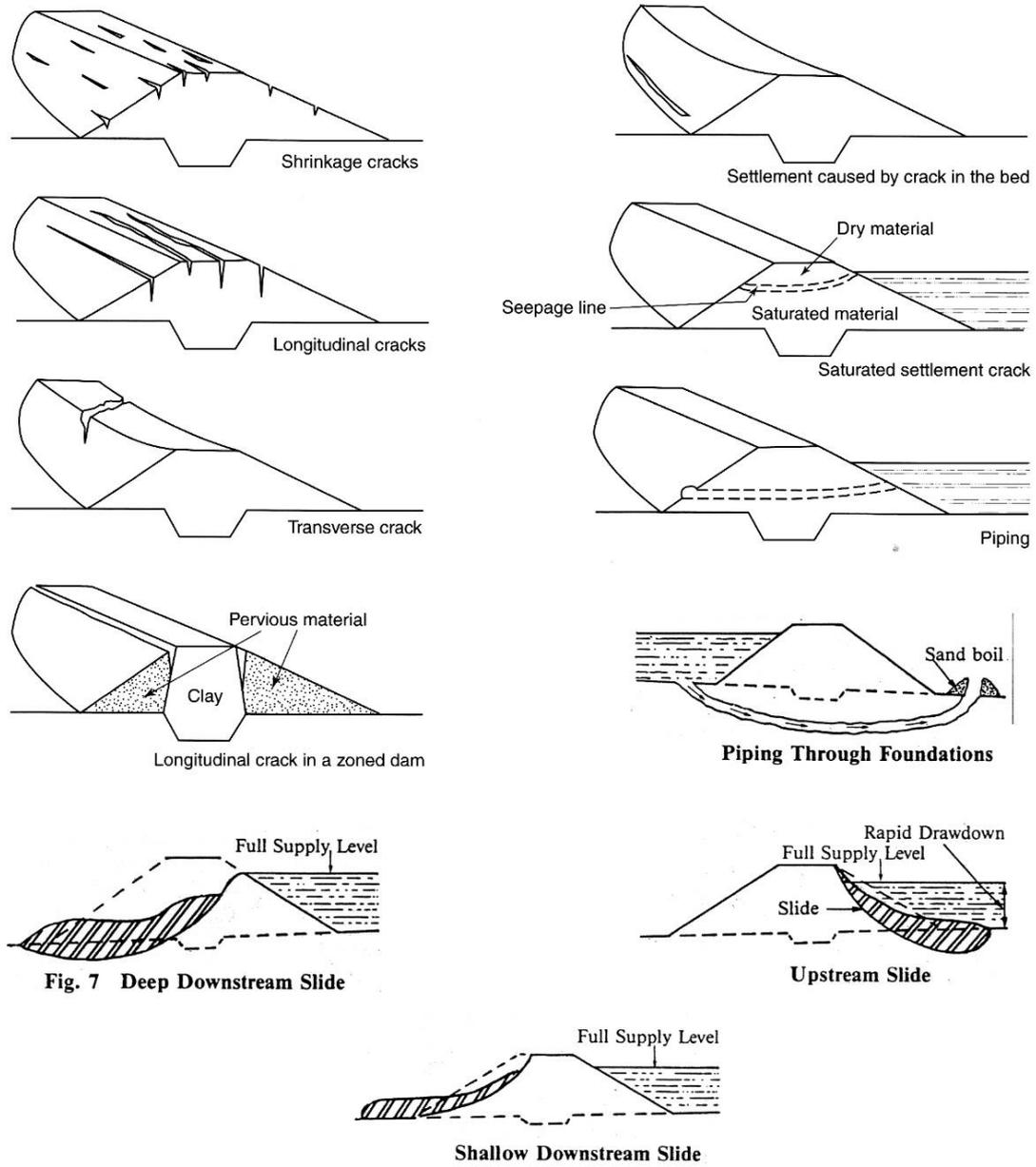


Figure 45. Types of potential problems with dam embankments (Lewis 2002, Nelson 1984).



8. KEY CONTACT PEOPLE

Eyre Peninsula Natural Resources Management Board
Water Resources Officers
Dave Cunningham or Seb Drewer

86 Tasman Terrace
Port Lincoln SA 5606
Ph: (08) 8688 3111
Fx: (08) 8682 5644
www.naturalresources.sa.gov.au

Please contact the EPNRMB for any queries on water affecting activities, or to obtain an update on consultants and contractors that are accredited by the Board, who work in line with best practice operating procedures for water affecting activities.

2

Local Examples

There are many examples of works and projects that incorporate the various options for harvesting and storing water on Eyre Peninsula. If you have a plan in mind relating to or similar to something you have read in this book then there could be a local example in your area. It might be possible to visit local examples and discuss things with other landowners or groups to help plan your works or project. To see if there is a local example call the Eyre Peninsula Natural Resources Management Board.

For dam and water-related industry consultants & contractors, look in the Yellow Pages under (for example):

- Excavating & Earth Moving Contractors
- Natural Resources Consultants
- Geotechnical Engineers & Consultants
- Pumps--Mfrs & Merchants
- Pump Repairers
- Water Treatment & Equipment
- Environmental &/or Pollution Consultants
- Boring & Drilling Contractors
- Tanks & Tank Equipment



9. GLOSSARY

Dam terminology – see Figure 1, page 2.

Dispersion – the spontaneous dis-aggregation of the clay fraction of a soil in water (page 19).

DSE – Dry sheep equivalent, a standard unit used to compare the feed requirements of different classes of stock. By definition, a 50kg wether maintaining a constant weight has a dse rating of 1.

DWLBC – Department of Water, Land and Biodiversity Conservation, Government of South Australia.

EPNRMB – Eyre Peninsula Natural Resources Management Board

Full supply level – the water level at a dam's full storage capacity.

ha – hectare (100m x 100m)

kL – Kilotitre (1000 litres)

m – Metre

ML – Megalitre (a million litres)

mm – Millimetre

Priority catchments – Catchments within the southern high rainfall zone of EP for which the EPNRMB has established principles for dam permitting, siting, design, construction and maintenance. These are defined by the Hundreds listed at the bottom of page 4 for administration purposes.

Runoff coefficient – the ratio of runoff to rainfall (expressed as a decimal fraction or %) and usually evaluated as a long term annual average.

Slaking – the immediate break-up of dry soil crumbs into smaller fragments when dropped into water.

Storage ratio – the ratio of earth moved to excavate a dam compared to the volume of water stored.

WAA – Water affecting activity



10. REFERENCES AND FURTHER READING

- Allen D. 2008. *Case Study: Gawler Ranges South Australia, Building Partnerships to Improve Rangeland Management*. Rural Solutions SA, Port Augusta
- Aquatain 2009. *Aquatain Liquid Anti-Evaporation Film* (web page), Accessed online 24/08/2009, <http://www.aquatain.com.au/>
- BoM 2009. 'Climate maps – evapotranspiration', *Bureau of Meteorology website*, Accessed online 1-09-2009: <http://www.bom.gov.au/climate/averages/climatology/evapotrans/et.shtml>
- BoM 2001. *Climatic atlas of Australia – evapotranspiration*, Bureau of Meteorology and Cooperative Research Centre for Catchment Hydrology
- BoM 2000. *Climatic atlas of Australia – rainfall*, Bureau of Meteorology and Cooperative Research Centre for Catchment Hydrology
- Bourchier J. (Ed) 1998. *Liquid assets: Water management for dryland agriculture*, Kondinin Group, Cloverdale Western Australia
- Charman PEV and Murphy BW. (Eds) 1991. *Soils: their properties and management – A soil conservation handbook for New South Wales*, Soil Conservation Commission of New South Wales, Sydney University Press
- Ciganovic P, Sindicic M and Liddicoat C. 2009. *Audit of farm dam issues on Eyre Peninsula*, Prepared for the Eyre Peninsula Natural Resources Management Board Sustainable Stock Water Project
- Craig IP. 2008. *Loss of storage water through evaporation with particular reference to arid and semi-arid zone pastoralism in Australia*, DKCRC Working Paper 19, The WaterSmart™ Literature Reviews, Desert Knowledge CRC, Alice Springs
- CSIRO 2009. *Australian Soil Resource Information System (ASRIS)*, Online database, Produced as part of the Australian Collaborative Land Evaluation Program (ACLEP), Commonwealth Science and Industry Research Organisation, Accessed online 14-08-2009: http://www.asris.csiro.au/index_ie.html
- Cummings D 1999a. *Soil materials for farm dam construction*, Landcare Note LC0069, Victoria Department of Sustainability and Environment, December 1999
- Cummings D 1999b. *Finding a dam site*, Landcare Note LC0084, Victoria Department of Natural Resources and Environment, December 1999
- Cummings D 1999c. *A gully dam or a hillside dam?*, Landcare Note LC0091, Victoria Department of Natural Resources and Environment, June 1999
- Cummings D 1999d. *How to maintain your farm dam*, Landcare Note LC0092, Victoria Department of Natural Resources and Environment, November 1999

A series of fact sheets on farm dams is available from the Victorian Government, via:

<http://new.dpi.vic.gov.au/agriculture>
> "Information Notes" > "Soil & Water" > "Water conservation (dams)"



- Cummings D and Thomas P 1999. *Organic pollution in farm dams: prevention and treatment*, Landcare Note LC0074, Victoria Department of Natural Resources and Environment, December 1999
- DKCRC 2009. *WaterSmart Pastoral Production™* (Project home web page), Desert Knowledge Cooperative Research Centre, Accessed online 24/08/2009: <http://www.desertknowledgecrc.com.au/waterSMART/>
- DWLBC 2003. *Low flow by-pass device* (Fact Sheet 19 – now under review), Department of Water, Land and Biodiversity Conservation, Government of South Australia
- DWLBC 2006. *State Natural Resources Management Plan 2006*, Department of Water, Land and Biodiversity Conservation, Government of South Australia, Accessed online 13-08-2009: http://www.dwlbc.sa.gov.au/nrm/state_nrm_plan/snp.html
- DWLBC 2007. *Sustainable limits of surface water use in South Australia* (Fact Sheet 81), Department of Water, Land and Biodiversity Conservation, Government of South Australia, Accessed online 13-08-2009: http://www.dwlbc.sa.gov.au/publications/fs_brochures.html
- DWLBC has fact sheets relating to farm dams and low flow bypasses, currently under development and review, but will eventually be available via the web at: www.dwlbc.sa.gov.au/publications/fs_brochures.html
- Edwards JA, Moore SD and Schultz GJ. 1977. *Storing water in farm dams*, Bulletin No 29/77, AGDEX 583, Department of Agriculture South Australia, Reprinted November 1989
- EPNRMB 2009a. *Natural Resources Management Plan for the Eyre Peninsula Natural Resources Management Region, Volume 2: Caring for our Resources - NRM behavioural change framework for Eyre Peninsula*, Eyre Peninsula Natural Resources Management Board, Government of South Australia
- EPNRMB 2009b. *Natural Resources Management Plan for the Eyre Peninsula Natural Resources Management Region, Volume 4: State of our Resources – Recognising the state of natural resources of the Eyre Peninsula*, Eyre Peninsula Natural Resources Management Board, Government of South Australia
- Fitzpatrick R. 1999. *Rising saline watertables and the development of acid sulphate soils*, Information Sheet No. 13, Research Project Information from CSIRO Land and Water, June 1999
- Hipsey M. 2002. *Using windbreaks to reduce evaporation from farm dams*, Farmnote 72/2002, Western Australia Department of Agriculture
- Hughes B and Prance T 2004. *A basis for maximum stock and domestic water requirements in the Eastern Mount Lofty Ranges*, unpublished Rural Solutions SA report, prepared for the River Murray Catchment Water Management Board
- Lewis B. 2002. *Farm dams: planning, construction and maintenance*, Landlinks Press, Collingwood Victoria
- Matthews D and Moore S. 1993. *Water supplies for South Australia's pastoral zone*, Bulletin 5/92, AGDEX 580, Primary Industries South Australia, May 1993



- McMurray D. 2006. *Impact of farm dams on streamflow in the Tod River catchment, Eyre Peninsula South Australia*, Department of Water, Land and Biodiversity Conservation, Report DWLBC 2006/22
- Moore S. 1984a. *Maintaining water quality in dams*, Fact sheet No. 7/84, AGDEX 582, Department of Agriculture South Australia, April 1984
- Moore S. 1984b. *How to prevent dams leaking*, Fact sheet No. 10/82, AGDEX 754, Department of Agriculture South Australia, Reprinted April 1984
- Moore S. 1979. *A method for the estimation of floods in the agricultural regions of South Australia*, Soil Conservation Branch Report S12/79, Department of Agriculture South Australia
- Nelson KD. 1985. *Design and construction of small earth dams*. Inkata Press, Melbourne
- Nelson KD. 1984. 'Problems with farm dams built in droughts', in *Aqua*, June 1984, pp20-22
- Pilgrim DH. (Ed) 1987. *Australian Rainfall & Runoff - A Guide to Flood Estimation*, Institution of Engineers, Australia, Barton, ACT
- RMIT 1999. *Aquacaps to save Water*. RMIT News (web page) July 1999, Royal Melbourne Institute of technology, Accessed online: 24/08/2009, <http://rmit.com.au>
- South Australian Department of Agriculture. 1986. 'Chapter 5: Engineering aspects of water erosion control' in, *Soil conservation technical manual, Internal publication*
- Stanton D. 2005. *Farm dams in Western Australia*, Western Australia Department of Agriculture, Bulletin 4609, March 2005
- State of Victoria. 2008. *Guidelines for meeting flow requirements for licensable farm dams – Victorian guidelines*
- Stevens C, McFarland I and Ashton B. 2005. *Feeding and managing sheep in dry times*, Bulletin 4651, Department of Agriculture Western Australia, November 2005
- van de Graaff R and Patterson RA. 2001. 'Explaining the mysteries of salinity, sodicity, SAR and ESP in on-site practice' in *Proceedings of On-site '01 Conference: Advancing On-site wastewater systems* by RA Patterson and MJ Jones (Eds), Published by Lanfax Laboratories, Armidale, pp 361-368
- Victorian DNRE. 2002. *Wildlife and farm dams* (fact sheet), Land for wildlife notes LW0015, Prepared by the Wildlife Branch, Victorian Department of Natural Resources and Environment (first published Feb 1992)
- VGDSE 2007. *Your dam your responsibility. A guide to managing the safety of farm dams*, Victorian Government Department of Sustainability and Environment 2007.
- Western Australian Department of Agriculture and The University of Western Australia 2009. 'Damcat4' (Dam and improved catchment water supply design software), available via webpage titled *Software Tools*:
<http://www.ecohydrology.uwa.edu.au/practice/farmwater/software>
- Wetherby KG, Moore SD and Sinclair JA. 1982. *The Tod River soil survey*, Department of Agriculture South Australia, Technical Paper No 2 (AGDEX 522)



Wright SJ and Ashton BL. 1978. 'The water consumption of sheep and beef cattle on northern Eyre Peninsula' in *Agricultural Record*, Vol 5, January 1978, pp 9-12

RMIT (1999). "Aquacaps to save Water." Accessed online: 24/08/2009, <http://rmit.com.au>.

Personal Communications

Moore, Steve. 2009, Retired Senior Engineering Hydrologist, Department of Primary Industries and Resources South Australia (PIRSA)

Davis, Peter. 2009, Port Lincoln Mayor & Farmer (Boston Island)



APPENDIX 1. REGIONAL MAPPING INFORMATION

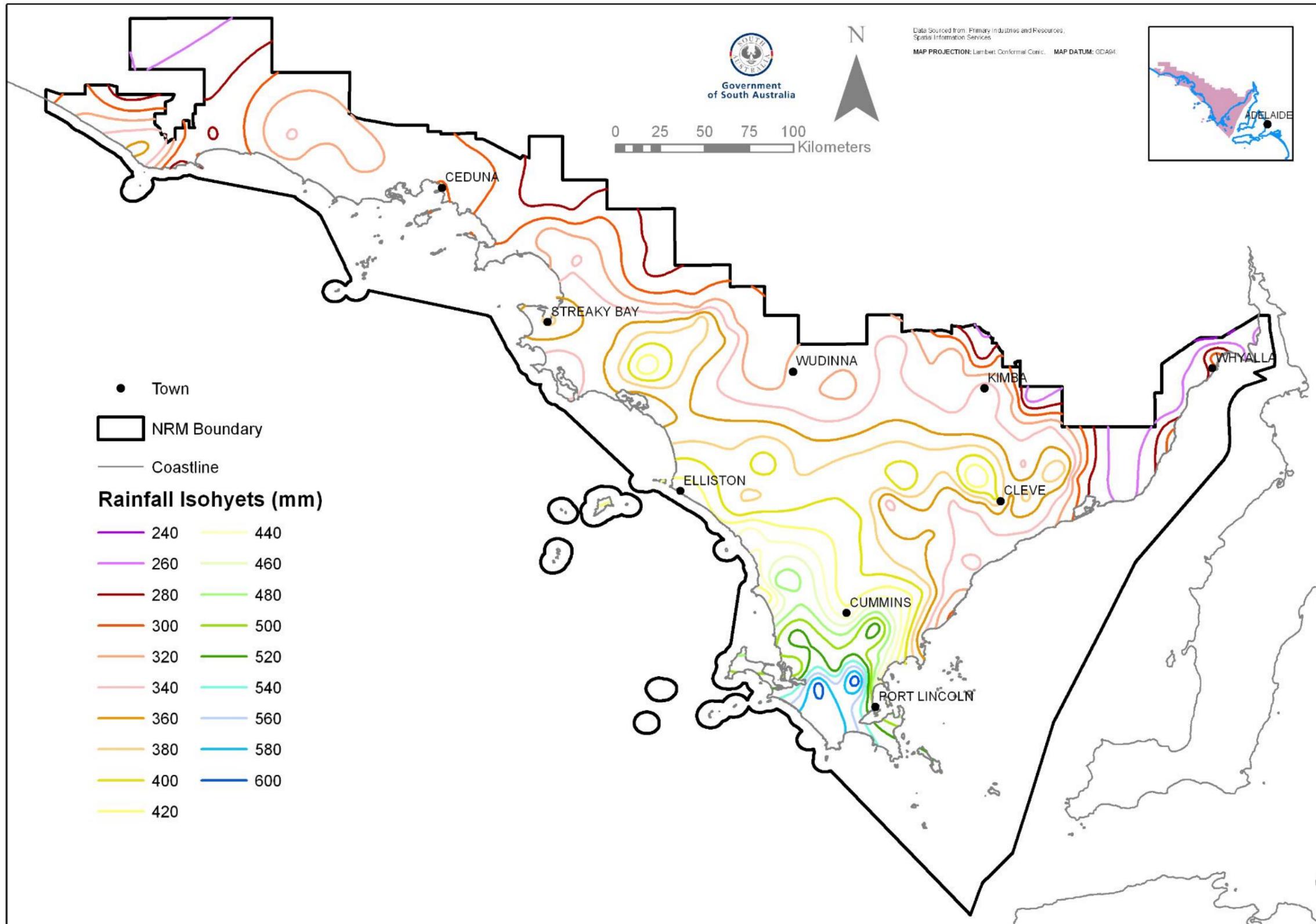


Figure (1) Average annual rainfall isohyets (data source: PIRSA)

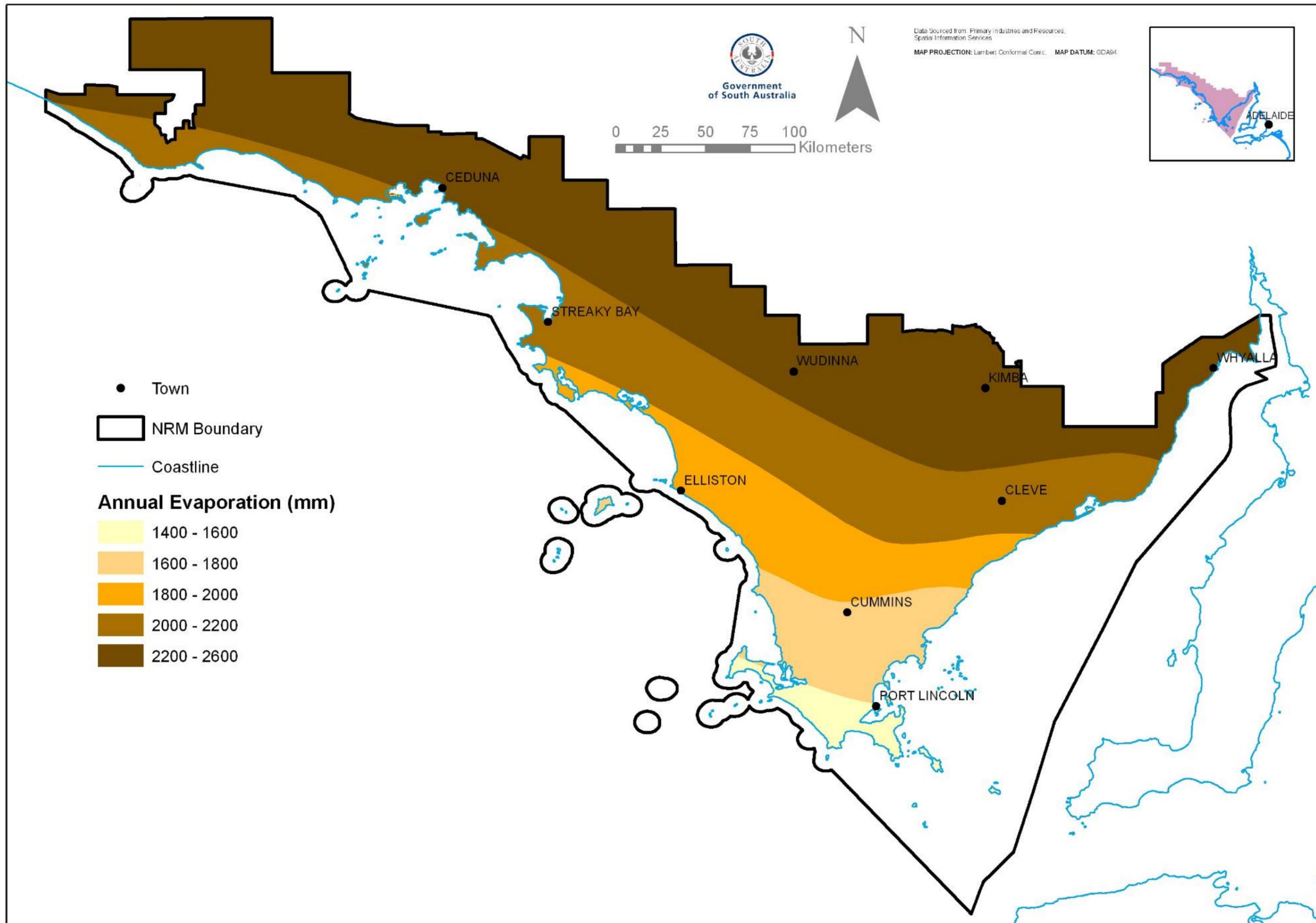
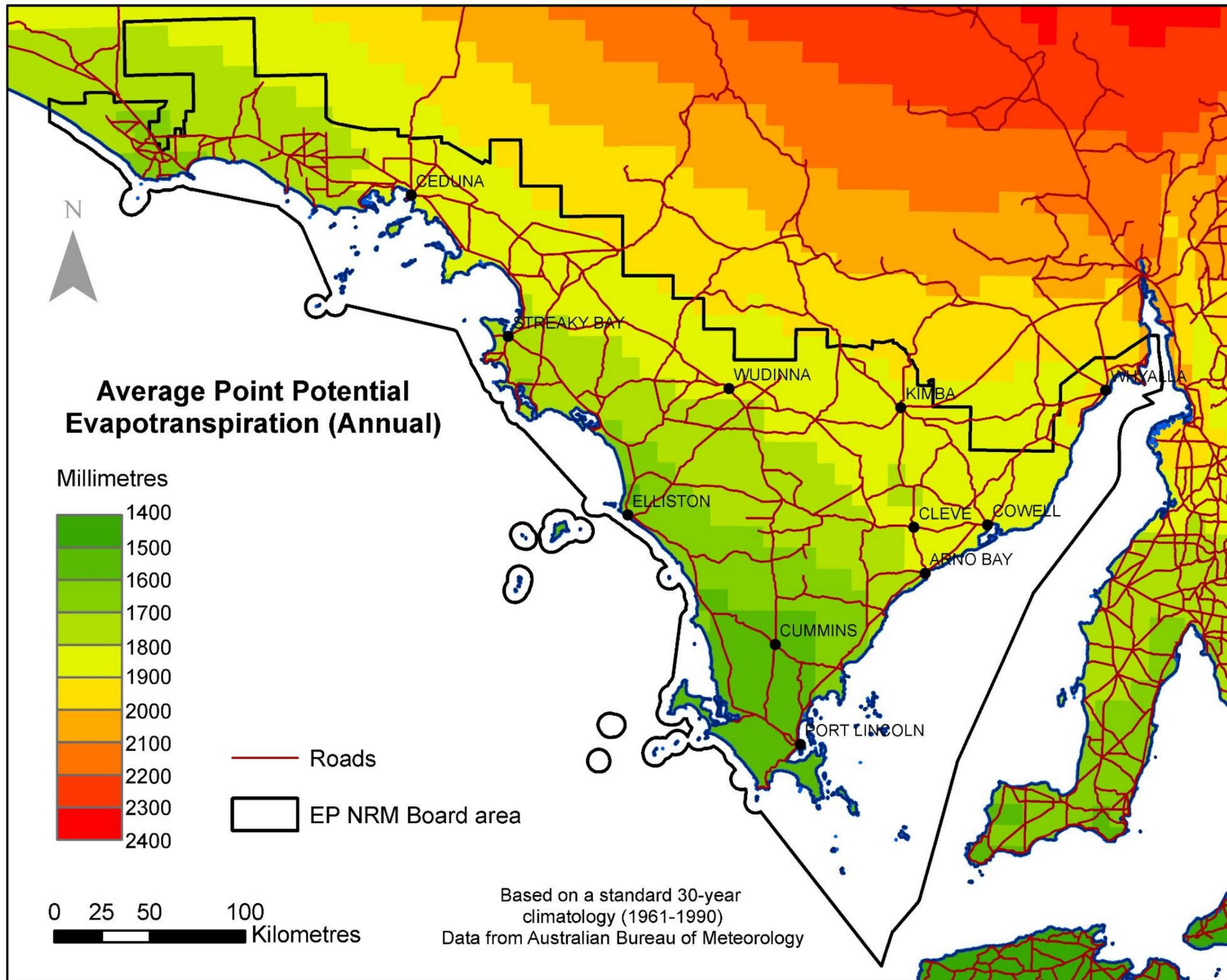


Figure (2) Average annual evaporation (data source: PIRSA)



Note: 'Class A Pan Evaporation' which is the traditional measure of evaporation (see Figure 2) actually over-estimates the evaporation from dams. This is because a larger body of water will have a larger thermal mass (ie. keep cooler at the surface where evaporation occurs) and have higher localised humidity levels. Both of these effects mean that larger bodies of water (e.g. farm dams) will evaporate less water than shallow Class A pans. This map gives a rough estimate of evaporation losses from water bodies (< 1 km²) surrounded by a dry area (eg. farm dam) and is around 75% of Class A Pan evaporation levels.

Figure (3) Average annual point potential evapotranspiration – a better guide to evaporation from dams (data source: BoM)





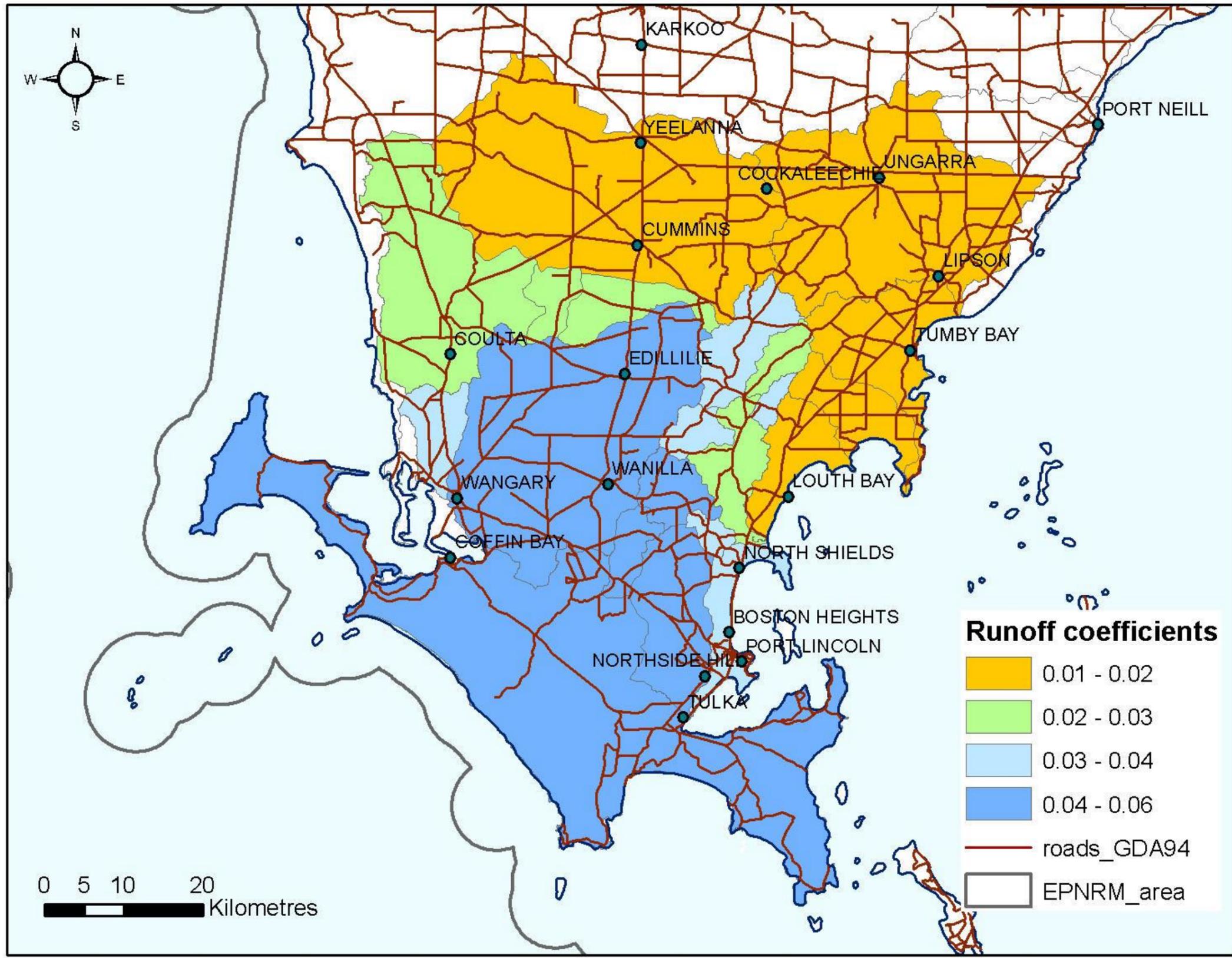




Figure (16) Estimates of runoff coefficients in priority catchments (derived from EPNRMB 2009a)



APPENDIX 2. PRINCIPLES OF DAM CONSTRUCTION (IN PRIORITY CATCHMENTS)

Source: EPNRMB (2009a), pp 30 - 35

Principles

1. The combined capacity of all dams in a catchment shall not exceed the total catchment capacity (see Column F, Table 3).
2. When the total catchment capacity has been reached or exceeded no new dams will be approved in that catchment.
3. Where a new dam is constructed, the
Allowable dam volume (ML) = area of *allotment (ha) x allowable volume (ML/ha) as defined in Column E of Table 3 page 27,
*Allotment means section, lots or allotment identified on a certificate of title, including two or more adjacent allotments owned or occupied by the same person and operated as a single unit for the purpose of primary production.
4. Water may be collected and diverted in a dam, wall and other structure as specified in column E (Table 3).
5. In order to minimise downstream impacts on water dependant ecosystems or other users:
 - a. dams shall not be located within third order or higher order watercourses (see Notes below)
 - b. any dam or structure that collects or diverts water from a watercourse shall incorporate a low flow bypass mechanism
 - c. the low flow bypass mechanism shall be of an approved design and remain operational
 - d. any overflow from a dam, or water diverted by a low flow bypass mechanism shall not be recaptured or diverted.
6. Provision shall be made for flow to pass the dam (ie. low flow bypass) as follows:
 - a. A diversion structure within a watercourse shall include a device that prevents the diversion of water from the watercourse during periods of flow at, or below, the threshold rate
 - b. A dam, wall or structure located within a watercourse shall include a device that regulates the diversion of any flow at, or below, the threshold rate, away from the dam and returning it back to the same watercourse or drainage line below the dam, wall or structure.

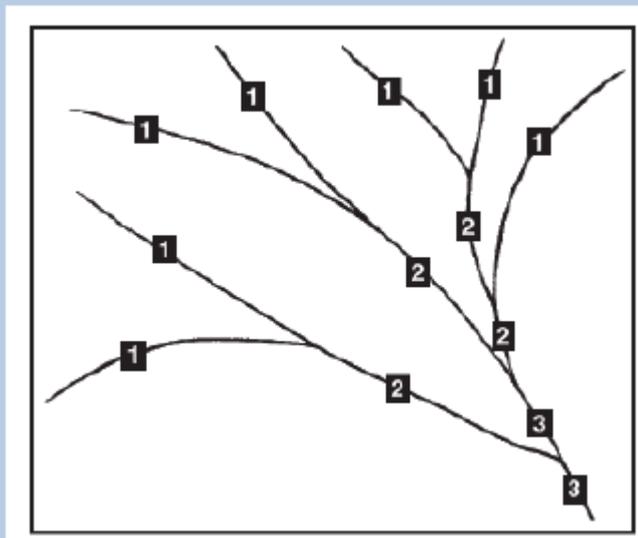


Notes

For the purpose of principle 5, a 'watercourse' means as defined in the *Natural Resources Act 2004*. In addition, this regional NRM plan identified that a watercourse must have a defined channel with both bed and banks (as distinguished from a mere fold or depression or contour in land along which surface water flows).

Watercourses are commonly classified according to the Strahler system of ordering watercourses. Watercourse order describes the relative size and frequency of well-defined watercourses.

Starting at the top of a catchment, any watercourse that has no watercourses flowing into it is a 1st order watercourse. Where two 1st order watercourses join, the watercourse becomes a 2nd order watercourse. When two or more 2nd order watercourses join, they form a 3rd order watercourse. A 3rd order watercourse does not become a 4th order watercourse until it is joined by another 3rd order watercourse and so on.



Note: For the purposes of principle 6, the threshold flow rate (litres/second) means:

- a) The flow rate of a watercourse or drainage line (litres/sec) determined by multiplying the unit threshold rate (litres/sec/hectare) by the area of catchment (hectare) that contributes to the watercourse, that is above the point where the water is diverted from the watercourse or drainage line, or
- b) 0.002 litres/second, whichever is the greater.

For the purposes of (a), the unit threshold flow rate of a subcatchment can be determined by dividing the 10th percentile flow rate (litres/second) for a subcatchment (hectare). Where the 10th percentile flow rate is the flow rate (litres/second) obtained from a time weighted annual flow duration curve (with the time step being 1 day – mean flow), which is greater than or equal to 10% of all flows during that period.



7. Collection or diversion of water flowing in a watercourse, or over land, must not adversely affect downstream water dependent ecosystems by causing reduced stream flow duration, lengthened periods of no or low flow, or other such impacts, unless it is part of a regional natural resources management plan project of the Board (e.g. constructed wetland).
8. Dams shall not adversely affect the environmental flow requirements of ecosystems dependent on surface water or watercourses.
9. Dams for stock and/or domestic purposes may only be erected or constructed if there is insufficient or inadequate water available on the property.

Development matters

Where an activity is defined as 'development' under the *Development Act 1993*, a development application must be submitted to the local planning authority (usually the local Council) for assessment. As part of its assessment, Councils refer specific issues to State Government Agencies for advice or direction. Where a development application incorporates a water affecting activity, the applicant will still need to provide the same information that would be required for a stand-alone water affecting activity. This information will then be referred by the council to the Regional NRM Board and/or DWLBC for advice or direction, which is conveyed back to the applicant as part of the Council's response to their development application.

Location

10. Dams, including dam walls and spillways must not be located:
 - a. in, immediately upstream, or immediately downstream of ecologically sensitive areas
 - b. in areas prone to erosion;
 - c. in areas that may result in increase in land affected by salinity or water logging.
 - d. in an area that would adversely impact downstream water dependent ecosystems
 - e. in third order watercourses or higher; or
 - f. where it is likely to adversely affect the migration of aquatic biota

Dam construction and design

11. Dams shall be designed and constructed to incorporate a range of features to improve water quality and enhance ecological values where possible, for example:



- a. Storage efficiency and effectiveness are optimised by sufficient depth and minimum surface area
 - b. constructed in accordance to best practice
 - c. constructed in a manner that will prevent seepage to groundwater
 - d. should not cause adverse impacts to down stream users or neighbouring properties
12. Dams shall be sited and constructed to minimise:
- a. the loss of soil from the site through soil erosion, siltation and bank erosion
 - b. the removal or destruction of in-stream or riparian vegetation
 - c. evaporation.

Dam maintenance

13. Desilting of a dam does not require a permit provided desilting only involves the removal of unconsolidated material deposited since construction of the dam or material deposited since the dam was previously desilted.
14. Any excavated material removed (for construction and maintenance) or during the desilting of a dam must not be deposited within a watercourse, lake or floodplain of a watercourse.
15. The maximum holding capacity of the dam must not be increased by deepening or enlargement of the dam without a permit.



APPENDIX 3. DESIGN CONSIDERATIONS FOR EQUITABLE SHARING AND ENVIRONMENTAL PURPOSES (OUTSIDE PRIORITY CATCHMENTS)

Outside of the priority catchments, the *State NRM Plan 2006* (DWLBC 2006, DWLBC 2007) can provide guidelines on the sustainable limits of surface water harvesting, in the absence of better local information.

Outside prescribed areas, and until there is additional information, 25% of median annual adjusted catchment yield should be used as an indicator of the sustainable limit of the catchment surface water and watercourse water use. 'Adjusted' is defined as the annual catchment discharge with the impact of dam storage removed.

(*State NRM Plan 2006, Appendix 2*)

The *State NRM Plan's* '25% rule' has evolved from the *State Water Plan 2000* '50% rule'. This required that half the average runoff from any property should pass to downstream users, leaving a maximum of 50% to be captured. Due to a range of factors – lack of inflow in dry years, unharvestable spills in large flows and wet years, evaporation and seepage – experience has shown that only half of the volume captured can be reliably accessed from farm dams every year, giving rise to the '25% rule'.

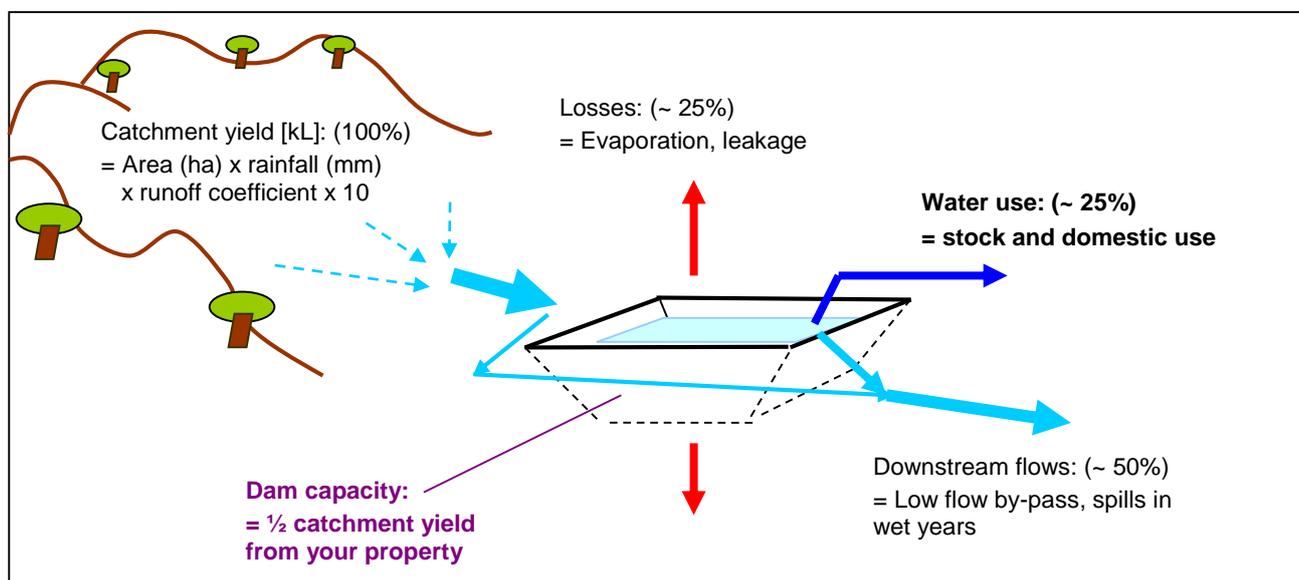


Figure (1) Rough water balance associated with the '25% rule' for sustainable water use. (100% represents the long term average annual runoff/ yield, including wet and dry years.) In this case, a suggested limit on dam capacity is ½ of catchment yield.

Important notes – the above guidelines are designed to protect environmental flows in surface water catchments and watercourses (including ephemeral watercourses) and the maintenance of recharge to useful (non-saline) groundwater resources. However, as the



guideline suggests there is a need for better localised information – which is an ongoing process.

There are potential problems in low rainfall regions with a broad-brush application of this guideline because of the non-linear relationship between rainfall and runoff, and the need for higher levels of water security required by livestock enterprises operating in regions of low and unreliable rainfall.

Moving into low rainfall (e.g. northern, inland) regions of EP, as annual rainfall declines, the % of runoff declines at a larger, non-linear rate. For example, considering two sites with the same soil type and land management, a rainfall difference of 10% may produce a difference in runoff of 30-40%. This relates to the threshold of moisture required to wet up a soil and produce runoff. The lack of runoff in low rainfall areas is exacerbated by high evaporation rates, no-till farming methods (which use more rainfall where it falls) and the recent run of dry years. This run of dry years have contributed to a longer-term trend consistent with the early stages of a projected drying climate.

In low rainfall, high evaporation areas:

- Leading farmers are already pursuing options (at high personal cost) to increase water availability and reliability to support the sustainability of their farming enterprises.
- Options include catchment runoff enhancement, e.g. via plastic sheeted, roaded and/or graded catchments, combined with dam evaporation and seepage control. In many cases, farms now have water available, where otherwise there would have been little or no water, either for farms or the environment.
- Where catchment runoff enhancements are made (e.g. sheeted, roaded or graded catchments), the standard runoff coefficients and expected catchment yields are no longer relevant.
- After enhancements, good reliable water supplies can be obtained from small catchment areas.
- This contrasts with the standard catchment where little or no runoff would be generated from a much larger catchment area, and soil moisture levels are quickly depleted due to high evaporation.
- Aside from production benefits, this increased water availability also offers increased potential benefits to the local environment.



APPENDIX 4. EXAMPLES OF LOW FLOW BYPASS DESIGNS

Source: *Guidelines for meeting flow requirements for licensable farm dams* – Victorian guidelines (State of Victoria 2008).

DWLBC has some draft fact sheets on low flow bypasses currently under development. These will be another important source of information when available from DWLBC's website:
http://www.dwlbc.sa.gov.au/publications/fs_brochures.html

Environmental flows are important for ecological and stream geomorphological processes and can be achieved by:

- Constructing dams away from watercourses and limiting extraction to periods of high flow (subject to necessary approvals), or
- Installing bypasses which allow controlled flows to pass through or around a dam.

Farm dams typically have a much more pronounced effect on catchment health during summer, and bypasses are intended to ensure that low flows and summer freshes are passed downstream. (Minimum flow requirements for on-stream dams in the EP priority catchments are described in Appendix 2.)

For on-stream dams there are 2 types of methods to construct a low flow bypass:

1. Diversion works from upstream of a dam

Options may include:

- Contour channel around the dam to a flow distribution pit, to pass low flows downstream of the dam.
- Upstream weir with bypass pipeline to pass low flows downstream of the dam.

2. Diversion works within a dam

Options may include:

- V-notch weirs upstream and downstream of the dam (which measure flow rates), with an outlet valve (on a pipe through the dam wall) operated to match the flows in summer.
- Gauge board in the dam to monitor water level and an outlet valve to release any inflows in summer.
- Floating offtake and manually operated outlet valve to release any inflows in summer from the dam surface.
- Pressure-operated, electrically-actuated outlet valve to automatically release summer inflows from the base of the dam.
- Floating offtake and pressure-operated, electrically-actuated outlet valve to automatically release summer inflows from the dam surface.



Some preferred bypass mechanisms for different situations are shown below:

Dam type	Local situations	Preferred bypass type
Turkey nest	Turkey nest dam and pumped diversion from waterway	Offstream type
Hillside	Broad sheet flow, no well defined depression or waterway	Contour channel and distribution pit
Hillside	Broad sheet flow, no well defined depression or waterway, catchment increased with diversion banks or catch drains	Upstream weir and bypass pipeline in a diversion bank
Hillside	Broad sheet flow, no well defined depression or waterway	Floating pipe offtake
On-stream	Typical on-stream dam, 50-200m long	Upstream weir and bypass pipeline
On-stream	Very long dams, typically 200-1000m long	Floating pipe offtake
On-stream dam	Multiple tributaries at dam site	Upstream weir and bypass pipeline on a significant tributary

(Source: State of Victoria 2008)

Some example designs for low flow bypass mechanisms are shown below. (Actual designs to suit your situation will depend on site-specific information.)

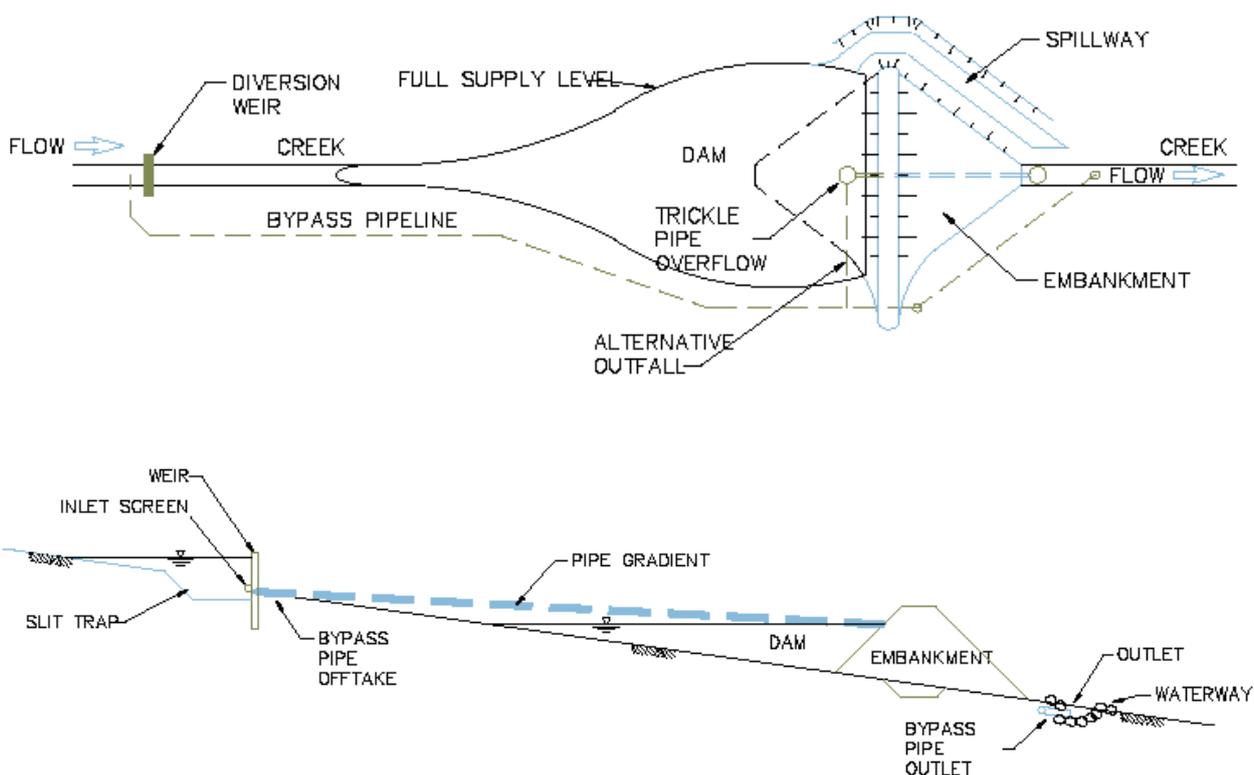




Figure (1) Upstream weir and bypass pipeline (State of Victoria 2008).

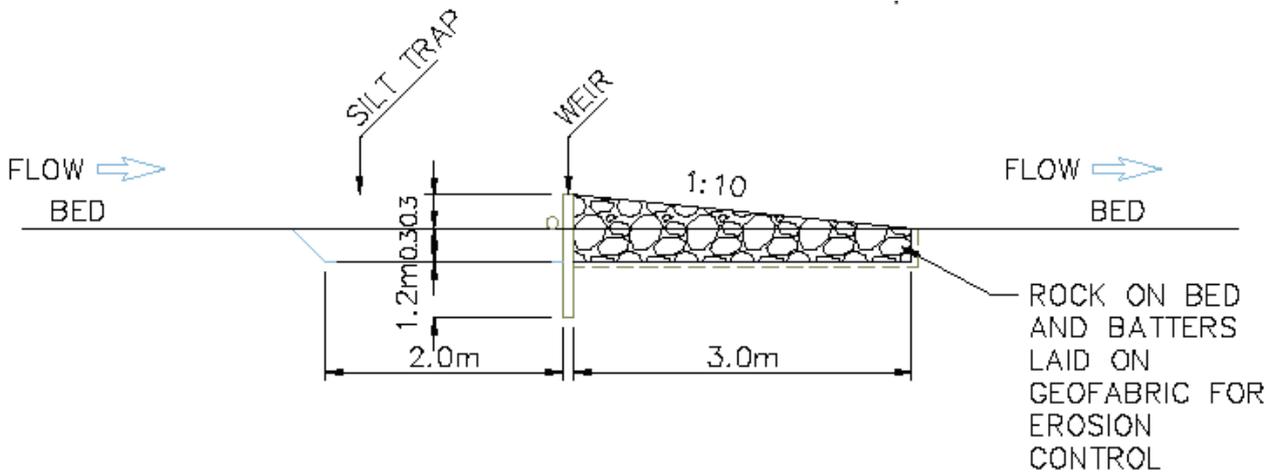


Figure (2) A typical weir arrangement (State of Victoria 2008).

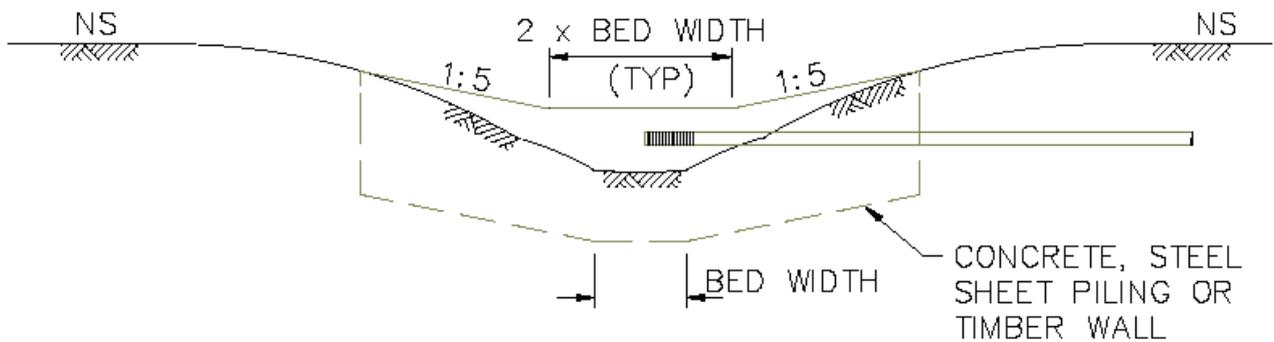


Figure (3) An example diversion weir, looking down the stream bed (State of Victoria 2008).

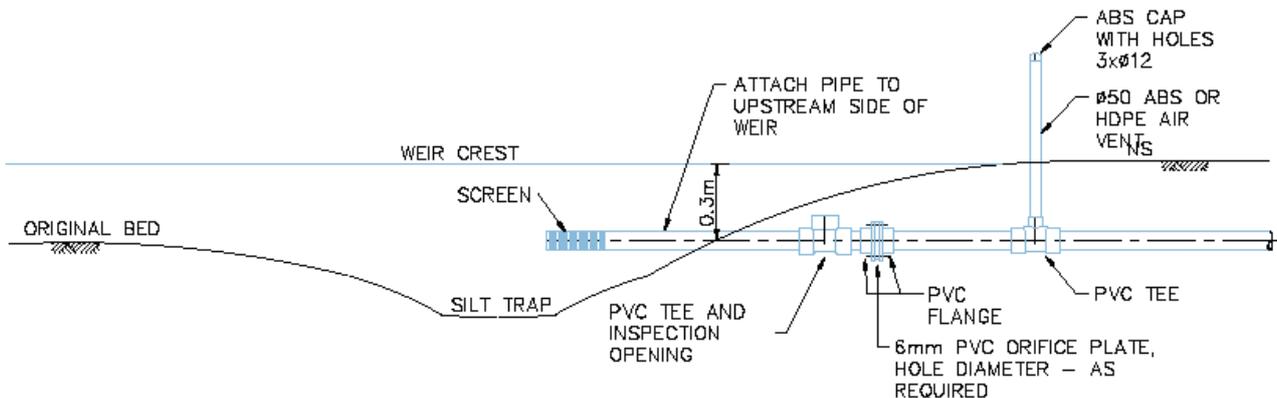




Figure (4) Example detail of a bypass offtake arrangement, showing silt trap, screened inlet, inspection hole and air 'breather' tube (State of Victoria 2008).

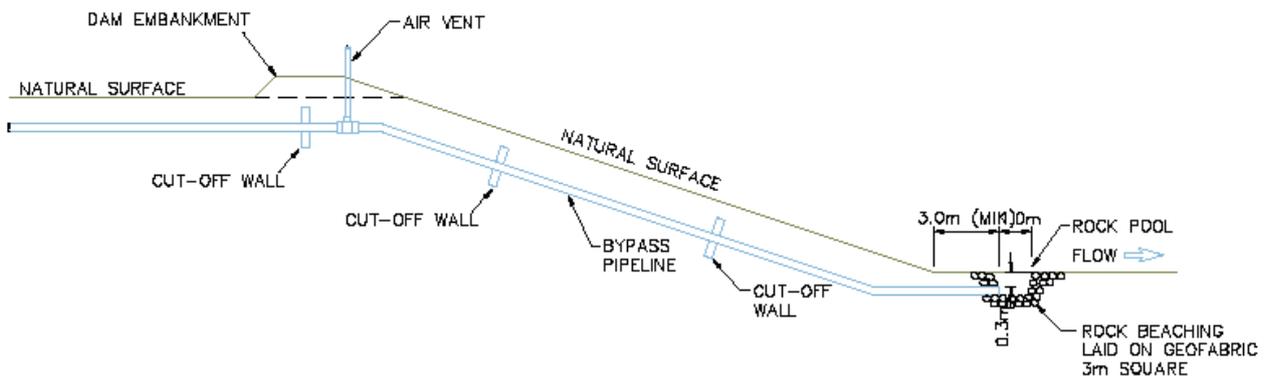
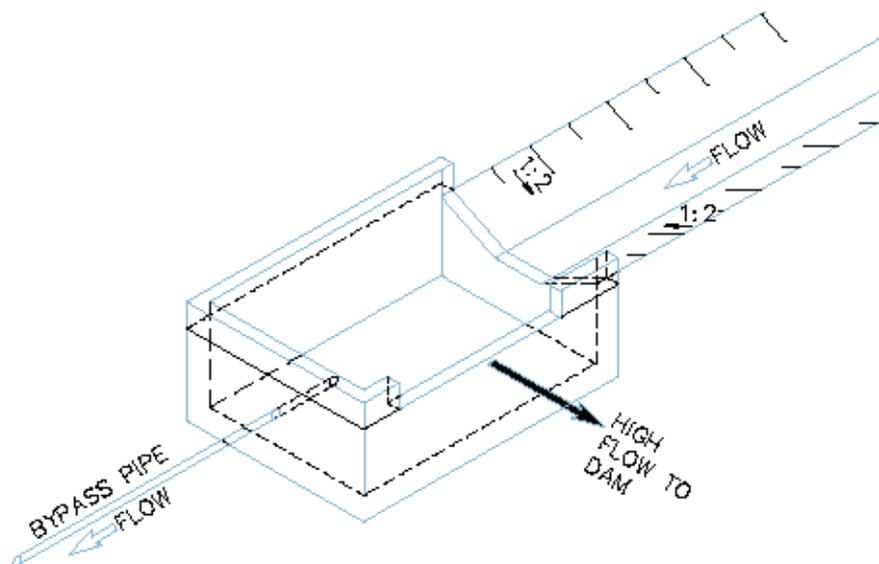


Figure (5) Piped outfalls should be constructed to discharge into the watercourse, hence avoiding erosion of the spillway, stream bed and banks. If pipes cut through the embankment wall, 'cut-off walls' (plates surrounding the pipe) need to be installed to prevent seepage (State of Victoria 2008).



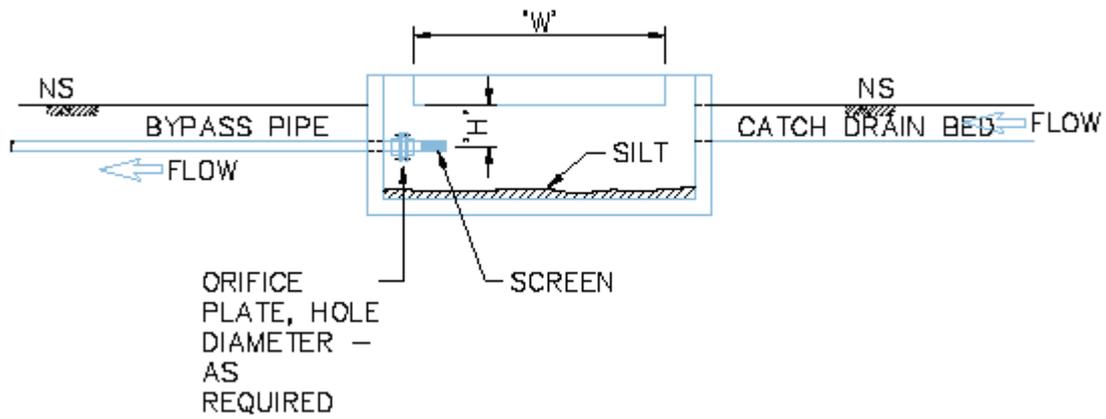


Figure (6) Contour channel and distribution pit (State of Victoria 2008).

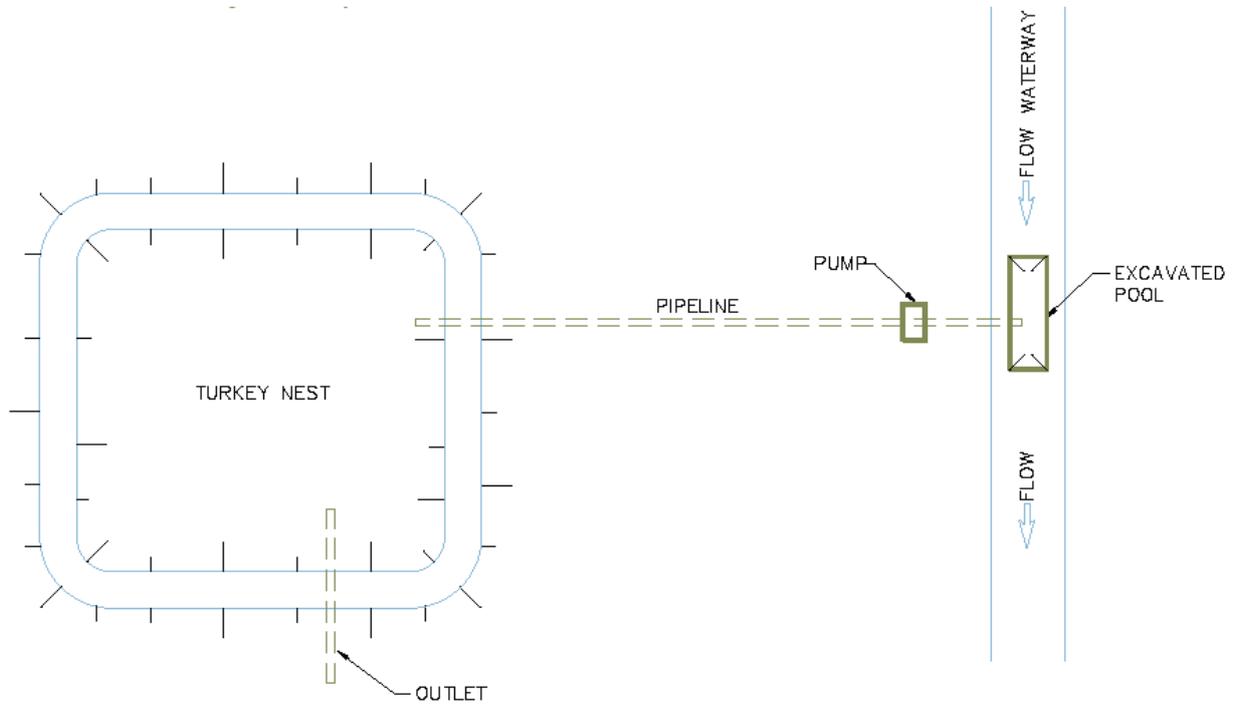
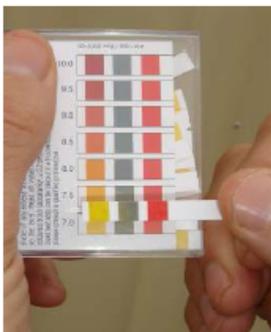


Figure (7) Example bypass mechanism for an off-stream storage (State of Victoria 2008).



APPENDIX 5. WATER TESTING FACTSHEET AND WATER QUALITY GUIDELINES TO SALINITY TOLERANCES

Proper management of water sources is important for achieving good water quality.



If you rely on water from dams or groundwater sources such as soaks, bores and wells, it is important to regularly check your water quality. Salinity is one aspect of water quality that should be regularly tested as a minimum and good records maintained. It is good practice to test important water sources twice per year. For example, a test once in February/March and another in August/September would be ideal. EPNRM can test your samples for salinity if you follow the steps listed below.

How do I collect good water samples?

1. Use a clean plastic or glass container with a good sealing lid that can hold at least 500ml of water. Washed drink bottles are fine.
2. Mark the container or attach the following details;
 - Your name
 - Phone number or postal address
 - Date of sample taken
 - Well, dam, or water source name/id
3. Rinse the container 3 times with the water to be sampled before filling the container to take the final sample.
4. Wells and bores not pumped recently will need to be purged before taking a water sample, this means pumping the well for a period of time to remove at least 3 well volumes of water to get a non contaminated water sample.
5. Call the EPNRM if further advice is needed.

How do I get my water samples tested?

For further information please call or go to our website:

86 Tasman Tce
Port Lincoln SA 5606
Ph: (08) 8688 3111
www.naturalresources.sa.gov.au

Or the Department for Water website:
www.waterforgood.sa.gov.au

1. Deliver your water sample(s) to an EPNRM office located at Port Lincoln - 8688 3111, Tumby Bay – 8688 2610, Elliston – 8687 9275, Streaky Bay – 8626 1108, Ceduna – 8625 3060 or Cleve – 8628 2077 for salinity and pH testing.
2. If you require water testing for other factors such as bacteria levels, algae or levels of other minerals, the sample will need to be sent to a professional laboratory.
3. If you have any questions or want to discuss your water test results, contact an EPNRM officer.



Water Quality – Guideline to Salinity Tolerances

Salt tolerance of stock to drinking water TDS (PPM) (Figures derived from NWQMS 2000)

Stock	Desirable maximum concentration for healthy growth	Maximum concentration at which good condition might be expected*	Maximum concentration that may be safe for limited periods*
		Water being used for stock in these 2 categories should be used with caution and/or expert advice sought.	
Sheep (dry)	5000	5000 – 10 000	10 000 – 13 000
Sheep (lambs, pregnant, lactating)**	3800	3800 – 5000	5000 – 6400
Beef cattle	4000	4000 – 5000	5000 – 10 000
Dairy cattle	2500	2500 – 4000	4000 – 7000
Horses	4000	4000 – 6000	6000 – 7000
Pigs	4000	4000 – 6000	6000 – 8000
Poultry	2000	2000 – 3000	3000 – 4000

* The level depends on the type of feed.

** Figures compiled from various information sources as NWQMS 2000 did not contain this information.

Tolerance of plants to salinity in irrigation water (Figures derived from NWQMS 2000)

Figure = TDS(PPM) / EC (µS/cm)

TDS estimated by 'EC x 0.56 = PPM'

Common Name	Average root zone salinity threshold	Threshold for crops growing in soils:		
		Sand	Loam	Clay
Olive	2240 / 4000	2856 / 5100	1624 / 2900	952 / 1700
Peach	1792 / 3200	2632 / 4700	1512 / 2700	896 / 1600
Grapefruit	1008 / 1800	1680 / 3000	952 / 1700	560 / 1000
Orange	952 / 1700	1624 / 2900	952 / 1700	560 / 1000
Grape	840 / 1500	1848 / 3300	1064 / 1900	616 / 1100
Apple	560 / 1000	1120 / 2000	672 / 1200	392 / 700
Zucchini	2632 / 4700	4088 / 7300	2352 / 4200	1344 / 2400
Broccoli	1568 / 2800	2744 / 4900	1568 / 2800	896 / 1600
Cucumber	1400 / 2500	2352 / 4200	1344 / 2400	784 / 1400
Peas	1400 / 2500	1792 / 3200	1008 / 1800	616 / 1100
Tomato	1288 / 2300	1960 / 3500	1120 / 2000	672 / 1200
Potato	952 / 1700	1792 / 3200	1008 / 1800	616 / 1100
Capsicum	840 / 1500	1568 / 2800	896 / 1600	504 / 900
Lettuce	728 / 1300	1512 / 2700	840 / 1500	504 / 900
Onion	672 / 1200	1288 / 2300	728 / 1300	448 / 800
Beans	560 / 1000	1064 / 1900	616 / 1100	336 / 600
Carrot	560 / 1000	1232 / 2200	672 / 1200	392 / 700

This is a general guide to ONE aspect of water quality, which is salinity, and must be used as a guide only. It is possible for situations to occur that lead to higher or lower salt tolerance levels in plants and animals such as feed types, temperatures and soil conditions. For stock, poor-quality water can reduce production, impair fertility and lactation and, in extreme cases cause animal deaths. Water sources can have issues of salinity, pH, algal growth, pollution, faecal contamination and toxic elements all contributing to the suitability of water for stock and other uses. Water quality issues can be the direct result of poor management at the water source and in certain cases can be avoided and water quality improved by simply adopting better management. Speak to your local NRM officer about how you might be able to improve the management of your water sources.

Always have your water routinely tested and protect your water sources with proper management.



