NSW Agriculture

WATERWISE ON THE FARM

On-Farm Water Storages

GUIDELINES FOR SITING, DESIGN, CONSTRUCTION & MANAGEMENT

Contents

Why develop an on-farm water storage?

For the economic benefits

On-farm water storages allow irrigators to:

- use water more efficiently
- capture drainage flows from irrigation or rainfall and store it for later use
- minimise water loss and loss of nutrients
- collect water from streams during high flow periods
- store water for later use, allowing irrigation when it is needed, rather than only when water is available
- simplify water management

For the environmental benefits

Council of Australian Goverments (COAG) water reforms and the NSW water reforms stress the need for increased efficiency in water use and for better management of pollutants in irrigation tailwater. On-farm storages allow irrigators to:

- store and recycle irrigation drainage, rainfall run-off, pumped groundwater and polluted farm water
- allow for a holding period before discharge of excess stormwater
- control erosion and sediment
- optimise the timing of irrigation to increase water use efficiency
- reduce the demand on unregulated streams during low flow conditions

Where local rules require, the storage may need to collect the 'first flush' of polluted run-off from the farm to avoid contamination of downstream waterways. In this case, the storage will need to be big enough and be managed so that it has space to capture this drainage.

For the 'engineering' benefits

Storages may also be planned as an outcome of excavation for other purposes, for example when spoil is required for channel embankments.

The stages involved in developing an on-farm storage

PROPERTY PLANNING

- Landholder checks on what permits and authorisations are required, including local regulations, and what funding may be available
- Landholder commissions designer to prepare options for storage of around X megalitres
- Designer surveys block
- Designer identifies two or three alternative sites, considering benefits and drawbacks of each site within the whole irrigated area of the farm, irrigation system, power supply and management
- Landholder and designer evaluate preferred sites for storage and pumping

If the landholder has prepared an irrigation and drainage management plan, or a whole farm irrigation plan, these steps will have already been completed.

EVALUATING ALTERNATIVE SITES

- Landholder and/or consultant checks and gets advice on conservation values etc. for alternative sites
- Designer or soil surveyor tests soil of each preferred site to make sure it won't leak excessively, typically using an EM31 assessment and other tests
- Designer or soil surveyor tests the soil of each preferred site to see if it is suitable for construction
- Landholder and designer evaluate each site for benefits, constraints and risks
- Landholder decides on storage location

DESIGN STAGE

- Designer designs storage, considering size, slopes, best protection against seepage, batter protection, cut-off trench, wind direction, freeboard, crest width, and any special construction requirements
- Landholder and designer prepare more accurate cost estimates, and finalise funding
- Landholder obtains all necessary permissions from local authorities to enable construction to start

CONSTRUCTION STAGE

- Contractor pegs out site and marks location of top water level, crest, and so on
- Contractor clears vegetation and strips topsoil, stockpiling it for later use
- Contractor rips foundation and lays fill, testing for compaction
- Contractor constructs and stabilises embankment

OPERATING AND MAINTAINING THE STORAGE

- Landholder takes care to manage first filling and filling after a dry time
- Landholder regularly monitors condition of storage
- Landholder ensures management meets requirements to store 'first flush', if required

Evaluating alternative sites for the storage

The location of any services (that is, phone, gas, water or electricity lines) is crucial when planning any excavation: cables and pipes should have been noted on property plans and with signposts in the paddock. If any services cross a possible excavation site, the designer must know their positions. The cables and pipes will need to be accurately and thoroughly marked before any construction starts.

Deciding on storage size and choosing its site must start at the whole farm planning stage. Ideally, the business management plan for the property, and the whole farm irrigation and drainage management plan that is part of it, will indicate whether a storage is required, and how it is to be used.

A storage is a key element in a farm irrigation development and it should be included at the basic planning phase, even if its construction is to be delayed. (Adding on a storage to the design later tends to be more expensive, and allows fewer options.)

In practice, however, many irrigators have not yet developed a detailed irrigation and drainage management plan. Instead, the landholder is likely to request a systems designer to survey the whole farm block and identify several sites for locating a storage. Many properties offer unique opportunities, and an experienced designer can often take advantage of site-specific conditions.

The landholder and the designer work together to test how feasible each site is.

Selecting the optimum size for the storage

The business plan for the property, the enterprise's physical constraints and its budget will determine the size of the storage.

Because the depth of water a storage holds affects the possible seepage rates from the storage, the designer will evaluate the desired storage size against the dimensions and location of the storage (see report from the (then) Rural Water Commission at Kerang, 1978).

Larger is better

In general, a good site allows for the construction of a large storage. Larger storages are preferred for several reasons:

1. If the storage is deep, this minimises evaporation loss.

Water should generally be stored for as short a time as possible, but, particularly if the storage is to hold summer rainfall run-off and off-allocation flows, its design should aim to minimise evaporation losses by having a minimal surface area. Evaporation rates at the height of summer can be over 8 mm a day—a shallow storage with a large surface area can quickly become a muddy, weed-filled depression!

Storage for short periods will minimise losses through evaporation and seepage, and prevent salts concentrating in the water. A short storage period, of course, does not match the irrigator's need to store for long-term security. Getting the most from the available storage means the irrigator has to make day-to-day management decisions and therefore needs good information and knowledge of likely rainfall patterns.

Note also that clay-lined storages may need to be kept moist to protect the integrity of the lining, and so may require more frequent filling.

2. **Building a large storage is one way of getting the most value from equipment and infrastructure.**

Because a large proportion of the overall cost of a storage system is in the pump, pipes and valves, it makes sense to spread this cost by increasing the storage volume and thus get more use from the infrastructure.

3. **A larger storage gives more flexibility in operation.**

A smaller storage is cheaper to build and maintain, and does not occupy as much productive land, but it may not provide the flexibility the farmer requires. A larger storage will allow for greater harvesting of off-allocation flows and the run-off from intense summer thunderstorms. Run-off in winter can also be significant, and harvesting this run-off will provide extra irrigation water in spring.

Split-level storages

A split-level storage can often be useful, allowing the landholder to store summer drainage in a smaller, deeper area (thus getting lower evaporation losses), but also to keep off-allocation water and winter run-off in a larger and shallower (and therefore cheaper) area.

Problems with small storages

Small storages often prove incapable of supplying their owner's water needs. This problem can usually be prevented by engaging the services of professional advisers, who can also give advice on other risks such as structural failure.

Meeting minimum requirements

In the Land and Water Management Plan surface irrigation areas, the minimum storage size is determined by the EPA requirement for the capability to capture run-off after a storm event. (The volume is specified in the various Land and Water Management plans.)

Any increase in volume above these minimum requirements is available to store water, ease management and capture 'accidents'.

Commonly, maximum volume is limited by the available site area or cost. It is possible to make the storage too large, so it is impossible to fill with the available or reasonably expected flows.

Choosing a location

A storage can be beneficial whether it is built next to the supply point, at the lowest point of the system, or somewhere in between. The type of storage the landholder chooses will be determined by weighing up possible locations against storage needs, the permeability of the soil at the site, enterprise needs and costs.

Below are some advantages and disadvantages for each storage type. Combining these basic types can be a solution; for example, a combination of an external sump at a low point and a turkey's nest constructed above-ground.

The advantages of above-ground or below-ground construction will differ for each location. If a padded channel is required, earthworks costs may be higher.

Highest point storage

Advantages

- Water flows out of the storage under gravity at high flow rates without pumping.
- Most paddocks can be commanded without the need for pumping.
- Often the pump can also be used to lift the supply water to give better command over higher country.

Disadvantages

- After irrigations and rain, drainage must be pumped into the storage. The pump must be large enough to cope with run-off rates and volumes.
- If there is a large fall across the farm, the main drain back to the storage may be quite deep, which can mean extra cost.
- With a high point location, the storage ratio may be low (that is, a large amount of earthworks may be required for a relatively small amount of water storage). This means higher costs per megalitre of water.
- This type of system often requires a complex pump-well and valve arrangement.
- Pump size depends on the buffer capacity of the drains and sump—a smaller capacity buffer requires a larger pump.
- High ground often means lighter soils that are too permeable for proper storage construction.

Lower point storage

Advantages

- A storage at the lower end of the system can fill by gravity from the drainage system, and so no pumping is required after rain.
- Lower sites usually have heavier soils that are suitable for water storage.
- Access to pump sites is not required during rainfall periods.

Disadvantages

- To recycle water into the farm supply system, the landholder may have to pump it a long way.
- Lower point sites often have a low storage ratio (every cubic metre of soil dug may result in only one cubic metre of water storage).
- There could be problems with shallow groundwater.
- In some localities, low point sites may straddle prior streams with sand beds underneath.

Intermediate point storage

Advantages

- Construction can be staged over time, with the drainage–recycling system constructed first, and the storage later.

Disadvantages

- The storage inflow and outflow rates depend on the size of the pump.
- This system usually needs a complex pump-well and valve arrangement to work properly.
- If there is little buffer capacity in the drainage system, the pump will need to be used immediately after rainfall.

Investigating environmental impacts

The landholder's preliminary assessment of the preferred sites will consider the conservation values of the area and in particular any legal constraints on siting a storage in that position.

The following checklist notes the main environmental 'no-go' areas. The landholder also needs to protect these areas from any risks or impacts from the storage or other developments nearby.

1. Avoid **high conservation value areas** such as wetlands, floodplains or riparian areas.

   The landholder is required by law to conserve native vegetation, including grasslands (as in the Native Vegetation Conservation Act 1997). In the past, black box depressions were used as convenient storage sites, but, depending on the area, they may contain significant remnant vegetation.
2. Avoid and protect any **habitats for threatened flora and fauna** species, as covered by the Threatened Species Conservation (TSC) Act.
3. Avoid and protect **heritage and archaeological sites** of significance, particularly Aboriginal sites containing scar trees, stone artefacts, middens, or burial sites, or areas of potential Aboriginal heritage value such as sand dunes and areas near natural water bodies.
4. Follow the Environmental Planning and Assessment Act on **watertable depth.**
5. Avoid these **unsuitable soil types** where possible:
   - sodic soils (not always suitable for construction, unless special precautions are taken)
   - acid sulphate soils (ASS)
   - potentially acid sulphate soils (PASS)
   - prior stream formation (PSF)
   - sand

   (A simple test or visual assessment for these soil types is all that is needed at this stage.)
   Note that storages can be constructed in these soils, but will require special design features and are usually more expensive.

Why to avoid PASS

When potentially acid sulfate soils are disturbed, they oxidise and produce sulfuric acid, which dissolves minerals from the soil. The resulting acid and metal-rich leachate can pollute groundwater, streams and water bodies, is toxic to plants and aquatic organisms and corrodes steel and concrete structures. The distribution of acid sulfate soils is primarily limited to the coastal areas of NSW and south-eastern Queensland.

Potentially acid sulfate soils are discussed in more detail in appendix 2.

Further information on conservation areas

When doing the preliminary environmental impact assessment the landholder or advisors should also identify where there is further information on known conservation values, for example:

- Murray Irrigation LWMP Inventory,
- NPWS Aboriginal Sites Register,
- NPWS Wildlife Atlas,
- NPWS Wetland Database,
- local field naturalists/conservation group/organisations, or
- local Aboriginal Land Councils.

The landholder and designer will also need to find out how to comply with SEPP 52 ('Farm dams and other works in land and water management plan areas').

GLOSSARY

sodic soils have an excess of exchangeable sodium (ESP greater than 6), causing dispersion to occur in clays. This dispersion can lead to piping, and storage failure.

sodicity: refers specifically to exchangeable sodium cations held on the surface of the clay particle. The greater the proportion of sodium in the total exchangeable cations, the more sodic the soil is.

TSC Act: Threatened Species Conservation Act 1995 (NSW). The TSC Act recognises that the habitat of a threatened species requires protection as well as the species itself. The Minister for the Environment can declare an area that is habitat for an endangered species to be 'critical habitat' which is then protected. The Director-General of National Parks must keep available for public inspection a register of all critical habitat areas.

Testing soils

The designer/soil surveyor will evaluate each of the preferred sites to check the waterholding properties of the soil (this is the primary requirement for a storage) and whether the soil is suitable for construction. The number of soil samples and soil tests the surveyor will take depends on the particular conditions of the sites being investigated.

To do this, the designer/soil surveyor will carry out tests on the dispersivity and permeability of the soils at the preferred sites, usually starting with an EM31 assessment.

See appendix 1, 'Locating sites for soil sampling'.
See appendix 2, 'Testing for suitable soils'.

The designer may also need to check the groundwater depth and salinity at the site; the permeability and infiltration rates of the storage floor, and the effect of the water to be stored on the permeability of the storage (for fresh, rainwater drainage, irrigation water or bore water sources).

How thorough does the testing process need to be?

The minimum investigation which the designer will carry out for any site evaluation is generally made up of:

- EM survey, and drilling for samples to ground-truth the EM results
- simple dispersion test (using water which matches the stored water quality)
- soil classification, and
- hand-texturing soil for storage and construction properties.

More tests will be needed when the site has particular problems, such as wide variation in soil types or soils which may be unsuitable for construction, or where the consequences of storage failure are serious.

GLOSSARY

electromagnetic (EM) induction: The EM31 instrument, made by the Geonics company, uses induced electromagnetic fields to map the apparent electrical conductivity (ECa) of the soil. The surveyor interprets these results to create contour maps of suitable or unsuitable soils, and locate watertables and areas of salinity, low soil moisture, and soil textures.

dispersivity: how easily the soil disintegrates when wet: if soil is highly dispersive, it is less suitable for storage construction and the design may need to be changed to compensate for the dispersivity.

infiltration: movement of water into and through soil.

permeability: a soil property that determines the rate which water can move through the soil particles: if a storage is made in highly permeable soil, water will leak out of it.

Evaluating the risk factors of each site

For each stage of the siting, design, construction and management process there are specific risks. Problems are more likely to be avoided at the investigation or site evaluation stage when the landholder is confident that the designer has a good knowledge of local rainfall and evaporation patterns and their probabilities, the soils found in the catchment and likely seepage losses. This means the designer will have enough information to avoid the risk of building a storage that might fail to hold or will not meet the expected demand.

The main risk at the investigation stage is an inadequate investigation of each alternative site, particularly a failure to investigate the soil conditions of each site. Poorly operated and maintained survey instruments could contribute to this problem.

If the designer/soil surveyor/laboratory staff do not carry out an adequate investigation of the soil properties at the site, structural failures might occur after construction. The key problem which the designer has to deal with is groundwater accession (losses by seepage to the watertable).

Other problems include:

- cracks in the storage embankment
- failure of the lining
- breaching by piping. This can be caused by dispersive soils and poor construction techniques.

Piping

Water seeping through a soil may form 'pipes' or tunnels. There are several possible reasons for piping failures:

- poor compaction during the construction of the storage;
- a soil which is easily detached and transported by water flow through the soil. (This is usually soil that has lots of dispersible clay or high levels of silt and fine sand.)
- a system of cracks or pores that provide a relatively rapid path for water to flow through the body of the soil;
- the head of water over the floor of the storage. This has a large influence on seepage losses, because seepage is often controlled by the difference between the height of the water in the storage versus the depth of the watertable beneath the floor of the storage.

Designing the storage

The key features which the designer will specify before construction are:

- the storage volume
- the borrow area
- the height of the freeboard
- the depth of the cut-off trench
- the spillway, if any
- the slopes on the batters, and whether the batters are protected
- the width of the crest

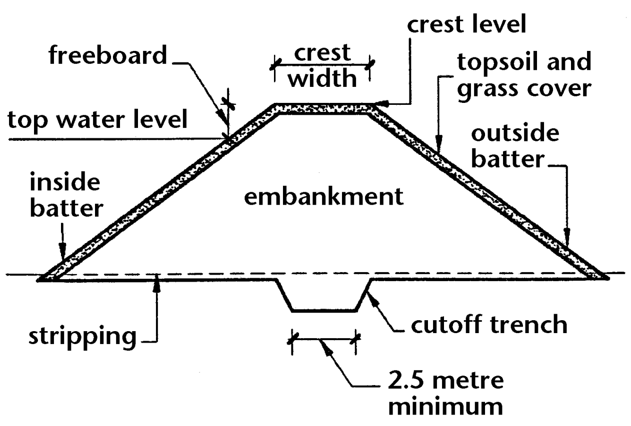
Appendix 3, 'Aspects of storage design', spells out the guidelines the designer follows.

Avoiding risks at the design stage

The risk factors at the design stage are lack of data, or, more frequently, the designer's failure to apply available knowledge about the basic properties of soils, the mechanics of earth storage design or the likely volume of water that has to be contained.

Even when all precautions are taken, seepage problems can still happen. Seepage is usually caused by the presence of permeable zones and high watertable conditions at the site.

Controlling seepage through the floor of the dam is very important and requires a thorough design study. The success of the construction depends on the designer and the earthmoving contractor giving sufficient consideration to site, soil conditions, and the use of appropriate equipment.



GLOSSARY

batters: The batters are the sides of the excavated area and the storage embankment. The slopes of each batter are described in terms of horizontal distance to vertical distance, as a ratio, in degrees or as a percentage. For example, a 4:1 slope means four horizontal units to one vertical. A 1:2 slope means one horizontal to two vertical.

Constructing the storage

If a storage has either a maximum water storage depth of 0.8 metre or greater against the constructed bank, or a storage capacity greater than 15 megalitres, then the guidelines detailed by Central Victoria & Riverina Geotechnical Pty Ltd (CVRG) are recommended.

A summary of these guidelines is presented below, outlining the steps of the process:

- mark the site
- clear vegetation
- strip topsoil
- prepare the subgrade
- install pipe(s) and cut-off trench
- form and compact the embankment
- cover embankment with topsoil
- protect the embankment with grass

Mark the site

Mark the storage site carefully, indicating the location of the proposed excavation, the storage embankment and the top level of the water.

Clear vegetation

Clear all natural vegetation within the area of the storage works and remove it as spoil, including any stumps and their roots. Clearing should cover the area to be occupied by the proposed earthworks (embankment and borrow areas) plus a further 0.5 metre on all sides.

GLOSSARY

borrow pit: the excavation that soil is taken from to build an embankment.

Strip topsoil

Remove topsoil from the excavation and embankment site ready for constructing batters, plus a further 0.5 metre on all sides.

The thickness of material to be stripped from the proposed embankment foundation will vary. This has to be assessed on-site during construction.

Keep the removed topsoil away from the area being worked until you are ready to spread it over the outside batter and the crest, ready for sowing with a grass to hold the embankment.

Prepare the subgrade before placing the fill

All construction has to be carried out layer by layer.

Before placing the first layer of fill on the stripped embankment foundation, scarify the surface to a minimum depth of 150 mm. When placing subsequent layers, if the surface of the previous layer has dried out or cracked, then rip or disc-plough the surface to at least 50 mm below the depth of cracking, then water and mix the layers.

Cut a clay cut-off trench

Constructing a clay cut-off zone and keying it into the existing subsurface minimises seepage beneath the embankment. The cut-off trench does this by providing a zone of relatively low permeability compared with the natural soil, which often contains fissures and large pores.

Construct cut-off trenches with a minimum base width of about 2.4 metres along the length of the embankment. The cut-off trench should have batters no steeper than 1:1, and the base and batters of the trench should be tined to a minimum depth of 50 mm to ensure good bonding with the in-situ material. In all cases the base must be wide enough to permit the operation of construction equipment and the use of temporary dewatering devices.

The cut-off trench has to be cut deep enough to extend at least 300 mm into impervious material but so that it is no less than 600 mm below the natural surface. This depth has to be determined on-site.

Compact the embankment

The designer must supervise the construction, or judge what supervision is required, so that he or she is confident that the moisture content of the material used when constructing the embankment is correct, and the appropriate standard of compaction is met.

A scraper is commonly used for embankment construction. It will achieve acceptable compaction as long as the layers are no more than 150 mm thick, and are effectively rolled by the scraper across their full width.

Setting an inside batter of 5:1 allows the loaded scraper to climb the bank at any point. A well-planned haul pattern dramatically increases the quality and uniformity of compaction throughout the compaction process. Hauling over the one place continually leads to areas of stratification within the embankment, increasing the risk of piping: if this cannot be avoided, these areas should be shallow-ripped, with, for example, scraper bucket rippers, before the next layers are added.

Compaction rollers are less commonly used, but can give excellent results when a suitable layer thickness is chosen.

Loose fill techniques using an excavator bucket or bulldozer, for example, are only suitable when a grader and a compaction roller are also used to spread and compact the fill.

Technical notes on compaction control are listed in appendix 4.

Place pipes

In selecting the site and designing the storage, the designer will try to minimise the number of pipes through the embankment. This is because it is difficult to get adequate compaction around pipes, because the soil can crack because of the different settling rates, and because it encourages tunnelling or piping along the pipe.

To avoid these problems, the contractor can modify the clay below, above and around the pipe with gypsum for a minimum distance of 2 metres. The trench for the pipe is cut into natural ground under the earth bank or through a compacted section of bank. Generally, pipe trenches should have a base width about 300 mm wider than the diameter of the pipe.

The design will probably provide for one or more concrete cut-offs around the pipe. These are installed around the pipe within the embankment, preferably into undisturbed ground, about one-third of the distance from the outside exit of the pipe. The cut-off, which could also be made of heavy duty plastic and taped to the pipe, makes it harder for water to use the pipe as a shortcut through the soil and thus cause structural damage.

The trench should be cut and the pipe installed as early as possible in the construction process to allow the excavation time to settle and compact: cutting through the completed embankment creates a point of weakness which may result in failure. After the pipe is in place, the trench is backfilled and compacted thoroughly with a vibrating packer, taking care to compact the backfill properly below the midline of the pipe. Pipe manufacturers' recommendations regarding installation, backfill materials and compaction must be followed.

Stabilise the embankment

For the inside batter

Wave action within the reservoir may erode the inside face of the batter, although a design which chooses an appropriate slope and avoids a long fetch in strong wind directions will help avoid this erosion.

For batters with a low slope, use hydrated lime as a stabiliser, mixing it into the batter with a harrow, elevating scraper or disc plough to a depth of 200 mm, and at a minimum mix of 2–3% hydrated lime by weight.

For the outside batter

A layer of between 100–150 mm topsoil is recommended. This serves to reduce surface erosion and prevent cracking. The crest is also protected with a topsoil layer.

Protection against piping failure

If the embankments have been constructed from a dispersive soil, the contractor can reduce the risk of failure by stabilising the embankment around the pipe ends with lime.

As an extra precaution, the landholder should make sure that, on first filling or after an extended dry period, the filling rate is no greater than 100 mm per day. Even slower rates may be required for a particular site, or where the soil has a high crackfill component.

The landholder may well decide not to stabilise the embankments with gypsum where the consequences of failure are minimal.

Protect the embankment with grass

The completed embankment should be planted with a good holding grass such as kikuyu, which can be watered and fertilised for quick growth. A light rate of gypsum may be applied to help stabilise the soil, and this will also help the grass get established. No trees or shrubs should be planted on or near the embankment, and grazing this area should be avoided.

Avoiding risks during construction

The construction stage is probably the one where the risks are greatest.

Seepage is often the result of poor compaction. The site may provide good soils for use in the construction of the storage, but poor compaction, or construction with thick layers and large clumps, can create the risk of excessive seepage and ultimate embankment failure, especially in dispersive soils.

Soil moisture levels need to be regularly checked during construction, and increased, using a water cart or other means, if necessary.

Other seepage sites

There are other sites with risks for seepage and failure:

- seepage and erosion along hydraulic structures, such as outlet pipes;
- uncontrolled seepage through the floor of the storage;
- excessive permeability of the soil, both horizontally and vertically;
- batters built on top of porous topsoil, and an inadequate cut-off trench;
- leakage along any exposed rock;
- deep porous seams under or around the cut-off trench;
- inadequate compaction of either the batter or storage area;
- embankments built of porous material;
- embankments built close above porous aquifers.

Operating the storage

Fill slowly when dry.

When the embankment material is relatively dry, as it will be on first filling or after an extended dry period, any rapid harvesting into the storage creates the potential for piping failure. If the rate of filling is sufficiently slow, shrinkage cracks swell and seal, preventing flow through the fissures. The landholder may not always be able to control the fill rate.

Draw water down slowly.

If draw-down is too quick, the inside batter of the embankment may become unstable or slump because of the difference in soil water pressure.

Keep the embankment at a constant moisture level.

Where the landholder can manage the level of the storage to achieve minimal moisture changes within the storage embankment, shrinkage cracks are less likely to appear.

Keep the water level a good distance below the top of the embankment.

Where possible, the landholder should keep the storage level below the designed freeboard limit.

Monitor any wave action on the embankment.

Check the storage after each large storm, and make repairs as needed.

Keep the embankment well covered.

At least 0.2 metre of good grass cover will protect the batters. Re-seed and fertilise the embankments whenever needed to maintain vegetation cover.

Monitor the water quality of the stored water.

Monitor the water quality within the storage regularly to determine if there is any increase in salinity: this may be increased by seepage into or out of the storage.

Selective herbicide should not affect the use of storage water for irrigation purposes.

Keep the outlet free of debris, and keep trees and shrubs and burrowing animals off the storage.

Check for erosion regularly.

Avoiding risks when operating the storage

The risk factors at the operating stage are

- rapid filling or drawdown
- overtopping, causing the crest to erode
- fluctuations in the storage level

Monitoring the storage

Local authorities

LWMP implementation officers will test the integrity of the storage after construction and report on how much water the storage is likely to contribute to the groundwater system. One method of checking hydraulic pressures that have developed in the storage and foundation through seepage and through compression of the soil structure is to use piezometers.

The landholder

The landholder will notice any change in conditions, and should regularly and thoroughly inspect the storage for:

- excessively soft areas of the foundation;
- cracks, settlement, or seepage in the batters or crest;
- slumps or bulging in the fills;
- operation of the inlet and outlet structure works;
- any turbidity, muddy water or increased flow;
- landslides in the storage or downstream areas;
- current reservoir elevation and freeboard; and
- the rate that the storage is rising or drawing.

Avoiding risks at the maintenance stage

The risk factors at the maintenance stage are neglecting to maintain the storage regularly or not monitoring its condition extensively enough.

Storages should be maintained as 'new' throughout their life. If a storage deteriorates, it could fail.

TECHNICAL APPENDICES

Appendix 1. Locations for soil sampling

The aim in selecting sampling locations is to identify representative soil areas. This can be done by taking samples on a regular grid or by using electromagnetic (EM) measuring to map the boundaries of soil areas.

For sites less than 2 hectares, either the grid sampling method or EM mapping may be used. For sites of 2 hectares or larger, the EM method is recommended.

Sampling on a regular grid

Mark sites for soil samples on a regular 50 m by 50 m grid throughout the area of the proposed storage. The properties of the soil at each location are considered to be representative of a grid cell centred on the hole.

Using EM31

EM31 measurements need to be taken across the whole area of the proposed site. Measuring locations should be between 10 metres (preferred) and 15 metres apart, and should allow you to draw up a square grid through the points.

At each measurement location, a Geonics EM31 instrument measures the apparent electrical conductivity of the soil (ECa). Standard operating procedures are detailed in the company literature (Geonics 1993). Measurements are taken holding the instrument in the vertical dipole orientation, one metre above the soil surface.

Mapping software smooths the data and plots the measurements as a contour map showing areas of similar ECa. The contour interval is 10 dS/m, and the soil within each contour interval is considered uniform.

Soil samples are then taken to find out the characteristics of the soil within each area of uniform ECa.

Soil sampling points

The number of soil sampling points required to obtain a representative sample of the soils at the site will vary according to the size of the proposed structure, the geometry of the site and local knowledge. For each soil sample obtained you should record its location, its depth and the rocks present, and briefly describe the layer. Topsoil need not be tested but can be used as the revegetation layer upon completion of the work.

As a minimum the following soil sampling points are recommended:

For the embankment: Use one sample site at each end or corner of the embankment centreline, one at the middle of the embankment, and in any depressions. For long embankments, additional sample sites at approximately 50 metre intervals are recommended.

Each sample site should extend at least to the full depth plus 300 mm of the proposed structure (3 metres minimum) or to the watertable. All sample sites at the embankment site must be backfilled.

For the storage and the borrow areas: Choose sites at intervals appropriate to the geometry of the basin and the volume of the embankment. As a guide, two sample sites per hectare should be considered a minimum.

Each sample site in a storage basin used as the borrow area should extend at least 0.5 metres beyond the full depth of the proposed excavation (3 metres minimum). For borrow areas outside the storage basin, each sample site should extend 3 metres or to the watertable.

Soil sampling frequency

Soil samples from each of the sampling points should be taken which represent the range of horizons found in the test holes. The number of samples which should be tested will depend on the number of soil sampling sites, the range of horizons in the test holes and local knowledge.

For sites with only one ECa soil class: Take at least three soil samples from every hectare of the site. Space the sampling locations evenly across the proposed area of the storage. The properties of the soil from each location can then be taken as representative of one-third of that soil class area.

For sites with more than one ECa soil class: Take at least three soil samples from each soil (ECa) class area (with a minimum of three samples per hectare). Choose sampling locations that are equally spaced within each soil class area across the floor of the storage. These three samples are averaged to give a mean for each soil class.

Sample depth

At each sampling location, whether obtained by the grid layout or as identified by EM measuring, the soil samples need to be taken to a depth of at least two metres below where the floor of the excavation would lie, preferably using a rotary drill rig.

Because soil testing may be carried out to check both the site seepage characteristics and the suitability of the soil for construction, soil samples may need to be taken from drill holes to suit the requirements of both sets of tests.

Appendix 2.
Testing for suitable soils

Prior to the construction of any earth dam the soil must be assessed for its suitability. To assess whether a soil is suitable, a number of tests ('test suites') must be undertaken at sampling points which adequately cover the embankment, storage and borrow areas.

The full range of test suites does not have to be undertaken at each of the sampling points, but representative soil samples taken from the sampling points must be tested.

Soil test suites

The soil tests described below are used to determine the soil's suitability for earth dam construction.

1. Particle size analysis

This is a measure of the clay, silt, fine sand, coarse sand and gravel that a soil sample contains. Any rock present in the soil but not collected in the sample must also be recorded. The particle size analysis is important not only to assess the permeability but also the stability of the embankment.

2. USCS Classification

The Unified Soil Classification System (USCS) is an engineering soil classification system that is used for the assessment of soil suitability for earthworks.

(See table 3 for an example.)

3. Dispersion percentage

The dispersion percentage determines the amount of soil that disperses in water. This technique is used to estimate the dispersibility (stability) of disturbed samples of soil used for earth dam construction. Soil that is highly dispersible is prone to piping failure. In contrast, soil that has a very low dispersion and is aggregated may be permeable.

4. Emerson Aggregate Test

The Emerson Aggregate Test is also used to determine the dispersibility of soil. It estimates the dispersion of a natural soil aggregate and hence can be related to the dispersibility in the field. This test is useful to confirm the results of the dispersion percentage test.

5. pH and EC

The pH is the acidity or alkalinity of soil samples. The EC is an estimation of the salinity of soil samples. A knowledge of these soil properties is useful when interpreting test results.

6. Linear shrinkage/volume expansion

These tests are an estimation of the shrink–swell properties or reactivity of soil and hence the potential for cracks to develop in the embankment. The volume expansion may also identify soils which are prone to slumping.

7. Atterberg limits

The plasticity index of the sample is calculated from the Atterberg limits, which are used to estimate the compressibility and trafficability as well as the potential for mass movement and shrink–swell properties.

8. Permeability tests

Permeability tests assess the rate at which water moves through the soil profile. This information can be used to estimate the potential for leakage that might occur from the dam.

9. Optimum moisture content

The moisture content of the soil is a critical factor during the construction of the dam embankment. The soil moisture content affects the amount of compaction that can be achieved.

Testing the site for seepage

In the Murray and Murrumbidgee valleys, the soil must meet the criteria for continuous (unrestricted) rice growing in order to be acceptable as a site for a storage. These criteria are given in the following table.

Note that these depths are taken as being from **below the floor** of the designed storage.

Table 1: Riceland soil classifications meeting the criteria for permanent rice rotations

Murray Region
More than 3 m of continuous heavy clay or medium clay in the top 3.6 m of soil
Murrumbidgee Region
More than 2 m of continuous heavy clay or medium clay in the top 3.5 m of soil if sodic B-horizon is present from 0.1 to 0.6 m
More than 3 m of heavy clay or medium clay if no low permeability B-horizon is present in the top 3.5 m of soil

Source: Murray Irrigation Limited 1997, Ricegrowing policy for 1998–99.
Department of Land and Water Conservation 1997, Recommendations for ricegrowing for 1998–99.

The clay content is judged by hand texturing a soil sample from each location (McDonald et al. 1984).

Where sites do not meet these criteria, a qualified soil engineer needs to specify what works are needed to ensure storage seepage rates are less than 1 mm/day.

The soil sample locations selected from the 50 m by 50 m grid, or from the EM31 survey, will provide sufficient sites for soil texture tests.

Assessing infiltration rate

If previous tests suggest the soil is only marginally suitable for a storage site, or if the consequences of the storage failing would be very detrimental, the soil should be assessed by a qualified soil scientist as well as engineers.

The soil scientist or engineer ensures that the storage, when made using current best practice and construction techniques, will have a maximum infiltration rate of less than 1 mm/day.

Testing the soils for construction

Testing for dispersive soils

The soil sample locations selected from the 50 m by 50 m grid, or from the EM31 survey, will provide sufficient sites for soil dispersivity tests. Tests for Emerson class number (ECN) are used to see whether a soil is dispersive or not.

- If any one sample returns an Emerson class number (ECN) of 1 or 2, when tested with distilled water, then the soil is dispersive.
- If a sample returns an intermediate ECN (Class 3, 4, 5 or 6) when tested with distilled water, then more tests are needed. Two samples of the lowest ECN should be tested with distilled water, using the dispersion method.
  - If these samples return a dispersive (D2) or highly dispersive (D1) result, then the soil is dispersive.
  - If these samples return a potentially dispersive intermediate (PD1) result, then SAR testing is needed.
  - If SAR testing is needed, the soil surveyor will test a saturation extract of the soil of the samples that return the two lowest ECNs.
  - The surveyor will also determine the total cationic concentration of the water to be stored in milli equivalents per litre. If water from a variety of sources is to be stored, each one should be tested, if possible.

Assessing soil sodicity

Storages which are designed to have a depth of water against the constructed embankment which is less than 0.8 m do not need sodicity assessment.

Storages with a designed water depth against the constructed embankment of greater than 0.8 m should be assessed as follows:

1. Take three soil profile samples (each being a bulk-up of three soil profiles taken as part of the EM31 survey's targeted drilling procedure) for soil analysis.
2. Within each profile, take samples to the maximum borrow depth (for example, if the depth of borrow is 0.9 m, only the first two samples would need to be taken), as follows:

   sample 1 0–0.5 m depth

   sample 2 0.5–1.0 m depth

   sample 3 1.0–1.5 m depth
3. Analyse the soil samples for the following:
   - Emerson class, using irrigation quality water; and
   - exchangeable cations, to determine cation exchange capacity (CEC) and the exchangeable sodium percentage (ESP).

Where soil tests show that the soil is only marginally suitable for construction, it would be advisable to get a qualified soil engineer to assess and advise on design and construction of the storage.

Avoiding potentially acid sulfate soils (PASS)

Although it is far preferable to avoid PASS when choosing the storage site, there are measures that can be taken during construction to avoid acid drainage from these soils:

- If no other site is available, try to avoid reaching pyritic soil by changing the storage dimensions.
- If pyritic spoil soils are uncovered during construction, and cannot be avoided, they should be buried under the watertable so no oxygen can reach them, or else protected, for example by clay blanketing. In this technique, pyritic soil is covered with 0.3 metre of good holding clay. Where spoil or fill contains pyrite soil, incorporate lime into the spoil, cap with about 0.3 metre of good clay, and cover with another 0.3 metre of topsoil, and plant with grass to avoid washing.

GLOSSARY

pyritic material: Pyrite is produced in a reduction phase of the geomorphic cycle of sedimentation through the reduction of the iron of ferric oxides and the sulfur of sulfate. These sulfides frequently occur in shales, under the clay of coal seams, and in other sedimentary rock, including some limestones. Pyrite also occurs as an accessory mineral in igneous and metamorphic rocks. Pyrite is common and contains a high percentage of iron.

Appendix 3.
Aspects of storage design

Freeboard

Freeboard is the distance between the top of the embankment and the full supply level of the reservoir. For small storages, normal freeboard is about one metre.

Freeboard also depends upon fetch for a storage (that is, the direction in which the prevailing wind blows). If there is long fetch, the freeboard may have to be increased as shown in table 2.

If possible, place the long sides of the storage at right angles to the strongest wind direction.

Table 2: Recommended total freeboard for various fetch lengths and likely wave heights

Fetch (m)	Wave height (m)	Total freeboard (m)
Small storages up to 400	0.3–0.4	1.0
600	0.5	1.1
800	0.6	1.2

Source: Nelson, K.D. 1985, *Design and Construction of Small Earth Dams*, Inkata Press, Melbourne.

Batters

Table 3 shows the typical slopes for batters for embankments less than 4 metres high. Analyse the soil to be used for the embankment using the Unified Soil Classification system, and then select the slope required, assuming that the soil is compacted at the correct moisture content to the appropriate density.

The slopes suggested in table 3 may need to be flattened to take into account the effect of dispersive soils, where these are found at the storage site. You may also wish to flatten the slopes to provide extra soil to try and avoid frequent repairs to the crest and batters.

If you are going to provide batter protection, the slope could be steeper, particularly on the inside face. For example, if a stabilising layer is adopted, you might use 3.5:1, rather than the 4:1 which is recommended for a non-stabilised face on an inside batter.

Construction techniques make make it more economic to construct the embankment with an inside batter of 5:1. This means that, during construction, the scraper can move up and down the embankment without restriction, and this could significantly reduce construction cost per cubic metre.

Flatter batters also suffer less from wind and wave erosion.

Table 3: Typical batter slopes for different soil classifications (USCS)

Soil classification (USCS)	Inside batter	Outside batter
GW: Well-graded gravels, gravel and sand mixtures, little or no fines GP: Poorly graded gravels, gravel and sand mixtures, little or no fines SW: Well-graded sands and gravelly sands, little or no fines SP: Poorly graded sands and gravelly sands, little or no fines	not suitable for embankment construction	
GC: Clayey gravels, poorly graded gravel–sand–clay mixtures GM: Silty gravels, poorly graded gravel–sand–silt mixtures SC: Clayey sands, poorly graded sand–clay mixtures SM: Silty sands, poorly graded sand–silt mixtures	3:1	2:1
CL: Inorganic clays of low to medium plasticity, gravelly clays, sandy clays and silty clays ML: Inorganic silts and very fine sands, rock flour, and silty or clayey fine sands with slight plasticity	3.5:1	2.5:1
CH: Inorganic clays of high plasticity MH: Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	4:1	2.5:1

Source: Murray Irrigation, Construction Guidelines for Storages built from Sodic (Dispersive) Soils, Murray Irrigation (Report 971137/3), 4 June.

Crest width

The crest width does not affect the overall stability of the embankment, and should simply be as wide as is needed for traffic during construction and later on: this is usually a minimum of three metres for most rollers and other construction equipment. The crest can be made slightly wider to make sure it is still trafficable after erosion. The crest should be slightly sloped to the inside to stop water ponding on its surface.

Appendix 4. Compaction control

Best compaction in embankment construction can be achieved by ensuring a minimum dry density ratio (AS 1289 5.4.1) of between 92%–95% standard compaction at a moisture content between standard optimum moisture content (SOMC) and SOMC plus 2%.

If the clay moisture content is between SOMC +2% and SOMC +3%, the dry density ratio can be as low as 92% standard compaction.

The loose layer thickness should be appropriate for the capacity of the compaction equipment used.

GLOSSARY

optimum moisture content (OMC): The water content at which a soil can be compacted to the maximum dry unit weight by a given compactive effort.

In high-risk situations

Where the water level behind the constructed embankment is high, or where the consequences of storage failure are severe, it may be worth testing the compaction properties of the soil on site.

In these cases, fill material density and subgrade are tested by a NATA-registered testing authority in accordance with AS 1289.

If the soils fail the tests, subsequent layers should not be placed until the compaction layer has been fixed and re-tested.

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Murray Irrigation Limited commissioned a series of studies (undertaken by Central Victorian and Riverina Geotechnical (CVRG) Pty Ltd) to determine suitable guidelines for siting, construction and management of on-farm irrigation storages. Their findings and recommendations have been considered in establishing these guidelines.

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About this document

This document outlines each stage in developing a new on-farm water storage. It has been written for people developing storages for surface irrigation systems in the Murray and Murrumbidgee valleys.

Irrigators, designers and contractors who are developing on-farm storages for irrigation need guidelines that indicate the quality of construction required to meet government approval standards. Throughout this outline we have noted where landholders, systems designers, council and government bodies, and their advisers, can monitor any risks involved and decide how to avoid, minimise or accept them.

The appendices give additional technical information on design and construction.

Development team

Saud Akbar wrote the original version of this document. It was then developed with the help of Eddie Parr, Geoff Beecher, Graham Barron, Richard Swinton, Bill Yiasoumi, Lindsay Evans, and Nick Austin, of NSW Agriculture, and Brendan Diacono, of the Environment Protection Authority NSW.

The team thanks the following people for their help and comments: Stephen Young, Scone Research Service Centre, Department of Land and Water Conservation; Phillip Gall, Shire of Wakool; David Laughlin; Murray Irrigation Limited, especially Geoff McLeod and Adrian Smith; and John White, Windouran Shire Council.

ISBN 0 7347 1029 1

Published by NSW Agriculture, July 1999

NSW Agriculture