

Guidelines for Ring Tank Storages



Second Edition

First edition

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Guidelines may be obtained from:

Irrigation Australia Ltd
PO Box 1804
Hornsby NSW 1635

Phone: 02 9476 0142
Email: info@irrigation.org.au
Website: www.irrigation.org.au

Disclaimer

The information contained in this publication is based on knowledge and understanding at the time of writing (October 2007). However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate adviser.

Guidelines for Ring Tank Storages

Second Edition

Edited by Dr Hugh Barrett

Preface to the second edition

The original edition of these guidelines was produced in May 1998 by the North-West NSW Branch of the Irrigation Association of Australia (IAA), when a large number of ring tanks were under construction or being contemplated. An unacceptably high proportion of ring tanks built at that time failed to some degree; hence, the objective of the original guidelines was to show farmers and contractors how to build safe storages.

Since then more storages have failed, some due to poor construction and some due to poor management and maintenance. This prompted a rewriting of the guidelines. The second edition includes all of the original information on correct construction techniques, up-to-date information on management and maintenance and a new section on responding to failure, both in the immediate and long term, should that be necessary.

The authors concede that there are still areas where doubt exists as to what constitutes best practice. Specific research needs have been noted and boxed in the text for some of these areas, to alert users of the guidelines to the deficiencies in knowledge, and to provide guidance to researchers in the relevant fields.

The North-West NSW and Darling Downs Branches of Irrigation Australia Ltd have overseen production of the second edition of the guidelines, which was prepared and authored by a committee comprising Hugh Barrett (compiler and editor), Peter Smith, Tony Lockrey, Emma Brotherton, Ashleigh Theuerkauf, Peter Leeson, SMK Consultants, Aquatech Consultants, FSA Consultants, Saud Akbar, Andrew Parkes, Erik Schmidt, Graham Harris and Terry Haynes.

Irrigation Australia Ltd, the CRC for Irrigation Futures, and the Cotton Catchment Communities CRC contributed to the production and publishing of this edition. The cover photograph is courtesy of David Anthony. Other photographs are courtesy of FSA Consultants and Ashleigh Theuerkauf.

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GETTING STARTED – PLANNING THE STORAGE

1.1 Storage Purpose

On-farm storage of large volumes of water has become an increasingly important water management tool for irrigators. On-farm storage allows:

- the capture of high stream flows, increasing the reliability of water supply
- the storage of allocated flows if they are delivered at an inopportune time
- the capture of farm stormwater runoff and tailwater, which:
 - provides more water for irrigation, and
 - reduces the opportunity for potentially contaminated water to leave the farm.

1.2 Storage Volume, Depth and Shape Size

The size of the storage needs to match the availability of water and the size of the area to be served. Money will be wasted if the storage is so large that it rarely, if ever, fills. Water will also be wasted, as it will be spread over a larger area than necessary in the storage, increasing evaporation. On the other hand, crop income will be foregone if the storage is too small to meet demands.

Modelling is generally required to determine the maximum size of storage which can be filled (or part-filled) with an acceptable level of reliability. Water availability can best be determined from

long-term stream flow records. In analysing the records, modifications due to the release rules of any upstream river storage must be taken into account, together with the accessibility rules. The effect of climate change on future runoff must also be considered.

Depth

Research in the McIntyre Valley has shown that between 15 and 40 per cent of the water stored in on-farm reservoirs is lost through evaporation alone (Dalton et al, 2001). Measurements taken by consultants in the Gwydir and Namoi Valleys since 2004 indicate that the average annual evaporation losses are around 15 to 19 megalitres per hectare of reservoir area (1.5 to 1.9 metre depth of water loss).

Evaporation losses are directly related to surface area, wind speed, temperature, humidity and solar radiation. Reducing any of these factors will reduce evaporation losses.

Table 1.1 outlines the effect of reservoir area on seepage and evaporation losses. It has been assumed that there is water in the 1000 megalitre reservoir for the eight hottest months of the year over the cotton growing season (September to April). The total water losses in a year are reduced from 550 megalitres with four metre banks to 330 megalitres with six metre banks: a total saving of 220 megalitres per year. At a gross margin of \$300 per megalitre for irrigated cotton, this equates to an extra \$66,000 'profit' each year.

Table 1.1 Evaporation, seepage losses and construction costs for a 1000 megalitre reservoir

Bank Height (m)	Area (ha)	Evaporation ⁽ⁱ⁾ (ML/year)	Seepage ⁽ⁱⁱ⁾ (ML/year)	Construction Cost ⁽ⁱⁱⁱ⁾
3.0	50.0	650	180	\$370,000
4.0	33.3	430	120	\$495,000
5.0	25.0	325	90	\$630,000
6.0	20.0	260	70	\$900,000
7.0	16.7	215	60	\$1,250,000
8.0	14.3	185	50	\$1,160,000

(i) Evaporation based on 1.8 metres of potential evaporation and eight months water storage per year

(ii) Seepage losses based on 1.5 millimetres per day seepage rate

(iii) Construction cost based on \$2.80 per cubic metre

The extra capital cost in constructing the higher reservoir is \$405,000. Assuming that the maintenance costs are roughly the same for all options (the higher bank is significantly shorter in length than the lower bank), the extra capital cost is paid off in just over six seasons. A reservoir with six metre high banks covers an area of 13 hectares less than a reservoir with four metre high banks, which means more land available for production.

RESEARCH NEED

Field assessment to determine the change in rate of seepage (millimetres per day) with increase in depth of water stored, for various soil types.

Shape

The most economical shape (the least length of bank for volume stored) is a circle (see Table 1.2). However, circles do not normally fit readily within an irrigation layout, and square or rectangular storages are more common. The closer a rectangular storage is to being square, the more economical it is. For earthworks efficiency, corners of much less than 90 degrees should be avoided if possible. These corners can be truncated or rounded to reduce earthworks quantities and facilitate construction, with little loss of storage capacity.

Efficiency of earthworks can be expressed as the storage to excavation ratio (S:E); that is, the cubic metres of water stored per cubic metre of earth in the embankment. Small ring tanks typically have a S:E of about four, while larger ring tanks typically have an S:E of 15 or more.

Table 1.2 shows the area of land enclosed by an embankment 4000 metres long for various configurations. The total volume of water stored is also shown, assuming a bank five metres high. Note that, for the same amount of earthworks, a circular ring tank (1) stores nearly twice the volume of water as a narrow, triangular ring tank (6).

1.3 Location

There is no one ‘best’ location of a storage on farm and careful planning is required to integrate the storage correctly with the irrigation layout. A listing of advantages and disadvantages for alternative locations is given in Table 1.3. The storage must also meet its legal requirements with respect to location and must not infringe on gazetted roads, stock reserves or neighbouring property.

Earthen embankments tend to ‘grow’ away a little from the outside toe because of batter erosion and grading. To provide for this, and to provide access for purposes such as maintenance, storages should not be constructed closer than ten metres from an existing fence (and preferably further). The

Table 1.2 Effect of shape on storage efficiency

	Embankment length 4000m		
	Shape	Area (ha)	Volume Stored (MI)
1	1	127	5,590
2	2	121	5,350
	3	100	4,510
	4	91	4,150
	5	77	3,590
	6	62	2,990
4			
5			
6			

embankment should be located a distance from trees that is at least double the height of the trees, to minimise the risk of root invasion. A storage should not be located in an area of high risk: for example, upslope of housing. Neighbours should be consulted to settle issues such as agreed distances from boundaries.

1.4 Allowing for Future Changes

Many ring tanks constructed originally to a relatively low height have subsequently been raised, divided into cells, or had an additional cell added. Often these changes had not been anticipated at the time of original construction. The possibility of future change should be allowed in the planning process, by:

- keeping borrow pits well clear of the toe of the embankment to provide further base width if the embankment is subsequently raised
- locating pumping stations at the midpoint of the longest dam wall (rather than near a corner) if the dam might later be divided into two cells

- providing a flatter outside batter of one wall, if that wall might later become the cell-dividing wall of a future cell added to the storage.

1.5 Legal Requirements

In Queensland, a dam is considered *referable* if it would threaten life if it failed. The threat is based on a Failure Impact Assessment, rather than on the height of the dam or volume of water stored. The assessment must be undertaken by a Registered Professional Engineer and is required for all dams exceeding the following criteria:

- more than eight metres high, and
- a storage capacity exceeding 500 megalitres

OR

- more than eight metres high, and
- a storage capacity exceeding 250 megalitres, and
- a catchment area which is more than three times the reservoir surface area at full supply level.

Table 1.3 Alternative reservoir locations

ADVANTAGES	DISADVANTAGES
Reservoir at top of farm	
• direct pumping from river to reservoir without relift • commands entire farm • big advantage if can gravity in from source eg. creek (may gravity into buffer and pump to ring tank)	• high channel from pump station to reservoir • may not be able to return tailwater • excessive range of head on pumps
Reservoir at centre of farm	
• easy access during operation • command $\pm$ 50 per cent of farm • collect all tailwater	• pump station may be complicated • more difficult to handle filling and emptying (change from gravity to pump)
Reservoir at bottom of farm	
• easy to fill from river and tail water • catch stormwater run-off by gravity	• majority of stored water has to be re-pumped for use

Following the assessment, the dam will be given a Failure Impact Rating, which will determine if it is referable. Referable dams require considerable documentation and procedures, which are available from the relevant authorities and usually published on the internet.

Construction of a referable dam in Queensland is an assessable development, requiring local government approval. In some parts of New South Wales, construction of an on-farm storage may require local council approval under the Local Environment Plan. Some councils may require a Development Application, supported by an Environmental Impact Statement where appropriate.

Authority to locate works on unallocated State land, reserves and gazetted roads requires a Permit to Occupy or a Lease granted by the relevant State Government. In some cases a road closure may be granted to accommodate the development.

Landholders contemplating a storage therefore should consult their relevant state water resources authority and their local council in the first instance, to gain a good understanding of their legal obligations. Clarification of these issues at the outset can overcome a range of problems which could arise during or after the development.

1.6 Risk Assessment

The consequences of failure of an on-farm storage can vary from minimal to disastrous, depending on the type of failure and when it is detected. Typical hazards include:

- erosion, which can be particularly severe if water runs into an adjacent water course
- damage to property such as fences, roads and irrigation structures
- damage to adjacent crops
- threat to life, particularly if the storage is near buildings or a road.

In addition, the loss of water can have severe economic consequences, particularly if water is required at a critical stage of crop growth.

At the very least, failure would result in the cost of repair and replacing the lost water; at worst, it could prove fatal.

Either way, the risk is unacceptable. The additional cost of constructing the storage properly in the first place is marginal. The biggest additional expense would probably be for compaction of the embankment, which would normally add about ten to 30 per cent to the cost of the earthworks. When the cost of the pipework and adjacent pumping facilities is included, the proportion decreases. In terms of the total cost of the irrigation development, the increased cost due to a properly constructed embankment amounts to only a few per cent, at most. This is cheap insurance and, unlike most insurance policies, is a one-off cost. There is no value in constructing storages to a low standard.

Reference

Dalton, P., Raine, S. and Broadfoot, K. 2001, 'Best management practices for maximising whole farm irrigation efficiency in the cotton industry', Final Report for Cotton Research and Development Corporation Project NEC2C, National Centre for Engineering in Agriculture Publication 179707/2, University of Southern Queensland, Toowoomba.

HOW RING TANKS CAN FAIL

Anecdotal evidence suggests about 20 per cent of ring tanks fail to some degree, varying from relatively minor seepage to catastrophic failure such as a breached embankment (see Figure 2.1). The aim of these guidelines is to outline measures which will reduce the risk of ring tank failure due to construction, maintenance or management inadequacies.

Cracking

Cracks can develop if a dam wall is allowed to dry out. Some soils are more susceptible to cracking than others. Transverse cracks run from the upstream side to the downstream side of an embankment and, consequently, are very dangerous. Longitudinal cracks run parallel to the crest. Sometimes both occur and a random pattern of cracks more than two metres deep can develop. Water can run through the cracks on filling, leading to dam failure.

Sometimes a bank will settle on part-filling. If fill has been placed in a too-dry condition, it may settle below the intermediate water level. The dry material above the waterline arches over the settled material, leaving a horizontal crack through which water can pass on subsequent filling.

Cracking can be minimised by proper design and by good fill compaction at proper moisture content. If necessary, a moisture barrier (sand layer) can be provided in the top of the embankment to prevent fill drying and cracking.

Tunnelling

Water may run through a crack and emerge from the downstream batter by 'piping' through the embankment. The dam crest may stay intact initially but will collapse after the pipe enlarges to form a 'tunnel.'

Figure 2.1 An irrigator's worst nightmare – a breached storage embankment



Soils high in sodium (dispersive soils) are most prone to piping and tunnelling. Rather than the soil swelling and closing the crack, it disperses into solution and washes out. Pervious (permeable) material incorporated into the embankment can have the same result. Sometimes a pipe can penetrate the dam foundations, following a sand seam under the dam.

Wave Erosion

Waves of considerable size and energy can be generated on a large storage. The waves attack the bank, eroding the batter, reducing the crest width and, in extreme cases, overtopping the bank.

Inlet/Outlet Pipe

One of the most common causes of failure begins with seepage that develops around a pipe barrel. Eventually, backfill material will erode and the embankment over the pipe will collapse. If a pipe itself is not strong enough to withstand the weight of earth or, more commonly, if it is installed incorrectly, it may collapse.

Overfilling

Irrigators are tempted to store as much water as possible while supplies are available. Although it is obvious that filling must stop before a storage overflows, there are many examples where storages have been filled above top water level, thus encroaching on freeboard. This can have disastrous consequences if the level rises into a zone of cracking near the top of an embankment, or if strong winds generate waves high enough to overtop the wall.

Seepage

Losses from seepage can have severe economic consequences, with insufficient water available when required by the crop. In addition, hydraulic pressure from the storage may result in rising water tables in adjacent areas, bringing salts to the surface and rendering land unproductive.

The potential for soils to leak may not be apparent from observation. Some soils that appear to be clays are in fact relatively permeable. In some instances, clay soils are underlain by sands or gravels that are exposed when the borrow pit is excavated (although these soils should have been identified during investigations).

RING TANK DESIGN

3.1 Investigations

***‘You pay for your investigations,
one way or the other’***

(old engineering maxim)

Background

Prior to constructing a ring tank, detailed soil investigations are required of:

- the embankment materials
- the foundation under the dam, and
- the reservoir area.

Electro-Magnetic Imaging (EMI), or EM survey, provides a tool for rapid identification of different soil types across a site and is now required by some government departments. EMI identifies soils of different electrical conductivities. These difference could be due to different moisture content, salt content or soil texture. For dam investigations, holes are dug in areas of different conductivities identified by EMI, to correlate the conductivities to texture (for example, gravel, sand, silt or clay). The correct EM instrument must be used, appropriate to the depth of investigation (for example, to four metres).

A backhoe is an excellent tool for soil investigations, allowing visual inspection of comparatively undisturbed materials to depths of more than three metres. The EM survey shows where backhoe pits can most effectively be located, ensuring that small pockets of suspect material are not overlooked. Hand and mechanical augers should be used only if a backhoe is not available, as they are slower and provide only disturbed samples.

Foundations

Dam foundation investigation should be undertaken to determine the depth of topsoil (including grass or roots) to be stripped, whether sand or gravel is likely to be encountered and whether the foundation material is strong enough to support the proposed embankment.

Test holes for checking foundations should be taken to a depth equal to at least three-quarters of the height of the embankment.

Where unsuitable material is found in test pits, the EM survey indicates the extent of that material. If necessary, the embankment might have to be realigned or relocated to avoid the unsuitable material.

Embankment Materials

Materials for ring tank embankments are generally obtained from within the storage area adjacent to the bank. In some cases, material will come from a pump sump or from a tailwater return channel outside the storage area.

For bank heights typical of ring tanks, visual classification of this material by a qualified and experienced engineer or technician will provide a reasonably accurate guide on soil suitability for construction. A dispersion test should also be carried out to determine susceptibility to piping, one of the most common causes of failure.

For high embankments and high risk sites, the engineer can advise if the soil samples require full laboratory testing to determine their suitability with regard to issues such as construction, stable batter slopes, optimum moisture content and required degree of compaction.

Permeability

Soils in the reservoir area need to be checked for permeability. A rule of thumb is that test holes should be dug beyond the proposed depth of borrow by 0.6 metres + 0.1 metres for every metre depth of storage, to at least 1.0 metre, whichever is greater.

The presence of sand or gravel is a good indication of potential seepage. If visual classification of the soils indicates any doubts, permeability should be assessed by filling test holes with water. Once wetted, impermeable soils maintain a constant water level.

The EM survey indicates the extent of permeable soils. A decision can then be made as to whether it would be economic to line the permeable area with a non-permeable layer of clay or other material, or whether it would be better to look for an alternative site.

3.2 Embankment Section

Embankment Types

Ring tanks are generally constructed with either a homogeneous or a zoned embankment section.

A **homogeneous embankment** is built from a single material type. It should be constructed with material of a sandy clay or clay nature. The compaction standard for the whole embankment is uniform; hence, this type of embankment requires full compaction over the whole section to ensure impermeability.

A **zoned embankment** is the most flexible and suitable embankment type for farm dams. Its main advantage is that stringent compaction and moisture control is required only for the central core, thus reducing construction cost and time. It also has the advantage that sandier or siltier material can be used in the outside zone without jeopardising the stability or permeability of the structure. With large ring tank storages, it is quite common to strike isolated patches of silty and sandy material, which can be used in the outside zone of the embankment.

Batter Slopes

Embankment batter slopes must be stable during both construction and operation. Farm gully dams are often constructed with 3:1 upstream batters and 2:1 downstream batters (where a 3:1 batter means 3 horizontal to 1 vertical). Often the upstream batter is rock protected.

Ring tanks generally face more severe wave action than gully dams, due to the larger area of exposed water. Rock to use for batter protection is generally hard to find and uneconomic, given the length of batter to be protected; hence, protection against wave erosion is usually provided by constructing the inside batter to a flat slope.

Early ring tanks were constructed with 3:1 batters. This often resulted in severe wave erosion, so subsequent embankments had 5:1 batters, as shown in Figure 3.1A. Erosion still tended to occur around the top water level, cutting into the crest, so the design cross-section has since been modified to that shown in Figure 3.1B. The two figures are

drawn at the same scale to show that the increase in the quantity of earthworks is minor (a few per cent, or six per cent in the case of a six metre high bank). The benefits for erosion control and maintenance are significant, however, as the 8:1 batter acts as a beach for breaking waves. Well compacted embankments of this section show little evidence of wave erosion.

For a dam constructed to the cross sections shown in Figure 3.1, the base of the embankment would be sufficiently wide not to cause excessive stress on the foundation, provided all topsoil, and loose and organic material were removed from the full width of the proposed embankment.

For particularly high embankments with steep batters and/or soft clay foundations, expert consideration of the bearing capacity of the foundation is required. Embankments of these dimensions fall outside these Guidelines.

Where storages are filled infrequently, consideration should be given to providing a sand layer about 0.3 metres thick over the top of the compacted clay core, to provide a barrier against moisture movement from the core. The sand should be covered with topsoil to retain the sand and provide a roadway.

Cut-off

Seepage through the foundation is controlled by constructing a cut-off trench underneath the embankment and backfilling with compacted moist clay. This trench should be excavated through topsoil and any permeable material, plus at least 0.5 metres into impermeable material beneath. The trench sides should be battered, not vertical, to facilitate bonding with the fill material, thus avoiding a cracking zone.

Freeboard

Freeboard is the vertical distance from the full storage level to the top of the embankment. Freeboard for ring tanks must be sufficient to allow for probable wave height, wind setup and any unevenness or settling in the embankment.

Wind acting on the water surface causes both waves and wind setup. The wave height is directly

Figure 3.1 Typical embankment sections (*not to scale*)

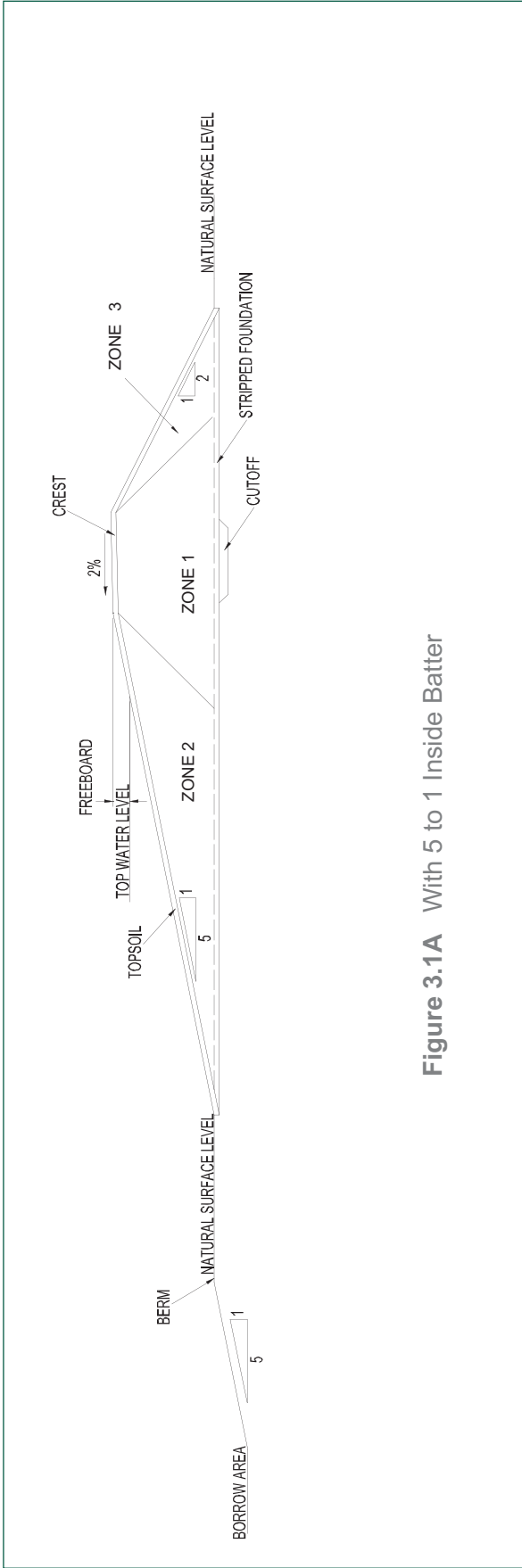


Figure 3.1A With 5 to 1 Inside Batter

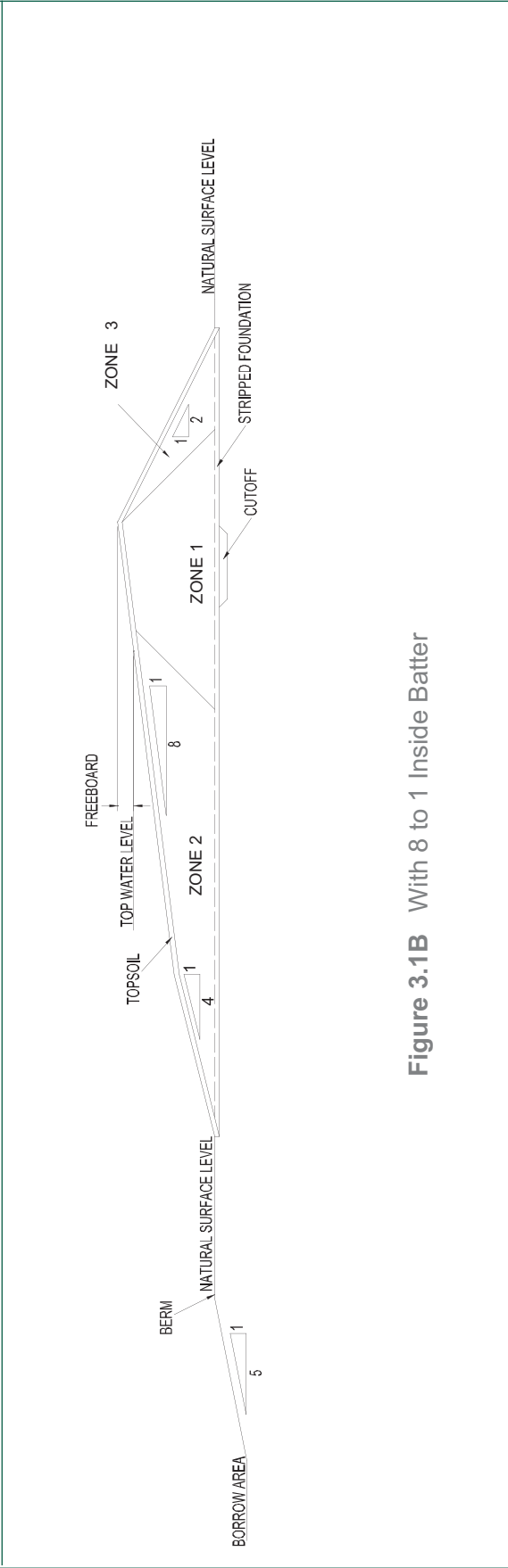


Figure 3.1B With 8 to 1 Inside Batter

proportional to the wind speed and the fetch length. The fetch length is defined as the longest exposed water surface of the storage. Wind setup is the result of wind drag on the surface of the water, with the water becoming deeper in the direction of the wind.

Table 3.1 shows wave heights and the freeboard which should be provided for various fetch lengths.

3.3 Inlet/Outlet Pipes

Pipes under an embankment need to be strong and non-corrosive. A pipe is most likely to fail when the storage is full, so the consequences are normally disastrous; hence, considerable care is required to ensure that the pipe is of suitable material and strength. Rubber ring-jointed concrete pipes are generally the most suitable for the sizes adopted for ring tanks. The pipes need to be manufactured to the appropriate Australian Standard (currently AS4058-1992).

The pipe class has to be selected based on the depth of fill, the likely bedding conditions, the width of trench in which it is to be laid, and the likely load on the pipe, including the weight of fully laden

scrapers to be used during construction.

Engineering evaluation is required. Backfilling with compacted granular material provides the best support for the pipe; however, under a dam embankment, this material may provide a seepage path and is unsuitable. Carefully selected clay backfill is more appropriate but it may be necessary to adjust the pipe class upwards to reflect the lower level of support.

One or more cut-off collars are often required around the mid-length of the pipe to eliminate seepage along the barrel, which could endanger the structure. The number and extent of cut-off collars depends on the soil type, the head of water above the pipe and the pipe length. Qualified engineers should complete this calculation. Cast-in-place concrete collars have commonly been used in the past. Care is required, however, to ensure that they do not lead to pipe shearing. More recently, barrier fabrics have been used successfully. The fabric consists of a bentonite clay sandwiched between two layers of geotextile. It is tied onto the pipe and pulled out perpendicular to form a 'frill-neck' collar before backfilling, which provides an effective seepage barrier.

Table 3.1 Freeboard for various fetch lengths

Fetch Length (m)	Wave Height (m)	Freeboard (m)
Less than 600	0.3	0.8
1,000	0.4	1.0
2,000	0.6	1.2
3,000	0.8	1.3
4,000	0.9	1.5

RING TANK CONSTRUCTION

4.1 Construction Contract

Verbal contracts are often used between farmers and contractors; however, given the scale and cost of ring tank construction, a written contract is advisable in order to prevent any misunderstandings. The written contract also allows competitive quotes to be obtained, where the contractors know that they are competing on the same basis.

The contract would typically be based on the following information:

- Information to Tenderers: advising them of the location of the job and any unique information
- Conditions of Contract: how they will be paid and other mutual obligations
- Specification: the standard to which the work is to be constructed
- Schedule of Quantities
- Schedule of Hourly Rates
- Schedule of Prices
- Form of Agreement
- Drawings.

Suitably qualified engineers can assist with drawing up the contract documents.

4.2 Embankment Construction

Foundation Preparation

To the extent permissible, the area to be covered by the embankment and borrow areas should be cleared of all trees, scrub, stumps, roots, dead timber and rubbish. Before construction of the cut-off trench, all grass growth and topsoil must be removed from the area to be occupied by the embankment and borrow areas to a depth of at least 100 millimetres. All water should be drained or pumped away and any loose soil, organic matter, debris, and soil with a moisture content higher than the surrounding natural material, should be removed. Particular care is required to clean out any stump holes and backfill with sound, compacted, moist fill.

The trench for the clay cut-off should be at least 2.5 metres wide (and usually the width of a scraper) and excavated a minimum of 0.5 metres into impermeable material, or further, according to conditions disclosed by the excavation.

If suitable, material other than topsoil excavated from the cut-off trench may be placed in Zone Three of the embankment (see Figure 3.1 on page 9) and/or around the outside base of the embankment to provide an access road.

The bottom of the trench should have a clean, uniform and moist surface and be free of all loose material before backfilling commences. If the material in the cut-off trench is significantly drier than optimum moisture content, a light watering should be applied to assist with the bonding to the backfill material.

Traversing a sheepfoot roller along the bottom of the trench and under the foundations will create indentations that will improve bonding with the next layer. Ripping the foundations and bottom of the cut-off trench is not recommended.

Compaction, even with a vibrating sheepfoot roller, can penetrate only some 150 millimetres, so even light ripping can create a permeable layer which will not be remedied by the sheepfoot roller.

The cut-off trench should be backfilled with material placed in thin layers and rolled as described in following sections.

Borrow Pits

Borrow pits for ring tanks are generally located in the reservoir area. Additional material may be taken from drains or external sumps.

Borrow pits within the reservoir area should be constructed as far as practicable to a depth and continuous grade that facilitate their free drainage to the reservoir outlet. This ensures that all water within the storage can be accessed. If required, a land bridge should be provided across the highest point of the borrow area, to facilitate future access to the reservoir bottom. Excavation within the reservoir area must not exceed the depth revealed by investigation or specified by the designer.

A minimum of 0.6 metres of impermeable clay must be left between the sides and base of any borrow areas and permeable sand or gravel layers inside the reservoir area. During excavation inside the reservoir area, any permeable material exposed must be trimmed and cleaned to a firm base and backfilled with compacted selected clay material suitable for construction of the embankment core. The depth of compacted material will generally vary from 0.3 to 0.6 metres, depending on the classification of the selected material.

Borrow pits within the reservoir area should be at least ten metres from the toe of the inside batter. This 'berm' reduces the risk of batter slumping and allows room for any future repair work. Berm width will need to be greater if there is a possibility that the embankment will be raised in the future. Considerably more fill material will be required if the original borrow pits have to be refilled first.

Moisture Content

Correct moisture content is necessary to achieve good compaction of the earth fill. Material too dry or too wet will not compact adequately, retaining air voids in the embankment. The moisture content of the material at the time of placing and compaction should be uniform within each zone, or the same throughout for a homogeneous embankment.

For a zoned embankment, material in Zones Two and Three can usually be placed at natural moisture content. Moisture would only be added if the fill were too dry to achieve adequate compaction.

On the other hand, material for Zone One must be sufficiently wet to achieve a high level of compaction. That means the soil must be wet enough to mould readily in the hand without breaking up or becoming friable but not so wet that it runs between the fingers when squeezed. In technical terms, Zone One material should be close to the "optimum moisture content" (the moisture content at which the maximum soil density is obtained when compacted). For practical purposes, the optimum moisture content is that which enables the material to be rolled between the hands into a thread four millimetres in diameter. At the

optimum moisture content, this thread will just begin to crumble at this diameter on further rolling.

If the natural soil moisture content of Zone One material is less than specified, the moisture content must be adjusted to within the specified range by mixing water uniformly with the soil before the material is placed in the embankment and/or by watering the material in the embankment and thoroughly mixing before compacting. However, adding water can double the cost of winning and placing the selected material; hence, considerable cost savings can be achieved if the borrow area is kept in fallow prior to construction to conserve moisture. Typically, Zone One material will be obtained from deeper in the profile (below, say, one metre), where the moisture content is naturally higher, provided this material is suitable in other respects.

If the soil moisture content of the material is higher than specified, the material must not be used until the moisture is uniformly lowered to within the specified range, by light ripping, disc ploughing or other methods that assist evaporation and drying.

During construction, the surface of the embankment should be maintained in a compacted and drained state to ensure that it does not become too wet from rain or other causes and to prevent undue soil evaporation.

In particular, the contractor should leave the embankment surface compacted overnight and complete compaction of all placed material if rain falls during construction. If the top layer dries out on the surface before the next layer is placed, the dry materials should be skimmed off with a light grading, or lightly watered before the next layer is placed. Any soil which for any reason becomes drier or wetter than specified after being placed in the embankment must be removed and dumped outside the area.

Spreading and Compaction

The purpose of compaction is to squeeze all air out of the embankment (zero air voids), removing pathways for water to leave or enter the

embankment, either of which could result in failure. Different types of construction machinery exert different pressures, as shown in Figure 4.1. The higher the pressure, the better the compaction.

The embankment should be built from successive horizontal layers, with each successive layer being placed at the specified moisture content and compacted to specification. Each layer should be spread evenly, no thicker than 150 millimetres, across each zone of the embankment and then compacted. Individual zones of embankment material must not be raised in the embankment independently of other zones.

Material must be placed and spread evenly throughout each layer and must not contain lumps or 'curls' greater than 100 millimetres thick. Lumps or curls that exceed specifications must be removed or broken up before compaction begins.

The embankment must be free of lenses, pockets, streaks or layers of materials that differ substantially in texture or gradation from the surrounding materials.

Each layer must be compacted completely before the next layer is placed. A well compacted embankment is both stronger and less permeable, because it contains fewer air voids. A lack of air voids is critical in the prevention of piping failure, particularly in dispersive soils.

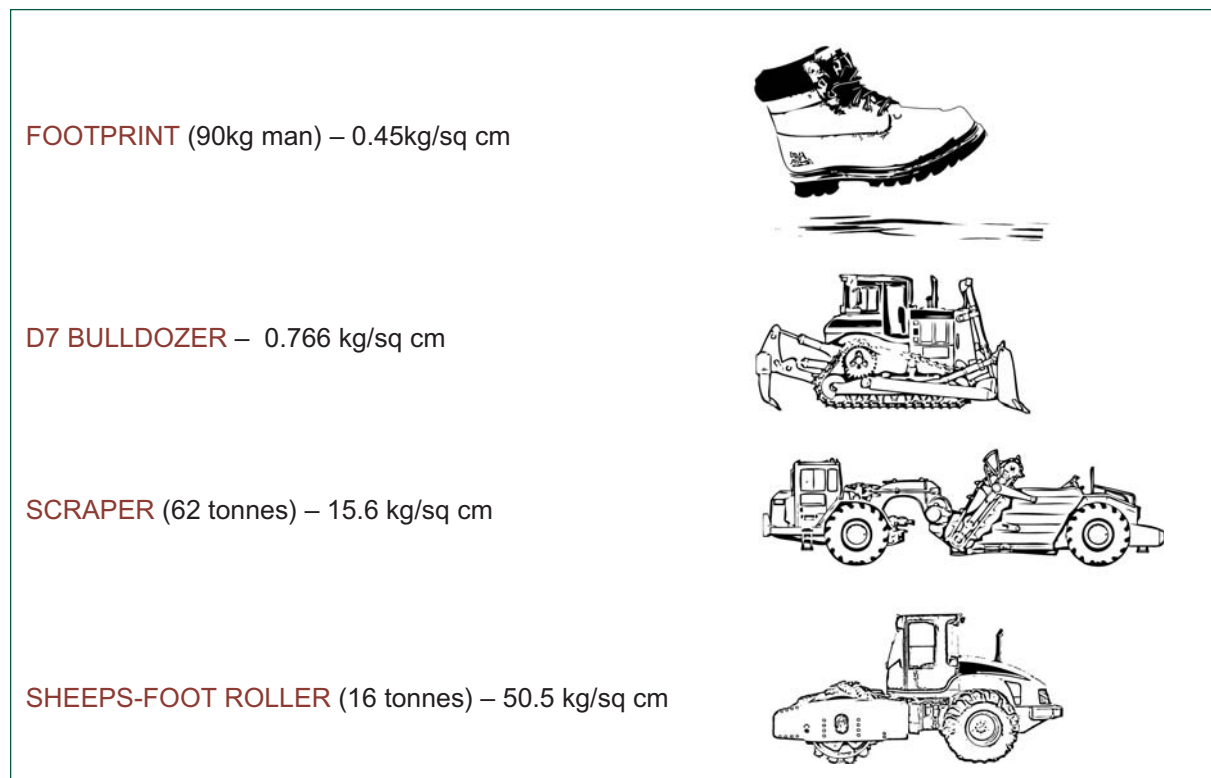
In **Zone One**, each layer should be compacted with tamping (sheepsfoot) rollers until the dry density exceeds 95 per cent of the maximum dry density, as mentioned under **Moisture Content** above.

Normally, six to eight passes of the tamping roller will be required to achieve the specified compaction for Zone One. In practice, the compactor should be 'walking on its toes' by this time but still leaving indentations (that is, not a smooth surface).

Zones Two and Three should be compacted by a minimum of three passes of a tamping roller and by traversing with construction traffic at all practical opportunities.

Suitable Roller. A variety of rollers are available which will achieve the required compaction. Typically, each drum of the tamping roller used for

Figure 4.1 Compaction pressures for different construction methods



compaction should have an outside diameter not less than one metre nor be more than two metres long. The length of each tamping foot should be at least 175 millimetres from the outside surface of the drum. A fully ballasted roller should not weigh less than three tonnes per metre length of drum.

Topsoil and Grassing

Batters of an earthfill embankment must be protected against wind and rain erosion, as well as against wave erosion of the inside batter. Past recommendations were to vegetate all exposed soil of storages, or at least the inside batter. However, it appears that roots of established perennial grasses have contributed to a number of storage failures by drying the embankment core, resulting in cracks and voids. These cracks have allowed water to flow into and eventually through the wall. This mode of failure has also occurred due to tree roots penetrating the core, from trees too close to the toe of the outside batter, or growing on the embankment.

A storage wall obtains its strength from a solid core of moist compacted soil bound well together. Maintenance of the structural integrity of the storage embankment is critical to storage survival. Allowing the core to dry causes fracture lines and zones of weakness to develop.

There is a risk involved in allowing any vegetation to establish on surfaces of the storage embankment where root penetration of the core may occur and cause drying in that zone. Until or unless an effective shallow rooted but drought resistant grass can be found, it is recommended that embankment surfaces not be sown to grass. An 8:1 inside batter has been shown to be effective in minimising wave erosion.

RESEARCH NEED

To determine the most effective shallow-rooted but drought-resistant grasses for batter protection in the different regions and how they should be managed in both wet and dry periods.

4.3 Pipes Under the Embankment

All silt, unstable or saturated soils and vegetation should be removed from the site before pipe trench excavation. The compacted embankment or natural ground level should be a minimum of 600 millimetres above the top of pipe level before excavation. The pipe should be laid during construction of the embankment, not after, to avoid an excessively deep, unstable trench. The trench width should be the minimum that will allow proper compaction around and under the pipes and the trench walls should be as close to vertical as possible.

The trench should be level across the bed. If excavation to the required foundation level reveals unsuitable material, the trench should be over-excavated and refilled with compacted moist select clay. This material should be placed in layers no more than 100 millimetres of loose thickness and compacted to achieve a minimum dry density of 95 per cent of the maximum dry density obtained from the Standard Compaction Test mentioned earlier.

In other situations, pipes are normally laid on a sand bed, to provide full support of the barrel; however, sand bedding is not recommended for pipes under water retaining embankments, as it would provide a seepage path. A bed of fine, selected clay is recommended, moistened and compacted after the pipe is laid. The material should preferably be taken from *in situ*, to ensure the same soil type for effective bonding with the trench walls.

For pipes with sockets protruding beyond the barrel outside surface, chases must be dug into the bed of the pipe trench in the appropriate positions to ensure that each pipe is supported along the full length of the barrel to prevent the pipe shearing near the socket.

The trench should be refilled with moist select clay. The fill must not contain any stones larger than 50 millimetres, nor more than 20 per cent with a size between 25 millimetres and 50 millimetres.

The fill should be compacted in a moist condition in layers not exceeding 100 millimetres loose

thickness to achieve a minimum dry density of 95 per cent of the maximum dry density obtained from the Standard Compaction Test. Extra care must be taken to compact the areas underneath the pipe barrel, by hand tamping or similar. Fill must be placed and compacted to equal elevations on both sides of the pipes before the next layer is placed. Mechanical rolling with construction equipment must not be used until at least 600 millimetres of cover has been provided over the top of the pipe.

‘Watering in’ of pipes is not recommended, as little compaction of the backfill is achieved. A very wet layer of material is left around the pipe, giving little support to the pipe. A pipe needs to be prevented from ‘squashing’ by providing strong support at the sides, as described above.

Rubber rings must be fitted strictly in accordance with the manufacturer’s specifications. The pipes must be supported while they are pushed together, to ensure that the rubber rings remain in the groove in the pipe spigot and form a watertight seal. The joint space between abutting pipe ends must be within the minimum and maximum specified by the manufacturer. Pipes that have marks indicating position (e.g. ‘top’) must be laid strictly in accordance with these markings.

4.4 Raising an Existing Embankment

Numerous embankments have been raised to meet the need for a greater volume of water stored on-farm, without increasing the area of land occupied by the storage. This also means evaporation losses per megalitre of stored water are reduced.

Two possible methods of raising the embankment are shown in Figure 4.2, on page 16. In the first figure (4.2A), the embankment is raised on the original profile (5:1 inside batter). The second figure (4.2B) shows the embankment rebuilt with an 8:1 inside batter. The second is preferable but requires more fill, particularly as there would be more likelihood of having to refill the existing borrow pit.

In both cases, a new core and cut-off trench is required, backfilled with compacted moist select clay. Foundations need stripping and topsoil is to be replaced. Considerable care is required when

removing the topsoil and erosion rills from the existing inside batter, to ensure that the rills are not simply filled with loose, dry material. Rills need to be cut right out. In raising the embankment, the exacting design and construction standards (as outlined earlier) are required for the new works, particularly as the construction standard of the original works may be unknown.

An undesirable option might be to place the new fill on the outside batter, particularly if the storage is holding water at the time. This option should be avoided, as the outside batter is often steep (1.5:1), making it difficult to bond the new fill to the old, thereby creating a potential failure plane (see Figure 4.3 on page 17).

The class of outlet pipe under the embankment needs to be checked to ensure it is strong enough to withstand the increased soil load. If not, the original pipe must be removed and replaced before the embankment is raised. Extra lengths of pipe will be required to accommodate the increased width of the embankment section. Under no circumstances should the batter be steepened over the pipes to avoid increasing the length.

4.5 Splitting Storages into Cells

Storage splitting allows a reservoir to be better managed to reduce evaporation and seepage losses. The construction standard of the dividing wall needs to be just as high as for the outside embankments. In this case, however, both batters need to be flat to minimise erosion: at least 5:1 and preferably 8:1.

In addition, the core of the dividing wall needs to be carried through to join the core of the existing outside embankment. That is, the inside batter of the original embankment needs to be removed at the proposed junction, leaving the core exposed. The scrapers should remove some of the existing core to provide a sufficiently flat slope to bond with the core of the dividing wall, by watering and rolling. The original batters are then re-established, joining with the new.

A similar procedure is required if a new, external cell is added to a storage, with the core of the new embankment bonded to the old.

Figure 4.2 Typical raised embankment sections (not to scale)

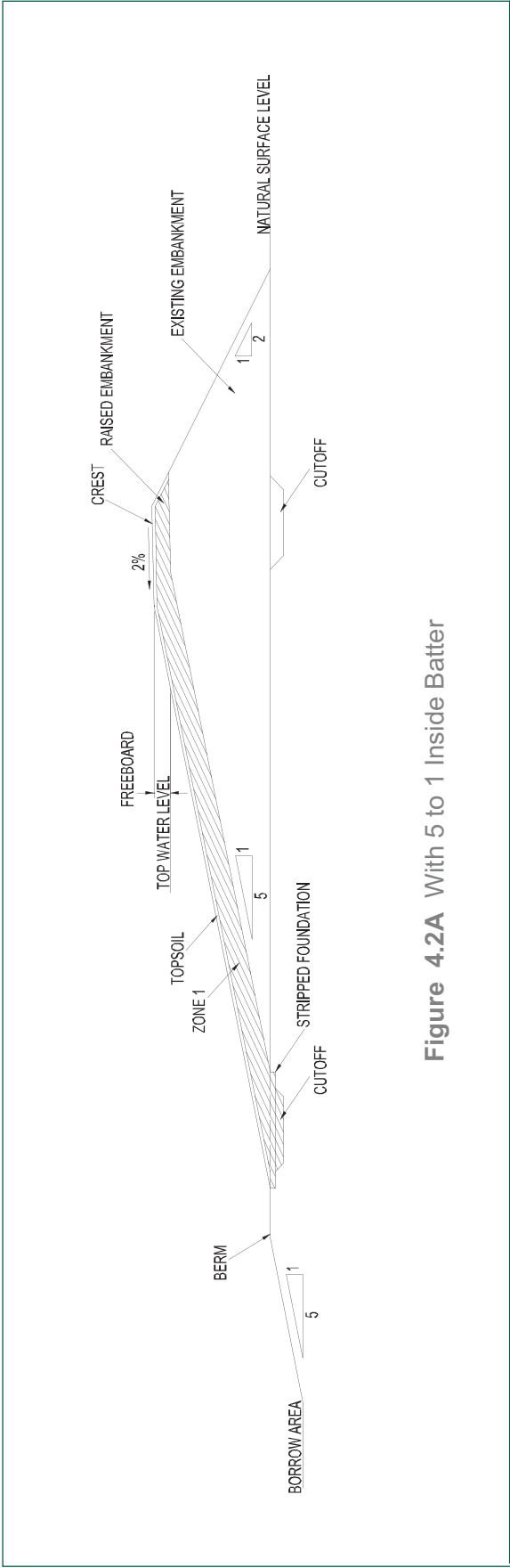


Figure 4.2A With 5 to 1 Inside Batter

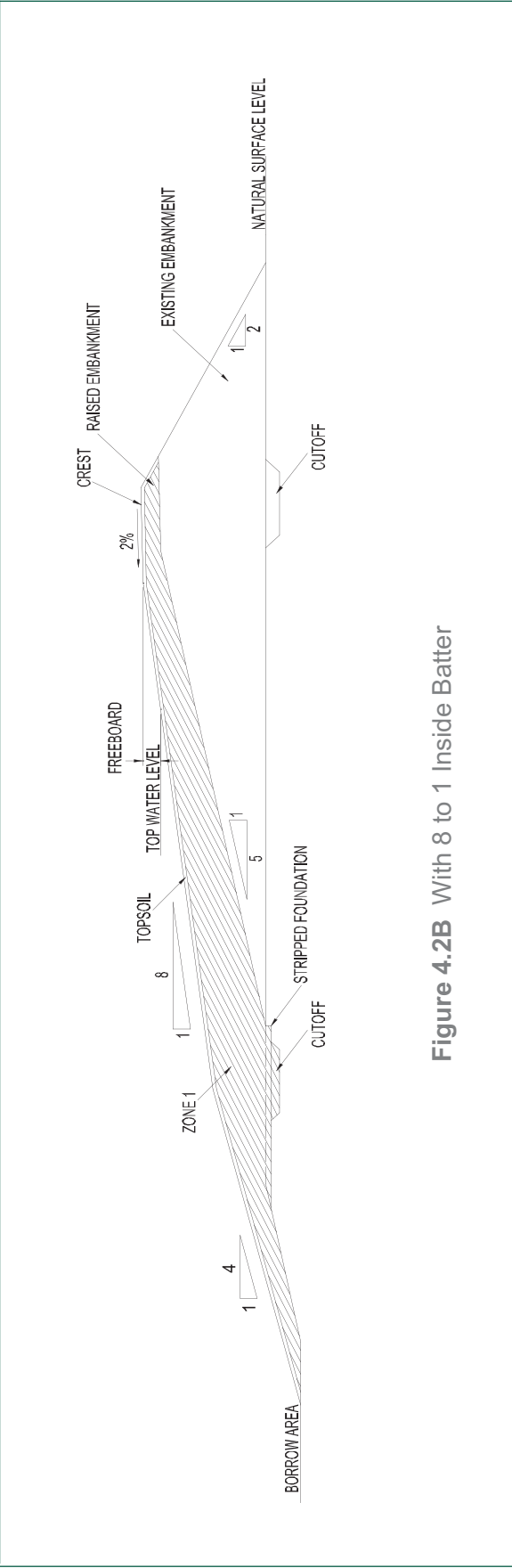
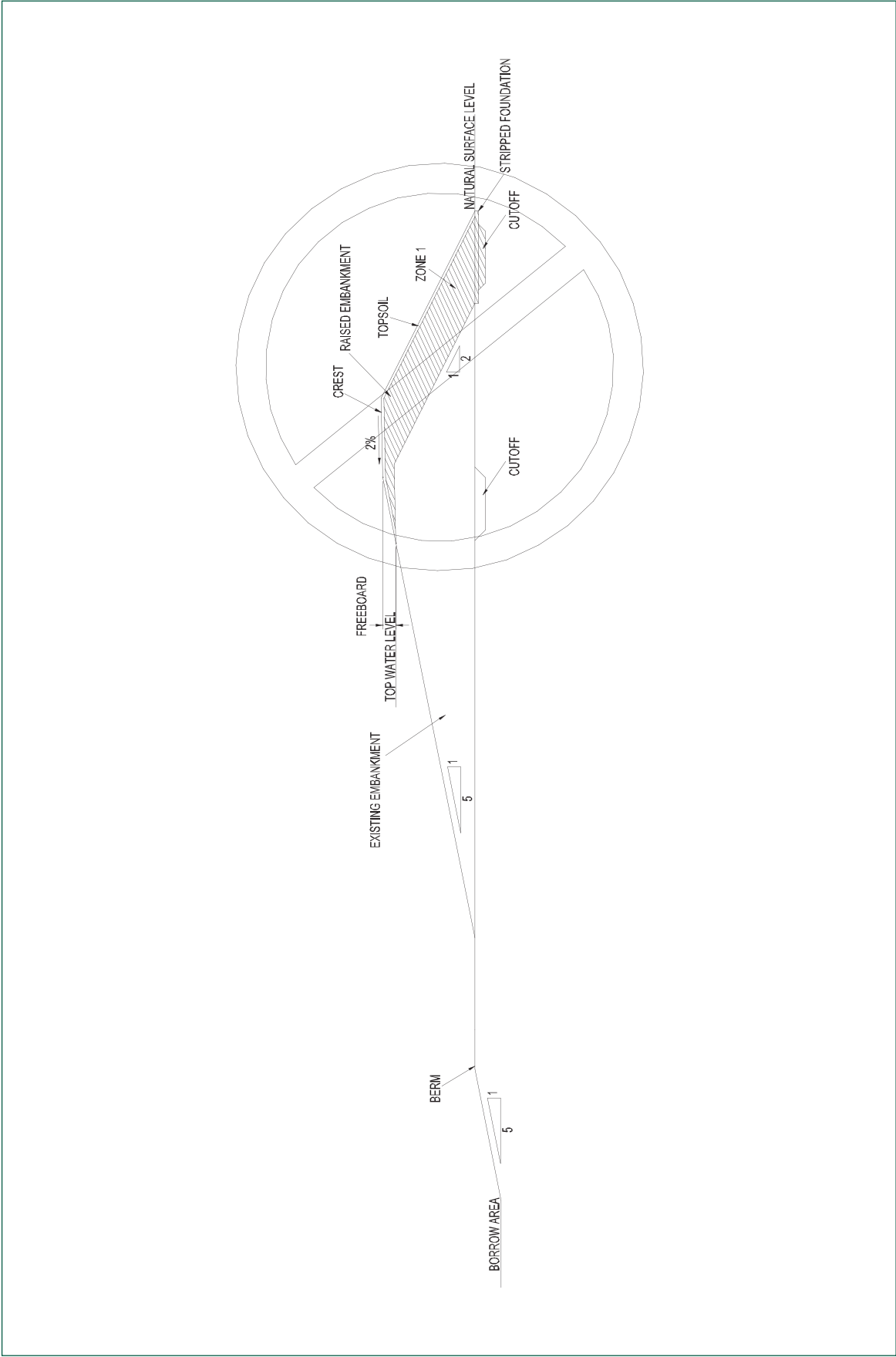


Figure 4.2B With 8 to 1 Inside Batter

Figure 4.3 Raising an Embankment from the Outside (*not recommended*)



STORAGE MAINTENANCE

Once constructed, storages are exposed to elements that will slowly reduce their stature and structural integrity. Left unchecked, natural processes such as erosion, wave action and wetting/drying cycles can result in the reduction of crest height, changes in wall cross section and batter shape and, potentially, in the failure of the storage. This unwelcome development is likely to happen at the worst time: when the storage is full.

The following is a basic guide to the routine repairs and maintenance required to ensure longevity of ring tank embankments.

5.1 Maintenance Program

A maintenance program should be set in place to ensure that the storage retains its original shape and function. This program will be based on regular observations.

Visual Observation

Visual observation is critical to a maintenance program. Visual checks should be carried out frequently (one to three-hourly) when filling, and regularly (every two to four weeks) during normal use.

Ensure vehicle access is provided to the whole crest and the base of the outside batter for this purpose. While driving slowly, look for cracking in the crest (longitudinal or transverse), erosion of inside and outside batters, tunnelling, vegetation, animal burrows (fox, rabbit or goanna), undercutting of inside batter, slumping of crest, and soft spots or seepage through the wall or at pipe structures.

Also observe silt plumes near the inlet/outlet to ensure that they do not interfere with water entering or draining from storage.

Objective Measurement

Visual observation may overlook subtle changes occurring with time. Measurements such as the following need to be taken every few years:

- Use a survey level and benchmarks to check crest height around the dam
- A Real Time Kinetic (RTK) Global Positioning System (GPS) can be used to observe crest height compared to natural ground level; however, tractor mounted units currently do not

provide sufficiently accurate height measurement for more than a rough check

- Set up a profile marker at a number of locations to assess erosion from the original shape
- Measure crest width at set points
- Check depth of silt on the floor at set points when empty. Some 30 year old storages with frequent use have accumulated 200 to 300 millimetres of silt across the floor, reducing their capacity by up to ten per cent
- Ground Penetrating Radar (GPR) has recently been found to be useful for looking into the embankment (four to seven metres down in a one-metre band) and discovering any anomalies, such as areas of dry core, root intrusion, deep cracking or tunnelling
- Objective measurement of the levels of compaction and moisture within the embankment can be carried out by extracting a core from the desired depth for laboratory density testing, using a neutron density gauge down a hole, or assessing with a penetrometer on site.

The long section shown in Figure 5.1 on page 19 is an example of the height variation that can occur in an embankment crest with time.

RESEARCH NEED

To determine the most cost-effective method of monitoring the condition of existing steel pipes under embankments

5.2 Maintenance of the Crest

Survey records of various storages indicate that the crest level generally decreases in height by as much as 25 millimetres per annum. This is usually caused by erosion but in some cases it is also caused by a loss of soil from grading of the crest and slumping of the crest into soil cracks.

The annual loss of crest height results in a reduction of available freeboard. Many storages have a marker to indicate top water level but, in some instances, top water level is judged from the

crest height. A loss of crest height is, therefore, a loss of safe capacity in the storage. Over a ten-year period, the loss of potential capacity could be as much as 2.5 megalitres per hectare of stored water. This could result in a significant decline in the value of the storage as a farm asset.

Once a storage is completed, the crest should be surveyed to establish the final crest height. This also provides a check for low points or high points along the crest. The survey should establish a suitable benchmark to provide a fixed height to reference future surveys.

Subject to the frequency of crest maintenance activities, a crest survey should be undertaken every five years to determine:

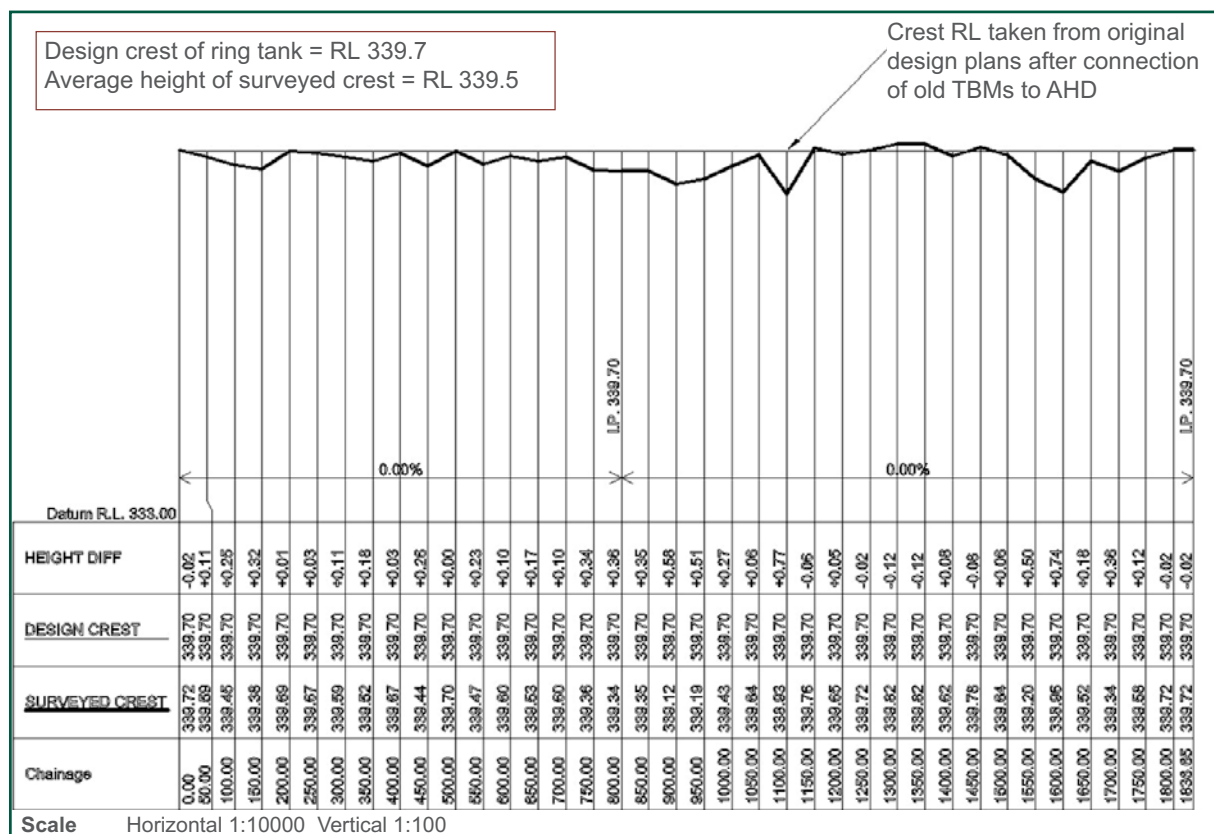
- current crest levels
- low spots in the wall as a result of slumping or erosion
- shape of the crest
- rate of crest level decrease, to enable suitable planning for resurfacing.

A grader with a belly blade and side sling blade is sufficient to correct minor damage to the crest and tops of batters, caused by erosion. The grader is used to fill small rills and even out the surface, so the next rainfall event does not concentrate in already-formed channels and enlarge them. Care should be taken not to grade-down the crest and reduce its overall width or height.

For dams with a crest (Figure 3.1A, page 9) rather than a continuous inside batter (Figure 3.1B, page 9), the crest should have an even flat surface with a slight slope (two per cent) into the storage so that runoff moves into the storage and not down the steeper outside batter. Runoff down the outside batter can be minimised by grading a 150 millimetres-high windrow along the top edge of the crest.

Wheel tracks or ruts around the crest should be flattened to avoid water running around the crest to a low point, then scouring a small gully or tunnel at that point.

Figure 5.1 Variation of crest height with time (5 years after construction)



If some differential settling has occurred and longitudinal cracks form on the inside edge of the crest, accumulated runoff water can enter these cracks and start tunnelling.

For banks constructed of soils that are prone to dispersion, a lack of maintenance places them at particular risk. For these soils, it is recommended that cultivation of the crest take place on a regular basis. This breaks down any tunnelling in its early stages. Care should be taken with cultivation to leave a smooth finish (with harrows), so that water does not accumulate and run along the crest in parallel cultivation rills before breaking out and forming a gully, or descending into a tunnel (see Figure 5.2). Unfortunately, this practice leaves the crest prone to wheel tracks and erosion, so alternative practices might need to be developed.

RESEARCH NEED

The optimum crest and batter maintenance procedure for different soil types and different climatic conditions is a matter of conjecture and needs further research.

5.3 Maintenance of the Outside Batter

The steeper outside batter suffers mostly from rain erosion (see Figure 5.3). It does not represent a large horizontal surface area to catch rain; however, its slope encourages higher velocity runoff that can carry a high silt load. The batter needs to be checked regularly for erosion and vegetative growth, and graded and sprayed for weeds as required.

5.4 Maintenance of the Inside Batter

For maintaining an inside batter surface eroded by wave action (see Figure 5.4), moist clay should be added and compacted into place in layers of the correct depth for the type of compaction used. Clay soil used in reshaping the inside batter should be borrowed from the storage floor after removing built up silt. (Care should be taken in excavating the borrow pit not to expose a layer of more porous soil that may result in increased seepage through the floor). The eroded batter surface should be prepared by removing loose material, then grading and rolling to allow bonding of the added material.

Figure 5.2 Cracking, erosion and tunnelling of embankment crest



Figure 5.3 Rills as a result of erosion on the outside batter



Figure 5.4 Wave erosion on the inside batter



Using a long boom excavator to pull silt back up onto the inside batter without compaction is a short term fix only, as the silt is more prone to erode, particularly if not compacted.

RESEARCH NEED

Investigate the use of floating baffles, or synthetic materials such as weed matting, polymers or bitumen to protect the inside batter at top water level and compare to a flatter batter for likelihood of soil loss.

5.5 Repairs

If tunnels or deeper gullies are discovered, it is not sufficient to grade dry soil into them as they may still have voids that can lead to water penetrating the bank. Dry soil is more easily washed through the tunnel/gully if not bound to the walls of the defect with moisture and compaction. These bigger defects need to be excavated to their extent and refilled with moist soil, then compacted to the same standard required for embankment construction so the structure is restored. Depending on the size of the defect, an excavator with bucket and tip roller may be required.

If a section of the core of the wall requires repair following discovery of dry soil, root intrusion, deep cracking or tunnelling, repairs should be completed with suitable soil at the correct moisture with adequate compaction. Excavators may be used to trench into the core along the embankment to the depth required, then backfill with moist soil and compact with a tip roller. This results in a core of compacted soil 0.5 to one metre wide and adequate depth through the affected area. Possibly the preferred method is to utilise a bulldozer or scraper to remove a section of core (about the width of the crest) to the depth required, then backfill with a scraper, using a water cart and roller to achieve the correct moisture and compaction.

5.6 Vegetation

Earthfill embankments with a good grass cover will suffer little erosion from wind and rain and limited wave erosion. Unfortunately, grassing has been shown to be a contributing factor in storage failure, where roots have penetrated the embankment, drying it out and initiating cracking.

Without vegetation, inside batter maintenance becomes more onerous and more regular work is required to maintain the inside batter that is subject to frequent wave action. More research is required to determine if suitable grass species can be found for embankment protection.

Current recommendations are therefore to construct the inside batter at an 8:1 slope and to keep the crest and batters free of vegetation. Non-residual herbicides should be applied as required.

Trees should be discouraged from growing anywhere near the embankment. Their roots will seek out moisture in the embankment, resulting in cracking when the storage is dry (see Figure 5.5).

RESEARCH NEED

Identify successful examples of strategies for managing and controlling vegetative cover.

5.7 Maintenance of the Floor and Internal Borrow Pits

Silt plumes obstructing or restricting water entry and extraction from the storage should be removed and dispersed.

The floor and borrow pits should be maintained to ensure the thorough drainage of the reservoir when drawn down, so that no 'dead water' or ineffective storage space remains.

Vegetation allowed to grow in the floor of empty storages will dry the soil profile. This can lead to a considerable volume of additional water (up to three megalitres per hectare of reservoir area) being required to fill the soil profile, before adding to the useful storage volume of the reservoir when filling. Drying and cracking of the floor can also reduce any compaction. The floor should be kept free of weeds (like a fallow paddock) to conserve moisture. Care is required in using residual herbicides,

however, as they may impact on subsequent crops grown with water from that storage.

Recent trials have indicated that high-impact compaction of the storage floor at the correct moisture content can significantly reduce seepage losses. This should be considered for storages with known seepage issues and adequate clay content for compaction.

Vehicular access to the floor of the storage and inside borrow pits is required for spraying weeds, as well as for compaction equipment. The floor should also be reasonably level for these purposes. An earthen ramp may be required across the borrow pits for access.

Different planes of the floor will be at optimum moisture for compaction at different times as the floor dries out. Weed control or compaction efforts may need to be staged as drying occurs.

Figure 5.5 Tree growth near storage embankments should be discouraged



STORAGE MANAGEMENT

6.1 Filling

A storage should be filled slowly, particularly when filling for the first time or after an extended dry period when the embankment material has been allowed to dry significantly. Filling a storage slowly allows for shrinkage cracks to swell and seal, reducing the risk of flow-through fissures.

Unfortunately, the nature of many on-farm storages is that they are empty for long periods, resulting in dry embankments. In addition, flood events are rare and often short lived, so it is not always practical to fill storages slowly. This is nearly always the case in an ungated 'gravity fill' situation, when there is greater difficulty in regulating the speed of the filling process.

It is important, therefore, to ensure management procedures are followed to help limit the risk associated with rapidly filling storages. All gravity-fed storages (or any storage that may be filled quickly) should be identified and given maintenance priority. When filling a storage that has only been part-filled in the past, the embankment will need to be observed particularly closely as the water level rises above the previous top water level.

Ultimately, filling any storage that has been dry for a period of time is a risk. If unable to reduce the risk by filling the storage slowly, it is recommended that the following procedures be in place:

- 24-hour surveillance of the storage to look for any signs of leaking
- Particular attention should be given to the outer batter and adjacent foundation for signs of cracks, slides, subsidence or the appearance of boggy areas resulting from seepage
- The outlet pipe should also be observed constantly for signs of seepage around the pipe barrel
- Have an excavator on site during filling in case any signs of failure are found
- If any problems are observed, filling should cease and the water level be lowered as soon as possible.

Table 6.1 Alternative evaporation reducing technologies

Product	Evaporation Reduction (%)	Installation Cost (\$/m ²)	Operation & Maintenance Cost (\$/ha/yr)	Breakeven Cost (\$/ML saved)
Floating Cover (E-VapCap)	85-95	\$5.50-\$8.50	\$112-\$572	\$302-\$338
Shade Cloth (NetPro)	60- 80	\$7.00-\$10.00	\$112-\$537	\$296-\$395
Monolayer 5-30 (Water\$avr)	\$0.00-\$0.38	\$826-\$4,050	\$130-\$1191	

- 1) Estimated breakeven cost is based on 2200 mm potential evaporation, all year water storage.
- 2) High operating and maintenance costs represent worst case scenario and are unlikely in most cases.
- 3) Evaporation reduction performance of the monolayer product trialled (Water\$avr) has been shown to be highly variable and in some trials 0%.
- 4) Table taken from: Controlling Evaporation Loss from Water Storages, I. Craig et al, NCEA Publication No 1000580/1, June 2005.

6.2 Reducing Evaporation Losses

The cost-effectiveness of constructing storages deeper at the outset is explained in Section 1.2. Most of the benefits are due to reduced evaporation.

With existing reservoirs, reducing evaporation losses becomes more expensive. Splitting a large reservoir into two cells is often cost-effective. Other options include floating covers and modular systems, suspended shade cloths and monolayer chemical covers. Results of preliminary research by the National Centre for Engineering in Agriculture (NCEA) into the effectiveness and costs of each of these technologies are summarised in Table 6.1.

A detailed ready reckoner has been developed to help estimate the cost/benefit of evaporation suppression systems and is available on the National Program for Sustainable Irrigation (NPSI) web site (www.npsi.gov.au/readyreckoner). Substantial resource material on evaporation reduction products is available on the NPSI web site and also on the NCEA website (www.ncea.org.au/Evaporation%20Resources).

Monolayers have the advantage of low capital cost but need to be applied on a regular interval (between two and 14 days). Application is usually through a pneumatic or hydraulic pump arrangement, although deployment by air is being considered. Monolayer products are broken down by ultraviolet light, and the distribution across the surface can be adversely affected by wind and wave action. Water quality is also likely to affect performance. This system offers potential for large storages where structural solutions are less viable. Another advantage is that it only needs to be applied when there is water in the reservoir.

RESEARCH NEED

Trials of monolayer technology show that the results are highly variable. Research is needed to better understand the factors affecting product performance and to develop appropriate application systems.

The floating covers tested showed the potential for very high water savings. Continuous covers are less suitable for large reservoirs, due to problems with stretching and tearing of the cover. Deformation of the cover may allow water to move from below to above the cover and evaporate. On larger reservoirs, tears require urgent repairs as any wind getting under the cover can cause considerable damage. Modular cover systems, whilst having slightly less water savings at around 80 per cent, have the potential to be used on larger reservoirs. The lifespan of the floating covers tested was quoted at 12 years, although some of the product monitored was ten years old and was not showing any signs of deterioration.

The shade cloth product is only suitable for reservoirs under five hectares. Having the cloth suspended above the water means that its effectiveness will not be altered by silt and debris accumulation or water inundation. Ultraviolet light will eventually break down the cloth and it will need replacing every 15 years. The reservoir usually needs to be empty for the cloth to be installed.

For a more comprehensive report on the NCEA findings, refer to Craig *et al* 2005.

6.3 Seepage

A reservoir constructed on suitable soils will have seepage losses of less than one to two millimetres per day. Seepage losses greater than four to five millimetres per day should trigger further investigation to remedy the problem. Monitoring of seepage and evaporation loss is possible using highly accurate seepage/evaporation meters. Deployment of meters for a period of around six weeks, during periods of no inflow/outflow or rainfall allows net water loss through evaporation and seepage to be measured. Estimates of evaporation can be made based on weather data and appropriate analysis procedures to determine the seepage component. Commercial services to assess reservoir seepage and evaporation losses are now available.

The cheapest way to minimise seepage losses in a reservoir is to complete an appropriate soil analysis on the proposed reservoir site before construction.

Remedies are available if seepage is found after construction but are generally not cheap and can cost as much or more than the initial cost of constructing the ring tank.

The initial step is to get an EM (electromagnetic) survey of the reservoir floor, as outlined in Section 3.1. Further soil analysis in each of the areas of similar electromagnetic conductivity is required to determine the probable seepage areas.

If there is a source of suitable clay soils nearby, the cheapest option is to line the problem areas with a 600 millimetre-thick layer of clay. This costs in the order of \$1.20 per square metre of area lined.

The next cheapest option is incorporating bentonite clay into the problem areas. This costs in the order of five to ten dollars per square metre. Bentonite is difficult to handle and incorporate into the soil. It also works best in sandy soils (which should have been avoided in the first place), where larger voids allow better bentonite penetration.

A further option is lining the reservoir with an impervious polyethylene membrane. A two millimetre-thick liner costs between ten and twenty dollars per square metre. There are thinner, cheaper liners available but it is highly likely that these will be torn during installation or soon after, rendering them expensive failures.

6.4 Emptying

Rapid drawdown of storages may result in slumping of the inside batter, due to the difference in soil water pressure. The Farm Water Supply Design Manual (Horton and Jobling, 1984) recommends a minimum 4:1 batter to reduce the occurrence of slumping. Generally, ring tanks are now designed with 5:1, or flatter, batters. Therefore, slumping should not be a problem for these storages.

In situations where slumping may be an issue with inside batters it is important to operate the outlet at, or below, its designed capacity, to reduce the rate of drawdown. Forward planning will also be important to ensure that the expected crop area and crop water demand can be met by the storage outlet design capacity. Operating above the design capacity will lead to increased erosion and silt loads as well as potential slumping of inside batters.

References

- Craig, I., Green, A., Scobie, M. & Schmidt, E., 2005, 'Controlling Evaporation Loss from Water Storages', National Centre for Engineering in Agriculture (NCEA) Publication No 1000580/1.
- Dalton, P., 2000 'WATER TIGHT: Whole Farm Water Use Efficiency – Determining your own water security', ACGRA 10th Australian Cotton Conference Proceedings, 395-413.
- Horton, A.J. and Jobling G.A., 1984, 'Farm Water Supplies Design Manual', Farm Water Supplies Section, Queensland Water Resources Commission.

RESPONDING TO A FAILURE

Faced with the unfortunate experience of responding to a storage that is failing, there are two phases to the task, plus an opportunity:

- 1 save the water and minimise damage
- 2 repair the storage
- 3 and while the opportunity is there, why not rejuvenate the storage to prevent further failure?

7.1 Crisis Response: What to do if failure is imminent or already occurring?

The first thing is not to panic: the situation is urgent but panic rarely helps. Reacting without thought leads to taking unnecessary risks and perhaps placing lives in danger. No storage or amount of water is worth losing a life. Keep in mind that one cubic metre of wet soil weighs about two tonnes. A person overcome by this relatively small amount is unlikely to survive.

The best preventative for panic is to have a risk management plan in place and ready to go. This plan should primarily be made in consultation with the farm family and workers but should also include others such as downstream neighbours.

Signs of a failure are:

- Water running out at the toe of the outside batter, which indicates that a 'pipe' or tunnel has formed within the embankment. Water is escaping through the embankment to ground level, then travelling along the interface between bank and natural surface
- A whirlpool on the water surface, which may occur if the flow through the embankment is sufficiently high and the inlet to the 'pipe' not far below the surface. Failure might be avoided if immediate action is taken and the inlet blocked with earth.

The embankment above the tunnel will be undermined and large voids may be developing. Driving over this area should be avoided. The size of the visible hole may give no indication of the chasm that could be there. Whole machines have been lost!

If a failure is occurring, then:

- contact neighbours as soon as possible to warn them of possible danger and alert them to capture escaped water in their storage (they might accept an arrangement to return some water when the storage is repaired)
- contact the water supplier/authority: neighbours will soon be inquiring about what is happening
- arrange for heavy machinery to come as quickly as possible. An excavator is most useful and two bulldozers are likely to be very advantageous
- seek to minimise water loss and erosion of the embankment until heavy machinery arrives.

The following suggestions must be assessed for suitability for each case:

- if a breach is just commencing, fill the gap
- drop the water level as quickly as possible to reduce the pressure on the failure area. Options include draining into another storage or cell, or to the tailwater return system, the supply system, surge area, or a fallow field. Filling the tail water and supply channels helps to minimise damage to these from the escaping water
- try to stop the water escaping:

Lowering the water level may be the most effective and safest option, especially if there is only a small seep which may self-seal

DO NOT put large, hard obstacles like boulders, chunks of concrete, hay bales, old vehicles, etc. in the breach. This creates higher local water velocities around the obstacle, which erodes the hole further. However, flexible obstacles such as bulk fertiliser bags filled with sand and dropped into the breach often work well and this may be a quicker option than getting machinery to the site

Tarpaulins placed over a tunnel or well-defined breach extending below the water level will reduce erosion of the embankment into the hole. The water will spill over the tarpaulin rather than the remaining earthen embankment.

The tarpaulin provides a temporary weir and should only be used to buy time until an excavator arrives. Tarpaulins should not be used if an excavator is on site, as putting them in place can be very dangerous and extreme caution is required. The tarpaulin must be secured under water by placing large weights, such as boulders or concrete, on the corners and edges to prevent it washing into the hole. A large volume of soil should then be dumped by excavator on the reservoir side of the tarpaulin to stop water flowing into the hole (see Figure 7.1). With flow stopped, more soil should then be dumped on the exposed face of the tarpaulin to stop flow underneath

If the hole is not too large, another process to try is positioning a panel from, say, portable cattle yards across the hole, then placing a tarpaulin over the panel and extending it over the adjacent embankment

- once machinery has arrived, if the breach is not too severe, bulk earthworks may work. The quickest and best is likely to be two dozers working on top of the embankment on opposite sides of the failure area, pushing large quantities of earth towards each other at the same time. This gives the best chance of placing enough soil into the breach to arrest the flow. Placing small quantities of soil at a relatively slow rate is unlikely to be effective
- keep fighting the problem even if water continues to escape, as saving the last few hundred megalitres is still worthwhile and is the easiest to achieve
- when the breach is plugged, continue dropping the water level until no more water is escaping.

7.2 Repairing a Failed Storage

The aim is to repair any breach rapidly, so as to minimise water loss and be in a position to recommence pumping as soon as possible.

Figure 7.1. An embankment (and water) saved by placing a tarpaulin over the breach, followed by an earthen coffer dam.



However, it must be done properly. In a crisis it is tempting to use inappropriate methods or soils but this risks another failure. If the leak stops, do not stop moving earth yet as the underlying weakness may not have been adequately addressed.

The first and immediate priority is to build a thick coffer dam bank around the breach to secure the remaining water in the storage. Once the coffer dam is stable, the material in the breach must be removed to 0.5 metres below solid dry clay, which is commonly below the depth of the original cut-off trench.

For a good repair, the roller takes precedence, not the scrapers. Quick turn around time is NOT the prime concern now.

The breach area must be battered on both sides in the direction of the embankment centreline, to a batter at least 4:1, and preferably 8:1.

A new cut-off trench should be cut into the existing bank and foundation to 'key' the repaired section into the old. Once the cut-off trench is excavated, it should be rolled with a sheepfoot roller, to

provide a roughened but compacted surface for the new layers. After filling the cut-off trench with moist selected compacted clay, the whole embankment and foundation area within the breach should be rolled with the sheepfoot roller. Practicalities might dictate that the entire embankment in the breach area be fully compacted, not just the core, as is usual practice for construction (see Figure 7.2).

New layers of moist select clay should then be placed evenly across the embankment in layers no thicker than 100 millimetres. It should then be compacted with the sheepfoot roller by a minimum of eight passes, or when the roller is up on the feet and no longer compacting. Only when each layer is compacted in this way should the next layer be placed. This process should continue to the top of the embankment. Finally, a topsoil layer of 300 millimetre thickness should be placed on the top and batters of the finished embankment.

The coffer dam does not need to be removed and can remain in place up against the inside of the new section of the embankment.

Figure 7.2. Compacting earth fill placed in an embankment breach



SEALING LEAKING STORAGES

Use of PAM, Gypsum, Bentonite and Lime

Materials

PAM and gypsum are generally used where highly dispersible clay particles are present. Bentonite is used as an additive to reduce soil porosity and lime is used to stabilise clay material in a layer over porous soils. These readily available materials provide a relatively low-cost option to reduce soil porosity. However, some sealants require regular applications to maintain the sealing effect and therefore become less cost-effective in the long term compared to using stable clay as a liner. (ANCID, 2001)

Description and Use

PAM is an anionic polyacrylamide used at low rates (for example, one kilogram per hectare) in irrigated agriculture for improving water infiltration and reducing soil erosion and runoff. PAM has been shown to improve the structure of sodic soils, increase the percentage of water-stable aggregates and hydraulic conductivity and reduce surface crusting (Wallace, Wallace *et al.* 1986a). Some tests have been conducted to use PAM products at higher rates for example, 60 kilograms per hectare) to bind soil particles and allow more dispersive soils to settle over a porous area and seal larger soil pores.

Gypsum (calcium sulphate) can be used as an ameliorant for dispersive soils. Gypsum initially provides an electrolytic effect to the soil, increasing its salt concentration. This prevents clay particles from swelling and thus reduces dispersion. A longer-term effect of gypsum is to replace exchangeable sodium attached to clay particles with exchangeable calcium that makes the soil less sodic and reduces dispersion. The net effect is similar to PAM, where the dispersed soil particles settle over a porous soil area to block larger soil pores.

PAM and gypsum can be applied directly to the soil surface to react with water. Both products result in the settling of dispersed soil particles. The deposition process then creates a sediment seal on the surface of the more highly porous material in the floor of the storage. Limited data is available to

determine rates of application and frequency of application of these products. The data available indicates that the sediment seal is vulnerable to wave action and water movements, which results in potential disturbances to the sealing process. Regular inspection and monitoring is required to assess the deposits and therefore determine the frequency of reapplication of PAM or gypsum.

Bentonite is the most common material used for sealing of soils with high seepage rates. Bentonite is an extremely fine montmorillonitic clay that has the ability to absorb water and expand up to 15 times its dry volume. In the presence of water, bentonite expands to seal soil pores. Bentonite ranges from low sodium-low swelling classes to high sodium-high swelling classes. The high swelling bentonite is more commonly used to seal storages and channels.

Bentonite is commonly used as a dam sealant in areas where suitable clay is not available or in short supply. It can be applied as a blanket to be incorporated in the soil and then covered with soil to reduce disturbance by waves or water flow. Alternatively, bentonite pellets or bentonite slurry can be applied to the leaking section of the dam to settle and seal soil pores. Bentonite maintains its swelling properties over time; however, if the bentonite is exposed to wave or water flow, the material would wash away with the water and therefore reduce the effect of the product. It is, therefore, more suited to still, permanent water storages and to areas of more permeable (sandy) soils, where it infiltrates below the surface. Application rates can be obtained from the supplier.

Lime (calcium carbonate) is commonly used as a soil stabiliser for construction of road subgrade from clayey gravels or clay soils, which shrink and swell extensively. The lime acts to flocculate fine-grained plastic clay soils to reduce soil plasticity, shrinkage and expansion. The net result is an increase in soil stability in soils that normally show impervious characteristics but extensive cracking as they shrink and swell.

Lime is more suited to the construction of storage embankments where highly plastic, high shrinking

clays are used. Lime is applied at varying rates, which are dependent on soil properties and economics. It is mixed with the core layers of an embankment and not used in the surface layers. Lime is prone to dissolve in water and, therefore, wash away if used in surface materials. Lime is mixed at a rate of two to six per cent with fine-grained soils to reduce shrinkage rates (ANCID, 2001). The mixing process requires uniform spreading of the lime, mixing of lime with the clay, grading and compaction of the clay in layers and covering with a minimum of 0.5 metres of clay material to protect the lime.

Soil Tests

Soil sealants are used to change soil structure and chemistry in situations where suitable clay sealants are unavailable. The use of these products requires an understanding of the soil type that needs to be sealed. Soil tests should involve both physical and chemical analysis. The following provides a range of soil tests needed to select suitable soil sealants and their rates of application:

- Particles size analysis: to determine sand and clay content
- Unified Soil Classification: to determine general engineering properties
- Dispersion percentage: to determine the volume of soil particles dispersed in the water
- Emerson Aggregate test: to determine a dispersibility index and soil properties
- EC and pH: to determine soil salinity and acidity/alkalinity balances
- Linear shrinkage: to determine how much the clay would contract as it dries below optimum moisture levels.
- Atterberg limits: to determine the plasticity index of soil as a strength assessment

Using the results of these laboratory tests, a soil technician can assess the best method and material for sealing a porous soil material. The rate of application is generally based on the soil classification; however, some field trials of various materials at varying rates might be warranted before committing to using a particular product over an extensive area.

Reference

ANCID, 2001, 'Open Channel Seepage Control', Published by ANCID.

