Dam design for pastoral stock water supplies

J S. Addison
R J. Law
G B. Eliot

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Dam Formulae

Catchment size
Formula

\[
\text{Area (hectares)} = \frac{\text{Length (m)} \times \text{width (m)}}{10000}
\]

Catchment Yield
Formula

\[
\text{Estimated annual catchment yield (m}^3\) = \frac{(a) \times (b) \times (c) \times 10}{100}
\]

Dam Storage Volume (excavated earth tank type)
(Kimberley)
Formula

\[
\text{Volume required (m}^3\) = \text{CU} \times 400 \times 0.05 \times 1.7
\]

Square or Oblong dam
Formula:

\[
\text{Volume (m}^3\) = \frac{(\text{Surface area} + \text{base area} + (\text{square root of top surface area} \times \text{base area})) \times \text{depth}}{3}
\]

Circular dam
Formula:

\[
\text{Volume (m}^3\) = 0.2619 \times \text{depth} \times (\text{top diam.}^2 + \text{base diam.}^2 + (\text{top diam.} \times \text{base diam.}))
\]

Wingbanks
Formulae

(1) Volume (m\(^3\)) = \text{Total wingbank length (m)} \times \text{average cross section (m}^2\)

(2) Wingbank cross sectional area (m\(^2\)) = \frac{\text{(Bank base width + bank top width)} \times \text{height}^2}{2}

Temporary ponding volume.
Formula:

\[
\text{Temporary ponded storage (m}^3\) = \frac{1.05hf (r1 + r2)^2}{2}
\]
### Appendix Table 2. Estimated monthly and annual evaporation from dams in various pastoral centres (mm)

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* $E_g$ = Evaporation from dam
  $E_p$ = Class A pan evaporation

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### CONTENTS

#### 4. Turkey nest dams

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- 4.2 Pegging
- 4.3 Construction
- 4.4 Overflow
- 4.5 Filling

#### 5. Gully dams

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- 5.2 Design formulae used
- 5.3 Catchment
- 5.4 Foundations
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- 5.6 Wall design and construction

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- 6.1 Inlet
- 6.2 Wingwalls
- 6.3 Modified natural catchments
- 6.4 Roaded catchments

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#### Bibliography/appendices

- Dam dimensions/volumes
- Pastoral centre evaporation data
- Dam Formulae
INTRODUCTION

These notes provide information on many components of water harvesting/storage systems designed for use in semi-arid areas. The notion of a water harvesting and storage system is deliberately emphasised. No single design component can be considered in isolation if the goal of a drought-proof water supply is to be achieved.

A drought-proof surface water supply is achieved by integrating the many design components of a water harvesting/storage system into a practical plan.

The diverse nature of the rangelands in Western Australia means that no two systems will be alike. The successful combination of catchment nature and size, dam design and location will be unique for each situation. However, sound water harvesting/storage systems should be based on principles and practices derived both in agricultural and rangeland environments.

Dams are generally constructed in areas where there is no suitable quality ground water or where it is too deep and costly to extract. In the pastoral zone the areas most affected are parts of Kalgoorlie-Nullarbor, the Murchison and Coastal Gascoyne. In these areas dams have been built on large catchments and vary in size from 2000 to 40,000 cubic metres.

Research by the Department of Agriculture has found that small efficient catchments contributing to a properly designed dam can be more effective than the traditional large catchment/large dam combination.

As our knowledge of catchment and storage water systems increases, risks previously considered too great are diminished. With modern excavation techniques, and a better understanding of soil properties, a water harvesting/storage system may now be considered a reliable and cost effective alternative to ground water supplies.

Disclaimer:
The Chief Executive Officer of the Department of Agriculture and the State of Western Australia accept no liability whatsoever by reason of negligence or otherwise arising from the use or release of this information or any part of it.
1. PASTORAL WATER CONSERVATION SYSTEMS

The success of any pastoral water storage system depends on:

- planning,
- design,
- construction, and
- management.

Each of these factors must be considered if the scheme is to achieve the desired result.

1.1. DEFINING THE PURPOSE OF THE DAM

Clear definition of the dam’s purpose is required so that total water demand, current and projected, can be catered for.

For example, if the dam is to service domestic demand this may include household and garden requirements. If the dam is to service livestock supply, this may mean either servicing one paddock only or multiple servicing by reticulation of supply. It may be a combination of domestic and livestock supply.

Factors influencing livestock water consumption rates are:

- lactation status
- size of stock
- species of stock
- daily temperatures
- pasture salinity
- forage moisture content
- water quality

1.2 QUANTIFYING TOTAL WATER DEMAND

(a) Domestic

Homestead demand varies depending on the numbers in the household and the size of garden. Water demand equivalent to 1000 DSE (dry sheep equivalents) approximates that of a household with a moderate sized garden. When more than one household exists this figure should be multiplied accordingly.

(b) Livestock

The total drinking requirement includes domestic, feral and native animals. The result should be expressed in dry sheep equivalents (DSE). A DSE refers to the drinking rate of a dry sheep of 45 kg live weight in forward store condition (condition score 3), grazing a sub-clover or annual species based pasture (see Table 1). Estimates of stock water consumption for various pastoral centres are given in Table 2.

Table 1. Comparative water requirements of different classes of stock (in DSE)

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Table 1: Comparative water requirements of different classes of stock (in DSE)
### Table 2. Estimates of stock water consumption for various pastoral centres

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### 1.3 Calculating evaporation losses

Evaporation losses are high in pastoral regions and must be accounted for when calculating water demand. The volume of water lost daily through evaporation depends on the surface area, water temperature, air temperature, humidity and wind velocity across the water surface.

**The following multiplication factors can be used to calculate drinking rates on various diets:**

- **Grain fed x 2 DSE**
- **Grass pasture x 1 DSE**
- **Saline pastures x 3 DSE**
- **Grain fed x 2 DSE**

### 2. System site selection

The necessity for well distributed watering points on pastoral properties has long been recognised as a key to better management and increased production. High costs incurred in developing new watering points warrant careful consideration of all practical options.
### Dam design for pastoral stock water supplies

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<th>proportion of length to width approx. 3 to 2</th>
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</table>

It is most advantageous to site a water supply so grazing animals may make the best use of forage in the paddock. Points to consider are:

- **General topography**
  - The site should be accessible from all directions. This will help reduce stock concentration and lessen the likelihood of land degradation.

- **Prevaling winds**
  - Some stock has a tendency to graze either into, or away from the wind.

- **Existing watering points**
  - The distance between watering points should be determined by the quality of the water and the type of forage available in the surrounding area. Saline feed and saline water reduce the distance stock will walk from water, hence the need for more watering points. Dam water being non-saline extends the grazing area and allows greater use of the more saline forage (Table 3).

- **Catchment**
  - The dam should be placed on the catchment in such a position that sufficient water is harvested to adequately service the available storage volume of the dam but avoids excess flows that are difficult to control with wingbanks and overflows.

- **Aerial photographs**
  - Aerial photographs should be examined to determine the extent of the catchment. The catchment should be traversed to determine if there is sufficient catchment that will shed water from relatively small rainfall events in order that the dam storage is replenished at every opportunity. The further the dam is situated from it’s catchment the greater the runoff transmission inefficiencies.

### Table 3. Influence of feed and water quality on sheep grazing

<table>
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<tr>
<th>Water salinity (mg salt/L) (=ppm salt)</th>
<th>Non-salty feed</th>
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* Assumes 360° access to a watering point

- **The stocking pressure on the water supply**
  - The grazing area for each watering point must be determined. A watering point centrally positioned in a paddock will allow a larger area to be grazed than one placed near the margin.

- **prevailing winds**
  - In a semi-arid environment the catchment must have the ability to shed water from relatively small rainfall events in order that the dam storage is replenished at every opportunity. The further the dam is situated from it’s catchment the greater the runoff transmission inefficiencies.

- **Examination of aerial photographs**
  - Aerial photographs should be examined to determine the extent of the catchment. The catchment should be traversed to determine if there is sufficient catchment that will shed water on the pattern of rainfall experienced at any given location. The features to look for are evidence of water movement across the surface and the type of surface crusting. The area of catchment that sheds water quickly gives a guide as to the volume of water likely to be collected. One millimetre depth of runoff from one hectare of catchment produces 10 cubic metres (10 kilolitres) of water. For a given rainfall event the runoff efficiency of whole catch-
ments is often low, less than 5%, but certain areas on that catchment may shed as much as 50% of the rainfall it received.

- Avoid major creek systems
  - Silt deposition and bank erosion make major creek systems very inefficient passageways for water. The ideal catchment is one where the water is collected and directed to the dam before it reaches incised drainage.

- Positioning the dam
  - The dam’s position should be decided after the catchment has been assessed. Factors for consideration are:
    a) proximity to the catchment;
    b) position of the overflow(s);
    c) alignment and size of wingbanks; and
    d) depth of suitable water holding soil.

- Dam site selection
  - Careful selection of a site for a new dam and adequate test boring minimises dam failures from excessive seepage. The small financial outlay for test boring is a sound investment.

### 2.1 Dam Site Soils and Test Drilling

Test boring, to dam depth plus one metre, will determine the presence or absence of good quality holding clay. Absence of rock (which may limit the depth), sand seams and salt water table must also be confirmed.

---

### APPENDIX

#### Appendix Table 1a. Dimensions of dams in metres (excavated earth tanks) with standard 1 in 3 batter slopes only

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<th>Capacity (m³)</th>
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<th>Oblong tanks</th>
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Running the fence out past the elbow also protects the overflow - maintaining the design criteria for the temporary ponding.

### 6.3. Modified Natural Catchments

Some light cleaning of collecting drains may be necessary after a few years. This activity can be carried out with a station grader when it is in the area carrying out other tasks.

### 6.4. Roaded Catchments

Roaded catchments lose efficiency as vegetation re-establishes itself on the catchment. Micro-ponding and increased infiltration is promoted by grazing animals breaking the crusted surface. If the catchment is fenced, vegetation growth may be controlled by heavy short term grazing followed by long non-grazing periods. This allows the surface crust to reform after the vegetation has been removed.

### Bibliography


Western Australian Department of Agriculture, Farmnote 114/81.

Pepper, R., Soil Texture Classification, and Testing Soils for Damsites

Western Australian Department of Agriculture, Technotes 4/85 and 5/83.


**2.1.1. Testing soils for water holding**

Soils from a proposed dam site should be given at least three tests in sequence, these tests are:

1. hand texturing for clay content;
2. hand moulding for strength; and
3. dispersion test in distilled water.

**Hand Texturing**

Soil from a proposed dam profile must contain sufficient clay to prevent dam leakage. A soil contains sufficient clay (ie. it contains at least 25 per cent clay) if it hand textures as a clay or clay loam. Despite some limitations, the hand texturing of soil provides a useful field guide to water holding characteristics.

The clay content can be estimated by squeezing moist soil out between the thumb and forefinger into a ribbon 2 to 3 mm thick. If a continuous ribbon 50 mm or longer can be formed, the soil contains enough clay.

**Strength**

The strength of a dam site soil relates directly to soil hydraulic conductivity and stability. The strength of a soil can be estimated by moulding the soil when it contains enough moisture to be plastic.

A strong soil has superior water holding characteristics. That is, the soil is stiff, with a high resistance to deformation when its moisture content is such that it starts to crumble when manipulated.

A weak clay, on the other hand, is very soft and easily deformed. It is usually these weak clays that cause piping failure in dams. These clays should be tested for dispersion.

**Dispersion**

Different soils show varying degrees of dispersion. The degree of dispersion of soil aggregates is judged visually after immersion in distilled water for 20 hours.

Soils with more that 25 per cent clay

Soils that are strong and show no dispersion should also be studied closely for structure. Well-structured soils (blocky peds) may leak. These should be avoided or further tested for dispersion in sodium tripolyphosphate (STPP) solutions to determine if the use of STPP might be a possible sealing technique. (STPP is a chemical used to improve water-holding characteristics of some soils).
Weak soils that completely disperse should be avoided as this indicates the possibility of piping, but weak soils with moderate dispersion are generally suitable for dam construction. Soils that show nil or slight dispersion should be tested with STPP.

Soils with less than 25 per cent clay

Strong soils with less than 25 per cent clay should disperse moderately if they are to hold water. If dispersion is nil or slight, they will leak and require testing with STPP.

Dispersion tests should be carried out on air dry aggregates in solutions of varying concentrations of STPP to determine the amount of STPP to dissolve in the dam water. Concentrations of STPP used to test dispersion are 0.05, 0.1, 0.2, 0.3 and 0.4 g/L. The air-dried aggregates are placed in these solutions and rated after 20 hours. A score of 0 to 4 is used to rate the degree of dispersion. A key for testing soils is shown in Figure 3.

2.2. Catchments

The catchment is the pivotal element of a surface water harvesting/storage system and should not be neglected during site evaluation. The purpose of the catchment is to collect and transmit surface runoff in sufficient volume to fully, but safely, service the storage volume of the dam.

Figure 2a. Soil aggregate showing no dispersion (Score 0), note how the original 1 - 2 mm aggregate has slaked into finer aggregates.

Figure 2b. Soil aggregate showing slight dispersion (Score 1), seen by a slight milkiness of the water adjacent to the aggregate.

Figure 2c. Moderate dispersion of aggregate (Score 2).

Figure 2d. Strong dispersion (Score 3), just over half the aggregate has dispersed; there is considerable milkiness.

Figure 2e. Complete dispersion of aggregate leaving only sand grains in a cloud of dispersed clay (score 4). Slaked aggregate also shown for comparison.

6. Dam/Catchment

Maintenance

Provided the design criteria and correct construction method have been followed there should be a minimal amount of maintenance required. However, there are a few points worth noting.

6.1. Inlet

A trash catcher should be installed at the inlet to:

a) prevent debris, such as small branches, getting wedged in the inlet pipe, causing blockages;

b) restrict the amount of organic matter which finds its way into the dam.

Where a concrete abutment and apron has been constructed at the inlet a ‘fire guard’ style trash catcher is adequate. After each run-off event it may be necessary to clean the catcher.

6.2. Wingbanks

One of the major causes of wingbank failure is that of stock pads. Continued traversing of wingbanks by stock creates pads that gradually reduce the effective freeboard on the temporary ponding area. Surge caused by a high intensity rainfall event may precipitate bank overtopping and breaching.

One way to overcome this is to run a livestock fence along the top of the wingbank.
Simple tests can give a guide as to the clay content and water holding capacity of a soil.

See section on Testing soils for water holding.

5.5. Spillway

In many gully dams the spillway is built without considering the quantity of water it may carry during periods of peak flow.

Under no circumstances should water overtop the wall as the result of inadequate spillway capacity or lack of freeboard. Overtopping is certain to cause dam failure.

Build the spillway to convey overflow water at as low a gradient as possible - preferably no greater than 0.25 per cent.

It may be necessary to protect the vegetation on the spillway by fencing. A good cover of vegetation will help protect the spillway from erosion.

5.6. Wall Design and Construction

Before dam construction starts the area to be covered by the wall and the area being used for excavation should be stripped of vegetation and topsoil.

Wall slopes should be 3:1 on the upstream side and 2:1 on the downstream side. For a high earth wall, make the upstream slope flatter to lessen the likelihood of soil slip. Cut a trench into impervious material along the full length of the dam wall. This trench may be quite deep in the lowest section if there is a streambed. Rip the bottom of the trench to promote good binding with the soil fill. The trench is then filled with impervious clay deposited in 100 mm thick layers and compacted.

To prevent dam failure the wall must be higher than top water level. This additional height is called freeboard.

Figure 14. The wall constructed throughout with an impermeable soil.

Figure 15. The wall constructed with a central core of impermeable soil surrounded by permeable soil.

Figure 16. The wall constructed with permeable soil except for a layer of impermeable soil on the upstream side, known as a “clay blanket.”

The volume of water collected in a dam will depend on the amount of runoff generated by the catchment, and how efficiently that runoff is channelled to the dam.

During rainfall events, most of the water remains on-site and infiltrates or surface ponds. Only a small proportion leaves the point of impact as surface runoff. The aim must be to maximise the collection of this runoff water. To achieve high collection efficiency, infiltration and transmission losses must be minimised.

Figure 4 illustrates the various pathways taken by rainfall on a catchment.

To compute the likely annual runoff production from a catchment the following information is required:

1. size of catchment;
2. modal* annual rainfall;
3. estimated runoff percentage.

Catchment production (m³) = \( \frac{A \times R \times P \times 10}{100} \)

where:  
\( A \) = catchment area (ha)  
\( R \) = modal annual rainfall (mm)  
\( P \) = estimated runoff (%)  

1 mm from 1 ha = 10 m³, hence the x 10 factor in the equation

An example:  
\( A = 30 \) ha  
\( R = 200 \) mm  
\( P = 15\% \)

Catchment production (m³) = \( \frac{30 \times 200 \times 15 \times 10}{100} \)  
= 9000 m³

* Modal annual rainfall is the annual rainfall that a station most frequently receives. It is always a lower figure than the average annual rainfall.
Estimation the runoff percentage is required to calculate a meaningful production figure. If in doubt, err on the low side and design the earthworks to handle any excess flows.

The risks of soil and vegetation degradation must be evaluated at the dam/catchment site before construction. Because livestock concentrations could lead to accelerated vegetation and soil loss, potential problem areas should be avoided.

2.2.1. Increasing catchment size
By constructing surveyed collecting drains away from the dam on a grade of about 0.25%, it is possible to harvest water that would otherwise by-pass the dam. By extending these drains it is sometimes possible to ‘steal’ runoff from neighbouring catchments. As there is some flexibility in the grade used for the drain, it is possible to avoid heavy timber that cannot be moved with a grader. The collecting drain must be constructed to allow for large flows of water that can occur during thunderstorms and also in a way that will minimise erosion.

2.2.1.1. Increasing catchment size
By constructing surveyed collecting drains away from the dam on a grade of about 0.25%, it is possible to harvest water that would otherwise by-pass the dam. By extending these drains it is sometimes possible to ‘steal’ runoff from neighbouring catchments. As there is some flexibility in the grade used for the drain, it is possible to avoid heavy timber that cannot be moved with a grader. The collecting drain must be constructed to allow for large flows of water that can occur during thunderstorms and also in a way that will minimise erosion.

2.2.1.2. Concentrating overland flow
Overland flow on the soil surface tends to be inefficient because of surface ponding and infiltration. To reduce these inefficiencies collecting drains, to intercept and concentrate these flows, can be constructed. Channelling of flow reduces transmission losses, hence increasing the runoff collected at the dam. These intercepting drains can either be discharged onto natural drainage lines or through a system of drains that direct runoff to the dam.

2.2.1.3. Increasing transmission efficiency
Some catchments begin flowing in the outer areas while it is raining but the water is lost before it reaches the dam. For example, drainage lines may disperse

Providing earth for the dam wall comes from within the area to be covered by water, the amount of water impounded will be the additional to the water held above ground level and the volume of the wall itself.

5.3. Catchment
The catchment feeding the waterway must produce enough runoff to fill the dam in all years.

Also see section on Catchment, in Excavated earth tanks

5.4. Foundations
Drill test holes with an auger over the whole excavation area to measure the depth of topsoil and check that clay is present; alternatively, use a backhoe. If large amounts of topsoil must be removed before clay is reached, the cost of the wall rises considerably.

Do not site a gully dam on:

- a gravel seam,
- a sand seam,
- ground-water seepage areas.

It is difficult to seal a dam wall built on rock and rock sites should be avoided where possible.

Soil used for the water holding part of a dam wall should contain about 25 per cent clay. However, significant improvements in water retention and bank strength can be achieved by compaction by a suitably ballasted static sheep’s foot or vibrating roller.
must be taken to ensure that the water from the overflow cannot erode the wall of the turkey nest.

4.5. Filling
The initial filling should be slow to allow the clay to moisten and seal. New turkey nests should be filled as soon as practical after construction. If left for a couple of seasons, the clay in the wall will dry out and on filling failure is more likely.

It is good policy to maintain turkey nests full even when not in use. This will greatly reduce internal silting caused by heavy rain on the dry steep banks.

5. GULLY DAMS
A gully dam is an earth wall put across a watercourse to impound water. Natural waterways or drainage lines are the usual sites for gully dams.

As gully dams impound water in a valley they require considerable care in siting and construction. A gully dam if correctly sited should have a storage/excavation ratio of at least 4:1. The higher this ratio the lower the cost per unit of water stored. The storage/excavation ratio is the volume of water stored divided by the volume of earth moved.

5.1. Site selection
The area must be surveyed to calculate the volume and depth of water that can be impounded and the volume of earth required for wall construction.

During the survey, pegs are placed at the ends of the proposed dam wall and around the edge of the area covered by water.

5.2. Design formula used
Volume of water stored above ground = area of the ‘triangle of water’ against the wall x 1/3 water reach.

\[ V = \frac{1}{2} \times L \times H \times R/3 \]

where:
- \( L \) = length of water on wall
- \( H \) = height of water on wall
- \( R \) = reach of water

The volume stored in the gully dam illustrated in Figure 12 would be:

\[ V = \frac{1}{2} \times 400 \times 200 \times 3 = 12,000 \text{ m}^3 \]

The volume of the dam wall illustrated in Figure 13 can be calculated as follows.

3. EXCAVATED EARTH TANK
The main type of dam employed in the pastoral areas is the excavated earth tank type.

When building a dam it is important to remember who is paying for the capital outlay. The contractor is employed to build the system to specification, thus ensuring the construction of an efficient and maintenance-free storage facility. The costs involved are high and the greatest savings can be made by employing an experienced dam-sinker significant savings may be achieved. Adequate supervision during construction is required to ensure that the dam is being built to design and that time saving short cuts are not at the expense of sound engineering principles.

The following is a checklist of the procedure that should be followed during the construction phase.
3.1. Before excavation

Clear the site by removing vegetation and any sand or gravelly surface soil that may form part of the banks or dam walls. Identify the location of the inlet pipe. Identify the centre of the dam by selecting a datum point that will not be disturbed during the building.

Rip the area that will form the banks and the walls.

Any preliminary earthworks that are required to key the wingbanks into the dam wall should be carried out at this time. Ineffective wingbank “keying” is one of the weak points in dam construction. With the use of “small” diameter inlet pipes it is essential that wingbank integrity be secured.

3.2. The excavation

The dam may now be excavated, ensuring that the predetermined batter slope is targeted from the outset. If the predetermined batter slope is not achieved the design depth will not be obtained and the system will lose efficiency.

Constructed batter slopes can be simply measured without the use of surveying instruments. Materials required to maintain a 3 in 1 slope are a spirit level and a piece of rod one-third the length of the level.

The heel of the spirit level is positioned on the batter slope to be measured and held horizontal, (check that spirit level bubble is central). If the rod cannot now be placed vertically between the toe of the level and the batter slope then the required batter slope is not being maintained.

3.3. Using explosives in dam construction

The use of explosives in dam construction is relatively new and experimental. The idea of using explosives to completely excavate soil has been discarded, as this technology appears to be more costly than conventional construction methods. However, there is a place for explosives in dam construction if used to loosen soil before excavation. The cost of bulldozing is such that by cutting the time spent ripping considerable savings are made in the overall costs. Blasting also tends

Scraper built turkey nests have a better success rate than those built by other methods. The main reason for this is the superior compaction offered by scrapers. Scrapers spread the layers of material and this is then driven over with successive loads achieving very good compaction, provided the operator is following a deliberate compaction strategy.

4.1. Planning and preparation

If at all possible, moist clays should be used as they allow much better compaction. Compaction is usually more important than the source material used in construction. The construction material is often blamed for failures when inadequate compaction is the real issue.

Before starting the bank, the base area must be stripped of topsoil. The base should then be lightly ripped or scarified and levelled. A layer of selected clay is then spread and compacted to seal the bottom of the turkey nest.

4.2. Pegging the wall

The outer and inner wall circumferences are pegged allowing over 300 mm extra on the inside diameter to make provision for over spill in construction and to maintain the calculated storage volume. The ideal outside batter is 4:1, but an economic compromise of 3:1 is satisfactory.

4.3. Construction

The topsoil from the borrow pit is stripped and placed around the outside edge of the base, or some can be stockpiled for spreading over the top and outside batteries on completion.

The wall is brought up to a height of 450 mm, compacting every 100 mm. At 450 mm a 100-150 mm deep trench is cut through the bank for the outlet pipe (75-100 mm diameter). The bulldozer blade or scraper tines are sufficient to cut to this depth. The trench is best cut with a fall to the outside of the bank so that the pipe leaves the wall close to ground level. Once the pipes have been joined and lined up, finely broken up clay (preferably dry) is packed around the pipe by hand. Clay (250 mm thick) is then placed over the pipes and well compacted. When this compacted dry clay becomes wet is will swell and seal the pipe(s) more effectively.

Construction then continues ensuring the best water holding clay is used on the inside of the bank, continuing to compact every 100 mm increase in wall height. When the wall height is reached, usually 3.3 m, the top is surveyed to check that it is level and the bank is shaped and smoothed.

On completion of the wall it is important to spread topsoil around the top of the bank. Encouraging vegetation growth greatly assists in erosion minimisation and so increases the longevity of the structure.

4.4. Overflow

An overflow pipe is essential, placed at least 300 mm from the top of small turkey nests or 600 mm on larger turkey nests. This is installed like the delivery pipe mentioned earlier, and should be of sufficient length to ensure that overflow water falls well clear of the turkey nest’s wall. The overflow can also be arranged on the outlet pipe by placing a tee in the inlet line and a pipe of the appropriate length standing upright.

Care
Water stored out front of the dam can also be pumped over the top with a high-volume/low-head pump to further increase storage, provided the inlet pipe has first been sealed.

### 3.8. Split Storage Systems

Split storage systems are used where dam depth is insufficient to satisfy evaporation losses and livestock consumption. This could be the result of a shallow saline water-table or the presence of sandy seams below the clay horizon.

Split storage systems consist of a shallow, below ground temporary storage dam and a circular turkey nest dam with above and below ground storage. Excavated material from the temporary storage dam is used to build up the walls of the turkey nest dam. Both dams should be excavated to the maximum depth thought safe. Inlet pipes should be fitted to both dams at ground level and the turkey nest inlet pipe should have a gate valve fitted. This valve should be closed when this dam is full to ground level. Water from the temporary storage dam is then pumped over the top into the turkey nest by way of a high-volume/low-head pump. A minimum of one metre free board should be established on completion of pumping into the turkey nest.

If there is sufficient slope in front of the turkey nest, the use of wingbanks as a temporary storage area may negate the need for a second dam. If this is the case, a soil borrow should be excavated at the front of the turkey nest. Material from this area is used to build up the walls of the turkey nest. This borrow area will also offer additional temporary water storage and can also be pumped into the turkey nest.

### 4. Turkey Nest Dams

Successful turkey nests depend on careful planning, construction and attention to detail.

---

*Figure 11. Split storage systems*

*Figure 7*
to break up the soil and mix it thoroughly. This lessens the possibility of leakage owing to small 'pipes' occurring in the soil profile.

The drilling pattern required varies from site to site depending on the type of soil and the moisture content. An example of a possible pattern for a circular dam is shown in Figure 7. With increased soil moisture the explosion will have a greater effect than if blasting in drier ground.

As a rule of thumb, the distance between blast holes should be about 5 m. The weight of explosives required for each hole is 4 kg per drilled metre depth. By using delay relay connectors (DRC) between each blasting circumference the blast will be from periphery to centre and the final shape of the loosened soil will be very close to that of the desired excavation. The DRC's produce "fraction of a second" time delays between detonations, assisting in blasting the dirt to the outside of the dam. The choice of ammonium nitrate and fuel oil (ANFO) as the explosive keeps costs to a minimum. It also facilitates ease in transport as the explosive elements are mixed on-site. The thorough mixing of 2.2 litres of diesel with a 30 kg bag of ammonium nitrate manufactures ANFO of required strength.

A booster charge is lowered into each hole on a length of detonating cord and the required amount of ANFO is placed on top of the booster. Trunk cord is used to connect all the charges and detonation is performed with a No. 8 detonator activated by safety fuse.

Explosives should be used only when a dam is being built on an 'hourly' basis, in dirt considered too hard to excavate without ripping, or when using a small station bulldozer.

Results from test drilling a site will determine if the use of explosives will be a cost effective alternative to ripping.

3.4. DESIGN SHAPES AND EFFICIENCY

Excavation costs dictate that the design of a dam must suit specific requirements. Once the depth of suitable soil is known, the design and life expectancies of various dam storages may be calculated. Dams with large base areas make poorer use of small inflows because the depth of stored water is less. It is of paramount importance to remember that water depth is by far the major contributor to the life expectancy of stored water.

Circular dams are the most cost-effective shape for stock watering purposes. For a dam of given depth, base width and baffle slope, circular dams provide less stored water than the conventional square dam but the effective storage life expectancy, in a drought is very similar, because of reduced evaporative losses. Any given inflow into the circular dam will create greater depth of stored water, thus increasing storage effectiveness. Therefore, a storage facility that is very comparable in performance is obtainable at lower cost.

Given dam design and the number of stock watering on it, it is possible to calculate monthly water usage and expected storage life of the dam.

- Seepage
  
  This will differ from dam to dam, therefore for the purpose of uniformity, seepage is assumed to be negligible.

\[
\text{Wingbank volume (m}^3\) = \text{Total wingbank length (m) x average cross sectional area (m}^2\)
\]

\[
\text{Wingbank cross sectional area (m}^2\) = \left(\text{Bank base width} - \text{bank top width}\right) \times \text{height}
\]

All sandy and gravelly material should be removed from the proposed wingbank site before construction. The surface areas on which the banks are to be constructed should be deep ripped longitudinally.

The wingbanks must be built from material sourced from the downstream side of the bank. The natural surface in front of the banks should not be disturbed; this particularly applies at the end of the banks at the point of overflow. Compaction of the banks during construction is essential to ensure there are no weak points and to reduce subsidence as the bank settles. The design height should be maintained along the full length of the bank. A surveyor's level is required to ensure this level is maintained; judgement by eye is not accurate enough.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure10}
\caption{Cross section of dam showing above ground storage.}
\end{figure}

At least one metre of free board should be maintained along the length of the bank (when water is flowing around the overflow to its maximum depth). On completion of the banks a dozer should deep rip the disturbed borrow pit area behind them to facilitate water penetration and provide seed niches to assist the revegetation of the site.

3.7. ABOVE GROUND STORAGE

Above ground water storage is possible where a dam is built on a slight slope, by fitting a shut-off valve on the inlet pipe. This allows the volume of water stored to be in excess of the actual excavated capacity. Correctly surveyed and constructed wingbanks can hold up to 0.5 metre depth of water above ground level on the front wall of the dam. Water will flow through the inlet pipe until water levels, inside and outside the dam are in equilibrium. The shut-off valve should be closed when this occurs.

The suction forces in a 150 mm, or larger, diameter pipe are considerable so extreme caution should be exercised when approaching an inlet pipe that is still flowing.
b) temporarily store runoff prior to transference via the inlet pipe to the dam;

c) allow for some above ground water storage. This should not exceed 0.5 metre. Wingbank construction costs become excessive beyond this depth of storage;

d) direct runoff, which is in excess of dam storage capacity to the overflow(s);

e) temporarily ‘still’ runoff water before it is transferred into the dam via the inlet pipe. The stilling allows for silt deposition within the temporary ponding area (and not in the dam).

Overflows should not confine water to a narrow channel. A wide flat overflow allows water to move slowly away from the dam with minimal erosion risk. Care should be taken to ensure water does not run back into the borrow pit down-slope of the wingbank. A stable surface is required for the overflow such as a heavily vegetated area or a very flat drainage zone. Steep slopes and bare erodible soils should be avoided. If necessary, the overflow should be protected from disturbance by appropriate livestock fencing.

The approximate volume of water held by the wingbanks can be calculated as follows:

\[
\text{Approximate volume of water ponded (m}^3) = \frac{1.05 f (r_1 + r_2)^2}{2} \]

where:

- \(r_1 + r_2\) = wingbank lengths
- \(h\) = depth of water at inlet when overflow commences
- \(f\) = fraction of circle covered by temporary water storage.

Example:

- wingbank lengths = 140 m and 160 m
- depth of water at inlet = 0.5 m
- fraction of circle ponded = 4/10

\[
\frac{1.05 \times 0.5 \times 0.4 (140 + 160)^2}{2} = \frac{0.21 (300)^2}{2} = \frac{201}{2} \times 150 \times 0.21 = 4725 \text{ m}^3 \text{ temporary storage volume}
\]

### Section 3.4.1. Batter slope

Regardless of dam size, the batter slope should be as steep as possible to ensure that for any given volume the dam depth is maximised. For a given volume, steep batters create less water surface area. Most dam sinking machinery is capable of constructing a 3:1 gradient, or steeper. Steep grades minimise stock bogging as animals do not wade into the water to drink.

### Section 3.4.2. Base size

The base area of a dam also influences its performance. A small basal area will create (together with other factors) a compact storage facility that best uses small runoff events. It will maximise storage depth for any given volume harvested.

### Section 3.4.3. Formulae for calculating volume

Square and oblong dams:

\[
\text{Volume (m}^3) = (A + B + \sqrt{A \times B}) \times D/3
\]

where:

- \(A\) = top surface area (m\(^2\))
- \(B\) = base area (m\(^2\))
- \(D\) = depth (m)

Circular dams:

\[
\text{Volume} = \frac{0.2619 \times \text{depth} \times [(Td^2 + Bd^2 + (Td \times Bd)]}{3}
\]

where:

- \(Td\) = top diameter (m)
- \(Bd\) = base diameter (m)

**Examples**

Square dam:

- top side length = 50 m
- base side length = 14 m
- depth = 6 m

\[
\text{Volume} = (A + B + \sqrt{A \times B}) \times D/3 = (50 \times 50 + (14 \times 14) + (50 \times 14))/3 = 2500 + 196 + 700 \times 6/3 = 7396 \times 2 = 6792 \text{ m}^3
\]
Circular dam:
Top diameter = 56 m
Base diameter = 20 m
Depth = 6 m

Volume = 0.2619 x depth x \([Td^2 + Bd^2 + (Td x Bd)]\)
= 0.2619 x 6 x \([56^2 + 20^2 + (56 x 20)]\)
= 0.2619 x 6 x \([3136 + 400 + 1120]\)
= 1.5714 x [4656]
= 7316 m³

Base diameter = 20 m
Depth = 6 m

Volume = 0.2619 x depth x \([Td^2 + Bd^2 + (Td x Bd)]\)
= 0.2619 x 6 x \([56^2 + 20^2 + (56 x 20)]\)
= 0.2619 x 6 x \([3136 + 400 + 1120]\)
= 1.5714 x [4656]
= 7316 m³

### 3.5. Piped Inlets

Correctly designed and installed piped inlets are cost-effective in minimising batter erosion and flow of catchment debris into the dam. Piped inlets minimise dam volume reduction by siltation that causes depth loss and a resulting increase in surface area of the stored water. This increases evaporation and reduces storage life.

Piped inlets are installed in conjunction with adequate wingbanks. The function of the wingbanks is to temporarily pond catchment runoff. This temporary stilling causes any silt to settle, leaving silt free runoff to enter the dam via the inlet pipe.

The design diameter of the inlet pipe is dependent on the capacity of the wingbanks to provide temporary water storage. The smallest practicable diameter inlet pipe should be selected. Large inlet pipes do not create enough time for the silt to settle. With the correct combination of pipe size and temporary storage area, the need for a silt pit is eliminated. A single 150 mm diameter inlet is usually adequate for dams of less than 10,000 cubic metre capacity. The discharge rate for 150 mm diameter pipe on a 5:1 slope is 310 cubic metres per hour. This flow rate is sufficient to fill a 10,000 cubic metre dam from empty in a little more than 32 hours. Dams with capacities greater than 10,000 cubic metres may require two 150 mm diameter inlet pipes or a single larger diameter pipe.

#### 3.5.1. Pipe types

PVC piping is generally recommended, as it is relatively inexpensive when compared with similar sized alternatives. PVC is light, easy to handle and is corrosion-free. Once buried it is very durable. However, PVC is ultraviolet light sensitive and should not be exposed to the sun. Additionally, unburied PVC pipe vibrates excessively during inflows and may shatter.

A major advantage of PVC is the ease with which individual lengths can be joined, without leakage occurring. Should leakages occur, water will tunnel along the outside of the inlet pipe, causing erosion of the dam front wall. If the leakage is serious the front wall may be undermined and deposited into the dam, together with the inlet pipe. This has occurred in pastoral areas where asbestos/cement culvert pipes have been used. These pipes are not recommended for dam inlets because of the difficulty in making joints permanently waterproof. Open fluming is also failure prone owing to overtopping during large inflows. This overtopping undermines fluming and eventually causes structure failure.

#### 3.5.2. Installation

Inlet pipes are normally installed during dam construction, but they can also be added to established dams if the dam is dry and/or having the silt removed.

When the excavation has been completed the trench for the inlet pipe should be excavated. The pipe should run from ground level outside the dam wall to within one vertical metre of the dam base. One method of installation is for the dozer to push from inside the dam piling the dirt out in front of the proposed inlet. When the trench has been built the dozer can construct the wingbanks allowing time to place and secure the pipe.

When the pipe is secured in position the dozer covers the pipe and rebuilds the wall. Placing a bag over the end of the pipe will prevent it from filling with dirt. To ensure that the position of the end of the pipe can be located, sighter posts that will not be disturbed during the covering operation should be used. If the pipe is placed in the centre of the channel the dozer can safely backfill the channel with 30–50 cm of dirt along the full length of the pipe, in the knowledge that the tracks will not run over the pipe.

The pipe should now be buried for its full length. This secures the pipe in position and reduces the chances of vibration. Vibration promotes water seepage at joints, promoting a ‘blow out’ (see above).

By using the sighter posts the dozer can safely push the dirt away from the pipe until the end is almost exposed. The remaining dirt can be removed by shovel.

To complete the inlet a cement apron should be constructed to protect the end of the pipe. Installation of a mesh guard is recommended (equivalent in area to 10 times the pipe’s cross sectional area) to prevent debris blocking the inlet.

At the outfall a concrete slab or similar should be constructed to stop water scouring the floor of the dam.

### 3.6. Wingbanks and Overflows

The purposes of wingbanks are to:

a) direct catchment run-off to the inlet pipe;