Section 3: Optimising dam construction for multiple benefits

This section provides guidance on the construction and renovation of dams for multiple benefits, particularly for the purpose of optimising water quality and persistence, and supporting biodiversity.

Dam construction is highly dependent on topography, soil type and many other factors that require expert consideration, so the advice in this guide should be regarded as general in nature. We recommend that NSW Soil Conservation Services, Agriculture Victoria or a professional dam engineer/builder be consulted before construction begins.

Additionally, contact your regional water authority for regulations and permits for new dam construction.

Key features of a well-designed farm dam

Building a new dam, or undertaking significant works on an existing dam, is an opportunity to create an asset for your farm that should last for several decades. However, the value and longevity of your asset depends on a set of factors including: construction quality, water storage capacity, site appropriateness, impact of stock on the dam, vegetation around the dam and biodiversity supported by the dam.

This section highlights the key features of a dam and what needs to be considered to ensure maximum performance from a newly constructed or renovated dam (Figure 6).

Dam wall, bank or embankment

The dam wall is usually built using the material excavated to create the dam storage. The wall is an essential component of the dam's ability to hold water, and must be compacted during construction. Choosing a site with soils that are appropriate for building the dam wall is particularly important.

The topsoil under where the dam wall will be built must be removed and set aside during construction, to avoid creating a leaky layer of earth under the wall. Once the wall is built, the topsoil should be returned to the top of the dam wall, enabling planting of grasses and other ground covers. Don't plant trees on the dam wall, as they can destabilise the bank and cause leaks.

Crest

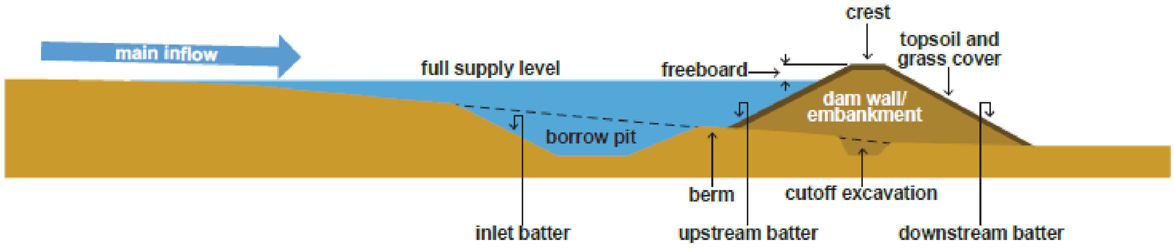
The top of the dam wall is the crest, and should be at least 3 metres wide.

Borrow pit

The excavated pit that forms the bulk of the dam's water storage capacity. All excavated areas should be covered by water once the dam is full, to minimise erosion.

Dam borrow pits are vulnerable to silting up over time, reducing the storage capacity of the dam. As well as enhancing overall storage, deeper dams have a better capacity to resist evaporation during dry times, so siltation can pose a significant risk to a dam's performance. This can be reduced through enhancing fringing vegetation that will filter inflow and minimise sediment flow into the dam, as well as minimising stock disturbance on the dam edge.

Cross section:



Aerial view:

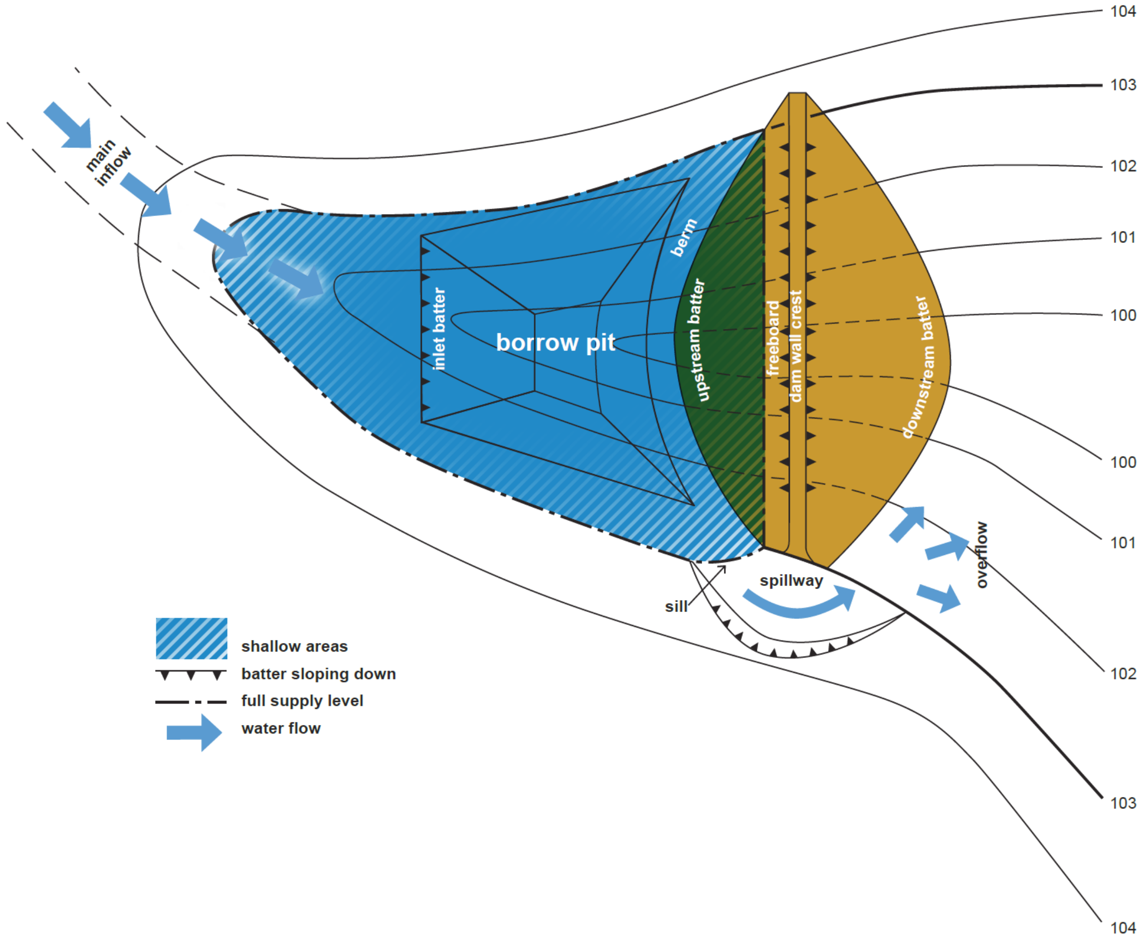


Figure 6: Key features of a properly constructed farm dam.

Batter

A batter is a receding slope – in this case, the slopes that form the inside of the dam storage, as well as the faces of the dam wall. A battered dam wall provides a wide base to support the weight of the water behind it. The batters of most concern in building a dam are:

- Inlet batter – upstream cut of the dam's excavation area. This is the batter down which water flows into the dam when it is filling. The inlet batter can be vulnerable to erosion if the water level falls sufficiently to expose it (see Figure 9).
- Upstream batter – upstream face of the dam wall. This is the batter that holds the water in the dam.
- Downstream batter – downstream face of the dam wall. This batter generally won't have water against it.

The slopes of the dam wall batters should be 2.5-3 horizontal to 1 vertical – in other words, for every metre of height, the wall should step back 2.5-3 metres horizontally. As dam sizes become larger and the depth of water stored against the wall becomes deeper so the batter slope needs to be shallower – a ratio of at least 3 horizontal to 1 vertical.

Berm

A flat area between the borrow pit and the upstream batter of the dam wall which helps provide structural support to the embankment.

Cutoff trench (keying-in)

A trench below the foundation base of the dam wall that is, like the embankment itself, impervious to water. This helps prevents seepage of water underneath the dam wall. Incorporating a cutoff trench is known as "keying in" – ensuring the dam wall is "keyed in" to the clay beneath it. This is an important part of any dam building project.

Downstream batter toe

The downstream batter toe refers to the edge of the downstream batter where it connects to the original ground surface. The toe is the point where the wall base is widest and is located at the farthest point downslope from the dam. It is often the point where seepage flows from under the wall will exit to the surface. It is a point that should be regularly inspected for signs of the dam leaking. If the seepage is cloudy then advice should be sought for guidance on if the dam is going to tunnel and/or break.

Freeboard

Height from the top water level to the top of the dam wall. The freeboard should be at least 1 metre.

Main inflow

The inflow area of the dam should ideally have a shallow gradient, so that water moves into the dam slowly and the dam does not get too deep too quickly. This shallow gradient also allows for the growth of plants that can handle periodic inundation and will help filter inflow water.

In addition to a shallow gradient, the creation of a shallow shelf in the inflow area will further support the growth of aquatic vegetation and attract a range of wildlife. This area should be less than 2 metres deep at full water level, to support vegetation and wading birds. In drier times when the dam level falls, this area may become ephemeral (temporary), which can also provide habitat for a different group of animals and plants.

Spillway

A spillway allows the exit of overflow water that would otherwise go over the dam wall or erode a new channel around the embankment. Most farm spillways are an excavated level channel, lined with grass to prevent erosion, but sometimes spillways are lined with concrete or rock, and can be supplemented with a trickle pipe through the dam wall. It is important to avoid woody vegetation growing on spillways, where it can impede the flow of water and cause erosion.

Sill

The sill is the level edge over which water overflows from the dam into the spillway. The height of the sill in relation to the structure governs the top water level if pipes are not used, and is therefore important in determining the freeboard.

Overflow

A wide, shallow area below the spillway enables overflow water to spread out, minimising erosion risk, hydrating a greater area and enabling the growth of plants that thrive with occasional inundation.

Trickle pipe

A trickle pipe through the dam wall can be helpful for gradual return of smaller amounts of water to the downstream catchment, along the same line as the water would have flowed originally. This can help keep the spillway, overflow and paddock dry in between larger overflow events.

Shallow areas

Shallow areas at the edges of the dam will, when the dam is full, provide important habitat for biodiversity. Shallow areas will also support the growth of fringing vegetation that may be suited to a range of water depths or periodic inundation. Supporting the growth of this vegetation in shallow areas during wet times will help minimise evaporation. During drier times, the water may retreat to the deeper parts of the dam.

Fencing

To improve water quality and ensure longevity of the dam structure, it is of paramount importance that dams be fenced to exclude stock access. Water can then be reticulated to where it is needed. Fencing dams helps in the following ways:

- Protects the structure of the dam (dam wall, spillway and banks) from erosion caused by heavy livestock.
- Allows fringing vegetation to grow, stabilising dam banks and filtering sediment and nutrients from water entering the dam.
- Reduces or removes the negative impacts of livestock on water quality, such as fouling of the water through defecation and disturbance of the dam edge and banks.

Note that a fenced dam should still have an access gate into the fenced area for future management access needs. See section 2 for more information on fencing.

Grassed buffer zone

A grassy buffer zone around the dam, particularly in inflow areas, will help filter the water and capture paddock run-off such as sediment, animal dung and other pollutants. This will improve water quality and help prevent sediment build-up in the dam, minimising the need to de-silt the dam in the future.

Air space

The part of the storage volume that exists between the level of a low flow outlet pipe and the spillway level. If a pipe is installed, it is usually set about 300mm below the spillway level. This space fills in flood flows. As soon as water reaches the pipe level, the pipe starts to discharge. If the flood is large enough then the flows will eventually discharge through the spillway. The flows through the dam will drop back to the pipe inlet level and the flow stops. The combination of the pipe and the air space is designed to take flow pressure off the spillway in large flood flows.

Full supply level

The dam's capacity when it is full. The dam's maximum capacity is usually determined by the height of the spillway sill.

Planning a new farm dam

This section will outline:

1. Water storage requirements
2. Required catchment area
3. Regulations on farm dam construction
4. Suitable sites for constructing a stable dam with optimum storage to excavation ratio

See Appendix 1 for a worked example of applying these principles to a farm in Illabo, NSW.

Water storage requirements

Undertaking farm water planning as outlined in Section 1 provides a picture of the water storage needs of a farm. When planning a specific dam, undertake the following steps:

1. Calculate water consumption according to use (e.g. stock, irrigation, house and garden) over a year. Sample tables for NSW are included in Appendix 1. Calculate the total amount of water expected to be required in a single year.

2. Work out the Critical Storage Period – how long the water needs to last for (consider dry times such as drought). The Critical Storage Period effectively provides a multiplication factor – if the period is two years, then the figure obtained in step 1 should be doubled.

3. Evaporation rates can vary significantly – seek local advice on expected evaporation rates. A good rule of thumb is that most dams will lose one metre per year (from the total dam surface area). This means that for 4ML of water, a 6ML dam is likely required.

Dam size required = annual water consumption x Critical Storage Period x Evaporation allowance

Required catchment area and peak discharge

Catchment yield

There is no point building a large dam, only to find that the catchment will not yield enough water to fill it. The Catchment yield equation can be used to determine the amount of runoff that can be collected from a catchment of a particular size.

Catchment yield (kilolitres) = Area (ha) x Rainfall (mm) x Percentage runoff (%)

To work out the area required to deliver a particular volume of water, the equation can be rearranged as follows:

Area (ha) = Catchment yield (kl) / (Rainfall (mm) x Percentage runoff (%))

Percentage runoff is the percentage of rainfall that runs off the ground, which is based on the soakage ability of the soil. See Table 6 in Appendix 1 for percentage runoff figures for different soil types.

Peak discharge and spillway width

It is also vital to understand the flood flows that a catchment can produce, as this will assist in forecasting how soon the dam is likely to fill as well as the spillway width required. Note that it is much better to have a spillway that is too wide than too narrow. Longer, wider spillways provide good opportunities for biodiversity improvements.

Dam construction regulations

Landholders have a right to access a share of water, but these rights are regulated. This means that in some cases dams can be constructed without a license, while in others a license is required.

It is also advisable to contact the NSW Department of Primary Industries or relevant authority in your region for advice on maintaining fish passage through dam structures.

NSW

In central and eastern NSW, the NSW Farm Dams Policy allows for landholders to capture and store the first 10% of runoff (the *harvestable right*) that occurs on first and second order streams on a property, without a license.

The Maximum Harvestable Right Dam Capacity (MHRDC) is the total dam capacity allowed under the harvestable right for a specific property, and takes into account rainfall, variations in rainfall pattern and evaporation rates. To calculate the MHRDC for your property visit www.waternsw.com.au and search for “harvestable right”. (Ensure you know the capacity of existing dams on the property, as these will contribute towards your MHRDC and must be taken into account when working out the maximum size of any new dams.) Appendix 1 provides an example calculation of MHRDC in NSW.

To determine whether your proposed dam is located on a first or second order stream visit bit.ly/nswhydrodata (also see Appendix 1, Figure 10).

In NSW, dams cannot be constructed on or within 3 km of a RAMSAR wetland site. There are 12 RAMSAR wetland sites in NSW (check the NSW Department of Planning, Industry and Environment website).

Victoria

In Victoria, dams constructed on a waterway require a license, while dams that are *not* constructed on a waterway may require a license depending on size and wall height.

For details visit www.water.vic.gov.au/water-for-agriculture/taking-and-using-water/private-dam-licensing.

Please check the relevant regulations for harvestable rights and dam construction as applicable to your state and region.

Site selection

The next step is to find a suitable dam site that meets regulatory requirements and also:

- Utilises suitable water holding soils
- Has a cost-efficient storage to excavation ratio
- Takes into account environmental factors such as erosion, supporting biodiversity and managing stock access.

It is easier to build large dams in flatter country, while steep country can mean opportunities to build dams are limited.

Soil composition and compaction

The ideal soil for dam construction has the following composition:

Sand	40-60%
Silt	10-20%
Clay	20-40%

It is ideal to have some minor dispersible clay present so that the clay will move between the sand and silt particles to help form a water tight seal. Ideally the clay should not be prone to excessive shrinking or swelling, to minimise the development of cracks in the wall.

A suite of basic soil tests should be undertaken to determine if the soil will hold water, or if additional measures are required. If dam must be built out of material that is outside the ideal range it is recommended that a plastic liner be placed in the wall of the dam, or the incorporation of gypsum at rate of $1t/750m^3$ of earth moved. See Appendix 1 for additional information on soil testing.

The soil needs to be compacted (this is usually done with a roller and a water cart on site) to keep the dam wall material close to optimal moisture content. Compaction is critical to expel air from soil pore spaces, with the remaining water helping fine particles to stick to the larger silt and sand particles. The compaction should ideally occur in layers 150-200mm thick that are compacted at optimum moisture content by a roller to ensure that compaction effort is spread evenly through each layer. The moisture and compaction effort also helps the dispersed clays to move into the old air pore spaces.

Storage to excavation ratio

To minimise costs when building a dam, choose a site that will enable high water storage for minimal earth moving costs. The excavation of the dam storage should provide enough earth to build the dam wall. This relationship is the storage to excavation ratio.

These considerations necessitate careful site selection to ensure that sufficient storage can be created without the need for an enormous, expensive dam wall.

Most agricultural dams are created by the building of an embankment using material excavated to create the dam pit. The best storage to excavation ratio is found by damming a narrow gully that widens upstream of the dam, and where the slope of the gully floor is less than 2% (Figure 7).

Alternatively, a hillside dam where the hill slope is less than 5% works well (Figure 8). At this slope the extra free water reaches its maximum (the area highlighted in blue in Figure 6). As slope increases beyond 5% the amount of extra free water decreases and extra earth is required to build the wall – storage to excavation ratio thus falls and costs become inefficient (Figure 9).

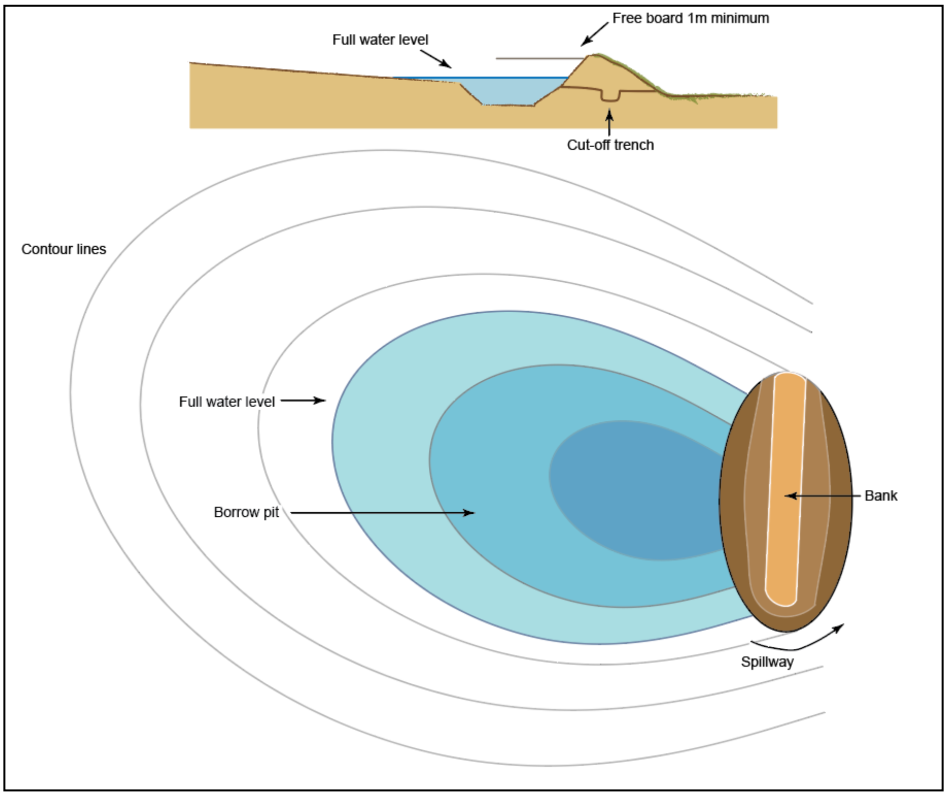


Figure 7: Typical configuration of a gully dam designed for multiple benefits. Note the cutoff trench underneath the dam wall.[1]

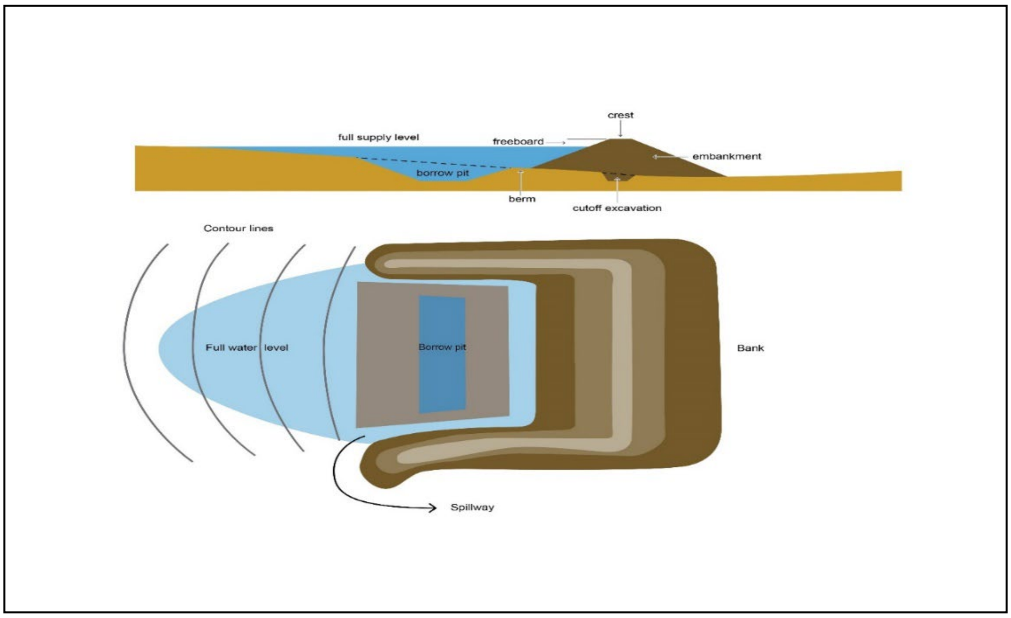


Figure 8: Typical configuration of a hillside dam.[2]

[1] *Rural Earthmoving in the Sydney Drinking Water Catchment* (2014, Sydney Catchment Authority).

[2] *Rural Earthmoving in the Sydney Drinking Water Catchment* (2014, Sydney Catchment Authority).

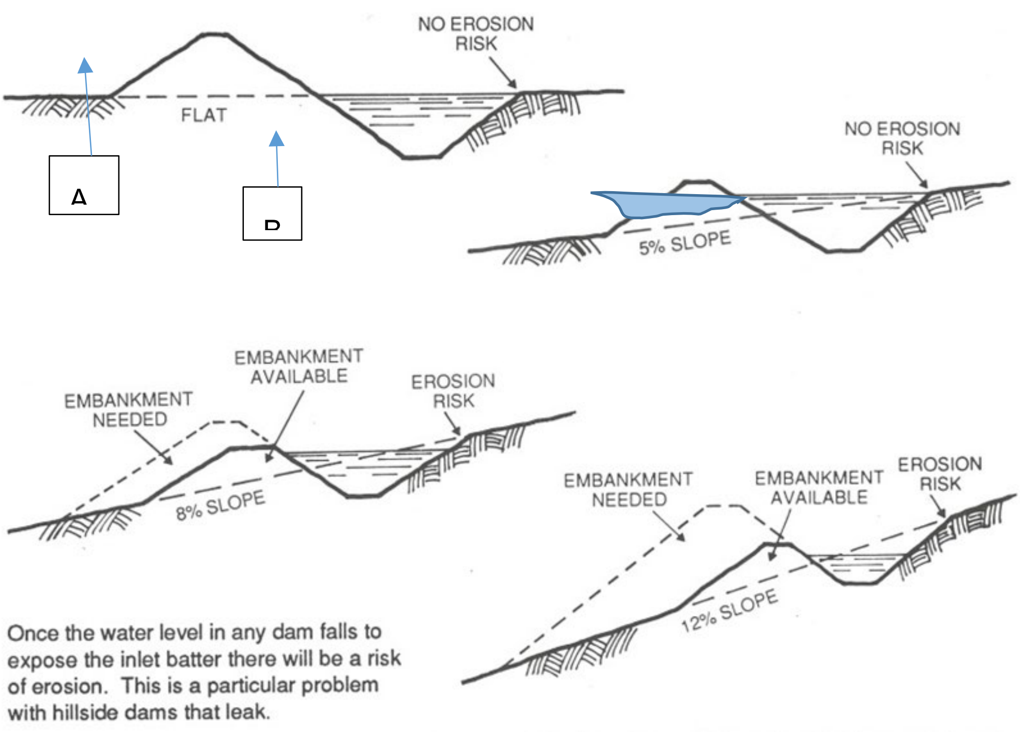


Figure 9: The storage to excavation ratio becomes increasingly inefficient for hillside dams built on slopes greater than 5%. Greater slopes also mean a greater risk of erosion on the upstream side of the dam.[3]

For both gully dams and hillside dams, the shallow area at the back of the dam can be used for planting sedges, reeds and grasses.

Other site selection considerations

There are a number of other factors in dam site selection that will help minimize environmental impacts caused by a dam and enable the dam to contribute positively to biodiversity.

Factors to consider include:

- Is the area below the dam site suitable and stable enough to return excess flows back to the flowline without erosion?
- Does the chosen site provide the opportunity for shallow areas in the dam? Shallow areas are particularly important for supporting wildlife and enabling the growth of fringing vegetation that will help filter inflows, keep the water cleaner and support biodiversity.
- Can the dam be easily fenced to exclude stock? For example, is it close to an existing fence line that can be extended? Excluding stock from a dam enables the growth of fringing vegetation that will shelter and filter the water, and prevents stock from pugging the dam edge and fouling the water.

[3] Greentree, D & Jackson, L (1991) *Earth Movers Training Course - Unit 9 Farm Dams*. Soil Conservation Service of NSW.

- Is the site suitable for enabling alternative access to water for stock – either by building a hardened access point for stock, or by piping water to a trough or troughs?
- What impact will the dam have on downstream water catchments? Following the dam building regulations in your region will mitigate these impacts, but bear in mind the potential impact on riparian areas or other dams downstream on your property.

Further resources for farm dam design and construction
Harris, G (1989) Water Supply and Farm Dam Construction, Soil Conservation Service. Nelson, KD (1985) Design and Construction of Small Earth Dams, Inkata Press. O'Connor, J & Yiasoumi, B (2009) Primefact 781. Building a farm dam. NSW Department of Industry and Investment.

Enlarging an existing dam

Undertaking farm water planning can indicate a need for increased water storage capacity in the form of dams. Enlarging an existing dam – particularly one that may require maintenance to address other issues – can be a good way of achieving increased storage without building a new dam.

However, it is important to note that enlarging dams increases a farm's water holding capacity, so may require a license depending on the regulations for your area.

For example, in NSW, dams on 1st or 2nd order streams can be enlarged as long as the farm remains within its harvestable rights. Dams on a 3rd order stream that were built before 1999 are allowed to be maintained, but cannot be enlarged without a license.

A dam construction expert should be consulted before dam enlargement commences.

Dam maintenance and de-silting

Dams should be regularly inspected and any dam maintenance issues addressed to avoid extensive repair work in the future.

Check for the following dam maintenance issues and address them early[4]:

- Is the dam wall leaking? Inspect the dam wall toe (where the wall meets the ground outside the dam) for signs of leakage. Patches of green grass that remain even when the rest of the paddock has dried off can indicate seepage through or under dam walls.
- Are there cracks along the dam wall? This can indicate slumping of the wall, and should be assessed by a professional.
- Has the depth of the dam been reduced due to a build-up of silt? If so, the dam will now be holding less water.

[4] The material in this section is based on Agriculture Victoria's 'Maintaining your farm dam' (https://agriculture.vic.gov.au/farm-management/water/managing-dams/maintaining-your-farm-dam) and South East Local Land Service's 'Farm Water Series' videos (https://www.lls.nsw.gov.au/regions/south-east/key-projects/farm-water)

- Has stock access to the dam caused tracking and erosion on the banks or the dam wall?
- Has the dam wall eroded? The wall may need to be built up or widened, or the dam batters re-built to obtain the correct slope.
- Has the freeboard been reduced? There should be a minimum of 1m vertical height between the full water level of the dam and the top of the dam wall.
- Are rabbits burrowing in the wall or banks? This will undermine the dam's integrity, so it is important to manage rabbits, dig out burrows and re-pack with clay-based material.
- Has the dam sill eroded, meaning that the dam is losing water before it is full?
- Is the spillway well-vegetated with grass? Is it clear of debris or other material that could impede the flow of water?

Drought can be a good time to undertake maintenance, if water levels have fallen significantly and the dam is not in use.

Things to consider when de-silting a dam:

- Move the silt from the base of the dam to the back of the dam, and use it to create shallow shelves for aquatic plants to establish on.
- Once the silt has been removed and clay is reached, use some of this clay to re-seal the inside of the dam wall if required.
- If the dam is not already fenced, consider fencing it to minimize inflow of silt in future.

A dam that is fenced and well-vegetated is likely to require less maintenance, for two reasons: the vegetation zone around the dam will help filter inflow and reduce siltation, and stock exclusion will prevent wear and tear on the banks and dam wall.