dam safety guidelines

Part 2: Guidelines for the building of minimal hazard dams

Introduction

This part is a guide to the design, construction and maintenance of dams classified as being of minimal hazard. It mainly applies to new dams. While the same principles can be applied to existing dams, it is seldom practical to upgrade existing small dams to meet modern design criteria. Using this guideline to review the adequacy of existing structures may result in undue cost outlays for the owner, and is not recommended.

In general a **minimal hazard dam** is defined as a structure that, in the event of failure, would not cause significant or extensive damage nor represent a significant threat to life or the environment. This guideline is not intended for designing culverts, flood detention systems or stopbanks.

The design concepts in Part 2 do not represent optimised solutions: these can only be achieved by specific design input for each particular site. Specialist engineering design input is likely to result in a design more optimum than that obtained directly from this guideline.

The main criteria for determining whether a dam falls within the **minimal hazard** category are:

1 **Dam height:** no greater than 4.0 metres

2 **Water depth:** no greater than 3.0 metres including flood depth

3 **Stored volume:** no greater than 20, 000 cubic metres

4 **Catchment area:** no greater than 20 hectares (0.2 square kilometres)

If there is any departure from the concepts in this part of the guideline, or if special circumstances need to be catered for (for instance, road access across the dam or existing geological problems), specialist advice should be sought, such as that from a registered engineer.

This guideline only covers dams where earth is the construction material. The vast majority of small dams are made of earth.

1.0 Data Collection

Before designing or building a dam some important quantities need to be defined to ensure that the dam is safe and that it meets the owner's requirements.

- catchment area
- catchment characteristics
- dam site profile
- annual rainfall

1 **Catchment area** – This should be determined to an accuracy of within 15%. This can usually be done using standard NZMS 260 1:50,000 contour maps.

The catchment area is needed to estimate how much water is available for storage and potential flood sizes.

2 **Catchment characteristics** – The shape and topography of the catchment affects the size and duration of floods generated during rainfall. Steepness, soil type and vegetation type need to be recorded.

3 **Dam site profile** – The approximate profile of the proposed dam site and reservoir is necessary to determine the size of storage, or the dam height required to achieve a required volume. Valley side slopes, stream gradient and the width of the valley floor need to be recorded.

4 **Annual rainfall** – The annual rainfall in the vicinity of the dam is the most important factor for determining the potential yield from a catchment. It is pointless building a dam to store 50,000 cubic metres a year if the catchment will only supply 20,000 cubic metres each year.

2.0 Dam concept

The dam concept can be described as the overall type, purpose and size of the proposed dam, as well as possible effects. Questions to consider include:

1. What will the dam be used for?
2. What will any water or other stored material be used for?
3. Will the storage be permanently full, or will levels fluctuate up and down?
4. How much stored water will be required?
5. Is there sufficient stream flow to meet my needs?
6. If water is to be taken from the dam, how will this be achieved?
7. Will the extent of flooding caused by the reservoir affect others or myself ?
8. How can provision for a spillway best be achieved for a given site?
9. Will the dam and ground around it provide an adequate seal?
10. How will / provide for any permanent flow bypass?

These questions must to be answered during the design process. Additional questions may also arise. Often examination of other dams in the area will provide useful background knowledge for answering these questions.

3.0 Dam components

A dam consists of several main components which must work together to ensure safe operation of the structure. Often it is the connection or interface between the different components that are the weak points in the dam design. The main components of a dam and the design criteria for each are:

- Storage
- Foundation
- Embankment
- Spillways
- Pipes and conduits

In many situations the criteria given below could be unduly conservative. Obtaining expert engineering input will typically result in a more optimum, and hence cheaper design by addressing site specific issues.

3.1 Storage

The purpose of most dams is to store water for use. The volume of storage and extent of flooding caused by the storage must be assessed. In the case of decorative ponds and dams, the volume of storage may not be an issue.

To determine the approximate characteristics of the dam storage a calculation guideline is provided in Figures 2.6 and 2.7 at the back of this part of the guideline

3.2 Dam foundation

The foundation of a dam is the natural soil or rock on which it stands. A clean stable foundation of adequate strength is vital for dam durability and performance. An adequate seal must be formed to reduce leakage from the dam - it may not fill or else the seepage may cause instability.

Key foundation requirements are:

- remove all topsoil and organic material from beneath the dam footprint
- remove any soft materials like peat or swampy deposits (unless expert engineering advice is obtained on the design)
- excavate a cutoff trench or 'key' under the dam, more-or-less under the crest line of the dam. The cutoff should extend a minimum of l.0m into firm natural material, be at least 3.0 m wide and have batter (side) slopes no steeper than 1 vertical to 1 horizontal (1 in 1). Extend the key right across the valley and up the side to at least the full water level
- pipe any springs or seepages encountered in the downstream half of the dam footprint to the downstream toe.

3.3 Embankment

The dam embankment, or fill, forms the blockage behind which the stored material accumulates. The embankment must be formed from clean clays and/or silts free of topsoil or vegetation. The fill should be placed at a consistency and moisture content so as to achieve high compaction standards.

The embankment profile should meet the following minimum standards:

Crest

- width to be not less than 3.0m if not used as a crossing
- width to be not less than 4.0m if used as a crossing
- surface to be protected by metal or other suitable material.

Slope angles

The upstream and downstream face should be no steeper than:

- 1 vertical to 2 horizontal for dams under 1.5m in height
- 1 vertical to 2.5 horizontal for dams above 1.5m in height.

Additional height

An allowance for settlement of the dam fill should be made by slightly increasing the dam height by an extra 10%.

Note: Tracked vehicles should not be used for compaction of dams greater than 2.5m in height.

Fill volumes

The volume of fill required to build a dam increases rapidly with height. The cost of the dam will similarly increase. Normally, fill for the dam embankment is taken from inside the area that will become the storage reservoir. This increases the volume of stored water behind the dam without the need for increasing the dam height.

Approximate fill volumes can be estimated using the method in Figures 2.8 and 2.9.

3.4 Spillways

Adequate spillways are crucial for the safe operation of dams. Two spillways should be incorporated into the dam design - normal (service) and flood spillways. In some instances this may be impractical, in which case specific design input will be required. Wherever possible the spillways should be constructed in firm natural ground to the side of the dam. The gradient of the spillways should be kept as flat as possible.

1 **Normal or 'service' spillways**

This spillway takes the normal stream flows. Set the inlet of the service spillway at the normal full storage water level and size it to take several times the mean winter flow.

The service spillway should consist of:

Spillway Type		For dams with a catchment	
		less than 20 hectares	Between 20 and 40 hectares
Either a pipe	○	200mm diameter	300mm diameter
or a½ round flume *	∪	400mm wide	600mm wide
or similar sized permanently (eg concrete) lined channel	⊔	eg 250mm square	eg 400mm square

Figure 2.1: Spillway Type and Typical Dimensions

* If a flume is to be used; a single section of pipe or similar should be installed at the inlet to limit the flow in to the flume.

Construction standards:-

Bed the downstream portion of the piped spillways from the dam crest onwards, onto a suitable drainage material such to minimise erosion/dissipate energy.

Keep the gradient and orientation of the spillway as consistent as possible. Changes in direction can cause the flow to jump out of flume spillways or damage pipe spillways.

Site the inlet of the spillway so as to limit the possibility of blockages.

Locate the outlet clear of the downstream toe of the dam and align it to direct flow into the stream downstream of the dam. Position the outlet so as to minimise erosion. Discharging the flow into an old trough set in the ground, or onto large boulders can help achieve this.

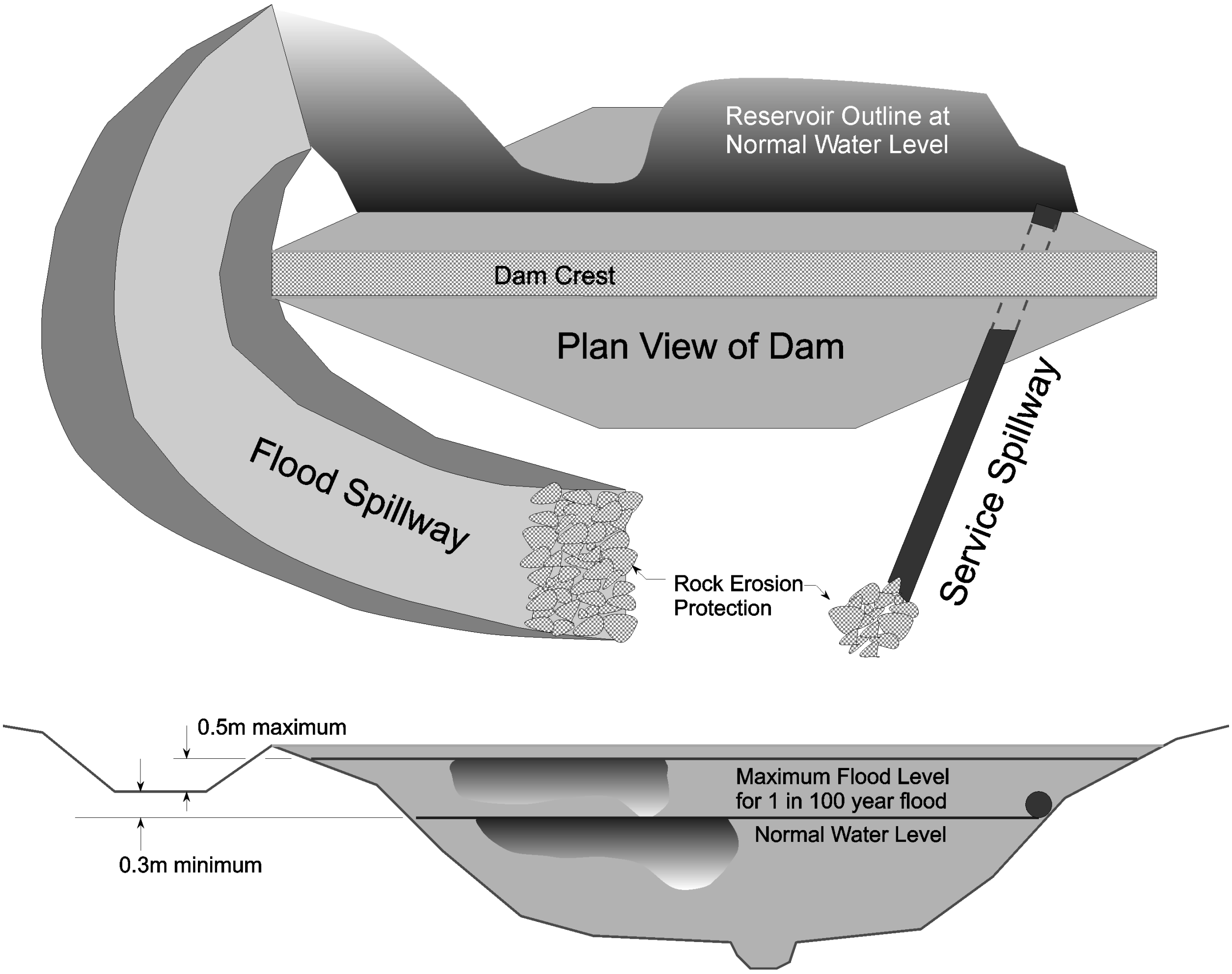


Figure 2.2: Typical Spillway Layout

2 Flood Spillway

This spillway takes the high stream flows generated during storms. The flood spillway should be formed around the end of the dam and extend downstream clear of the dam toe.

The following design parameters are required for the flood spillway:

- place the crest level of the flood spillway at least 0.3m higher than the invert (base) of the Service Spillway, or 300mm above normal full water level
- size the flood spillway to pass a 1 in 100 year flood event with no more than a 0.5m flood rise above the crest of the flood spillway, and without overtopping the dam
- form the spillway with a downstream gradient of no steeper than 1 vertical to 5 horizontal (1 in 5) to reduce erosion
- slope the batters either side of the spillway no steeper than 1 vertical to 2 horizontal (1 in 2)
- put rock protection at the spillway outlets for erosion control
- if the dam is to be used as a crossing, put some erosion protection on the spillway where traffic or stock cross it.

Spillway requirements and an example of a typical layout are shown in Figure 2.2. A simplified method for determining an appropriate width for the spillway is shown in Figures 2.10 and 2.11 at the back of this part of the guideline. Input of specific expert engineering advice would typically result in a more optimised spillway solution.

3.5 Pipes and conduits

Pipes are often put through the bottom of the dam for drawing of water but pipes through dams can be weak points for seepage, causing erosion of the dam fill.

Pipes through dams should meet the following requirements:

- dig them into the natural materials under the dam, wherever possible
- install cut off collars (or similar) around the pipe along the upstream half of the pipes length. Use at least one collar for dams of less than 2.5m in height, and at least two for higher dams
- place drainage material (eg .... mm diameter gravel) along the pipe for the downstream half of its length
- hand compact the fill around the pipe to ensure the pipe is not damaged.

Details for the design of conduits through an earth fill embankment are shown in Figure 2.3. Alternative designs are possible, with engineering input.

4.0 Dam construction

The following section gives brief details on good practice in small dam construction. If any difficulties are encountered during construction, an engineer experienced in dam design and construction should be contacted.

1 **Site Preparation**

Strip vegetation, topsoil and unsuitable materials from beneath the dam footprint and from the area to be used as dam fill material. Keep the topsoil for use as a coating for the dam to aid grass growth.

Remove trees and shrubs from inside the final storage area.

Instream dams not recommended.

2 **Stream diversion**

If the stream is flowing, divert it around or through the dam site while the dam is built. This can be done by piping or by building a channel to one side. The pipe option is often more practical and the pipe can then be used for drawing water from the dam or draining it in the future.

If a channel diversion is being used, the dam will need to be constructed in two halves.

An alternative is to form a temporary dam upstream and pump the flow from this to downstream of the working area.

3 **Foundation**

Excavating the foundation for the dam should include the cutoff trench, or key and pipe. Any springs or seepages encountered on the downstream half should be clear of the excavation.

Backfill the foundation and as soon as possible,

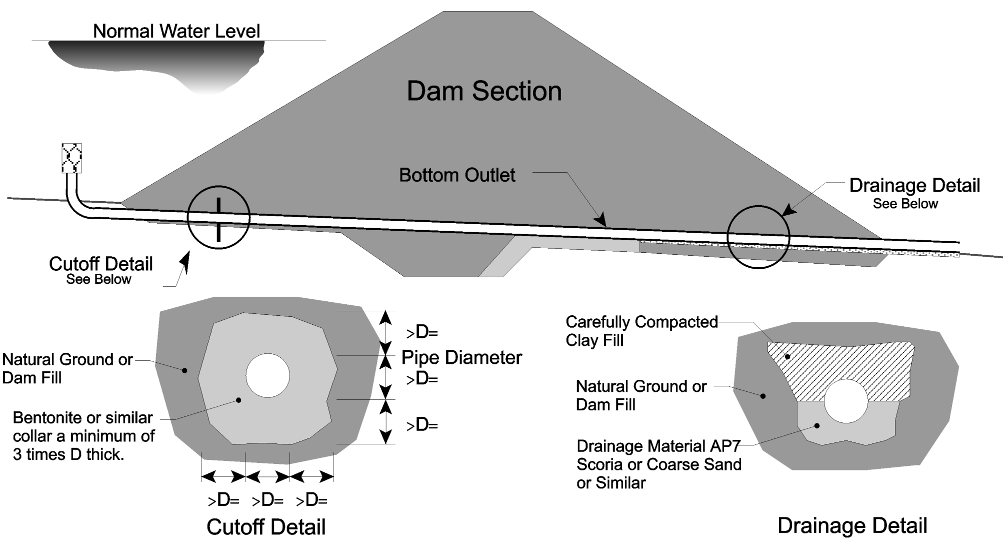


Figure 2.3: Guideline for Design of Conduits through Earthfill Embankments

to avoid softening or slumping of the key trench or valley sides.

Install foundation drainage at the required locations. Novaflo pipes (or similar) placed within the dam or foundations should have their upstream end blocked off.

4 Placement of dam fill

Compact dam fill in layers not thicker than 200 millimetres. Do not use tracked vehicles to compact dams higher than 2.5 metres. Use only clean silts and clays devoid of organic material. The fill material should be moist, not dry or wet, for best compaction results. Key placement issues are:

- the dam footprint should be free of drying out and cracking or anything that will prejudice the formation of a good bond with the dam fill
- the fill should be placed in 150mm loose layers if track rolled. 200mm layers can be used if a purpose-made compactor is used. Usually 3 passes is a minimum requirement per layer
- overfill and trim back to a neat final profile. Finally track roll up and down the dam faces
- if caught by rain, remove softened layers before continuing.

Install any conduits or pipes through the dam. Often it is more convenient to place fill to a higher level than the pipe then cut back down to install the pipe. Any internal drains in the fill can be placed in the same way.

5 Spillway construction

Install both spillways as soon as possible - definitely before the diversion pipe or channel is blocked. If a channel is being used for diversion, the piped spillway could be used for diversion while the channel is being filled.

Place rock protection at the spillway outlets once the spillways are completed.

6 Finishing works

- spread topsoil on the downstream face to assist grass growth
- regrass all bare areas above the final water level
- place riprap on the upstream face of the dam, if required
- metal and fence the crest
- metal the crest of the flood spillway, if access across it is needed.

5.0 Common dos, don'ts and avoids

Do	strip all vegetation, organic soil and soft soil from beneath the dam
Do	compact the dam fill materials in thin (approx. 200mm) layers
Avoid	pipes through the dam unless absolutely required
Do	install drainage to along the downstream half of pipes through the dam
Don't	use fill material that is to wet or to dry for constructing the dam
Don't	use fill material containing organic materials like topsoil
Don't	form the flood spillway to close to the dam
Avoid	sharp curves or angles in spillways
Don't	start to fill the dam until both spillways are constructed
Do	re-grass bare areas following construction
Do	closely observe the dam during the period of filling and for some time after.

6.0 Dam monitoring and surveillance

A simple walkover of the dam should be made regularly to look for and note any changes in the structure. Important details to look for include:

❍ damp or soft patches on the downstream face of the dam or ground to either side
❍ dirty flow coming from the drains within the dam
❍ cracking, slumping or movement of the dam fill
❍ erosion of the dam fill on the upstream face particularly at the water line

❍ blockage, erosion or bank slumping in the flood spillway.

Any changes or damage noted should be repaired or referred to an engineer experienced in dam design and construction.

A brief observation checklist is included in Figure 2.12 of this part of the guideline.

7.0 Dam maintenance

The life and safety of a dam depends on adequate maintenance. Good dam maintenance includes:

- maintaining a good grass cover on the dam and flood spillway. Trees and shrubs should not be permitted to grow on or near the dam or spillways
- repair of the spillway, if required, after flood events
- cleaning and clearing of the outlet from any drains to ensure continued operation
- replacement of lost riprap or erosion control measures on the spillway and upstream dam face.

A brief observation checklist is included in Figure 2.12 of this part of the guideline.

Storage characteristics

1 Calculating catchment yield

The following simple calculation will give an indication of how much water a catchment will supply each year. A worked example is also given below (Figures 2.4 and 2.5).

For most uses the value of net yield availability for dry year should be used.

Figure 2.4: Catchment Yield Calculation

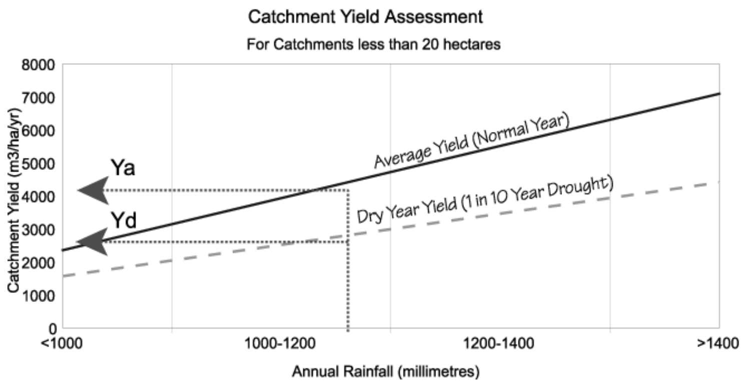


Figure 2.5: A Worked Example of Catchment Yield Calculation

Catchment Yield Calculation				
Data			***Worked example***	**My Dam**
Catchment Area		'Ac' (hectares)	*12 hectares*	
Annual Rainfall		'R' (millimetres)	*1150 mm/year*	
Yield per Hectare	Average Yield	'Ya'	*4300 m³/ha*	
(from Graph)	Dry Year Yield	'Yd'	*2800 m³/ha*	
Catchment Yield	Average Yield	'Ca' = Ac * Ya	*12*4300 = 51,600 m³/year*	
	Dry Year Yield	'Cd' = Ac * Yd	*12*2800 = 33,600 m³/year*	
Less Extractions Upstream (other users)		'E'	*10,000 m³/year*	
Net Yield Availability for my dam	Average Yield	'NYa' = Ca - E	*51600-10000 = 41,600 m³/year*	
	Dry Year Yield	'NYd' = Cd - E	*33600-10000 = **23,600 m³/year***	

Note: A more accurate estimate would be achieved with the help of a specialist engineer. Also note that the symbol of the asterisk (*) denoted a multipication sign.

2 Estimating storage volume

The following simple method will give an approximate stored volume. Two volumes are calculated, a "normal storage" volume, above which water will start flowing out of the service spillway, and a "maximum storage" volume, which will occur during an extreme flood event. A worked example is given below.

It is assumed that the valley profile upstream of the dam is relatively constant in shape throughout the storage.

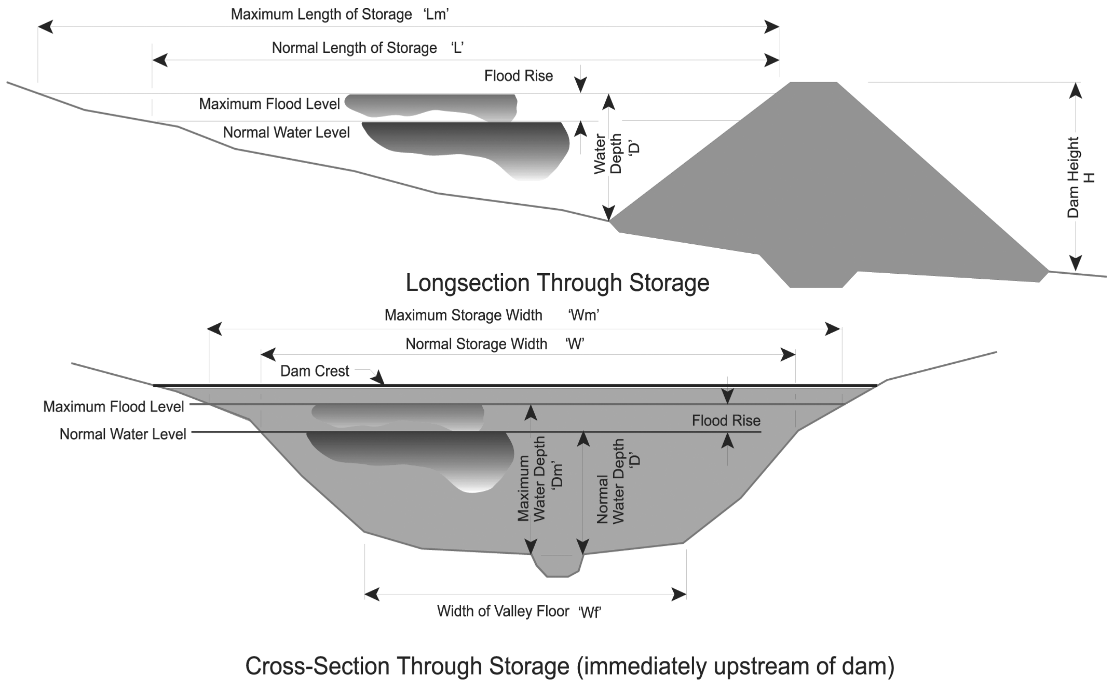


Figure 2.6: Storage Size Calculation

Figure 2.7: A Worked Example of Storage Size Calculation

Storage size calculation								
Data			***Worked Example***				**My Dam**	
			Normal		*Maximum*		*Normal*	*Maximum*
Length of Storage		(metres)	L	*100*	Lm	*200*	L	Lm
Width of Storage		(metres)	W	*25*	Wm	*30*	W	Wm
Water Depth		(metres)	D	*2.2*	Dm	*3.0*	D	Dm
Width of Valley Floor 'Wf' (metres)			*10 metres*					
Volume	Central Section	Vc = L*Wf*D) / 2	*100*10*2.2 / 2 = 1,100*		*120*10*3.0 / 2 = 1,800*			
	Side Sections	Vs = L*D*(W-Wf) / 6	*100*2.2*(25-10) / 6 = 550*		*120*3.0*(25-10) / 6 = 900*			
	TOTAL	V = Vc + Vs	V	*1100+550=1,650 m^3*	Vm	*1800+900 = 2,700 m^3*	V	Vm

Dam embankment

1 Embankment fill volume

The following simple calculation will give an approximate volume of fill required for the dam embankment. Also calculated is the area of the dam footprint, or area covered by the base of the dam. For simplification it is assumed that both the upstream and downstream batter slopes on the dam are equal. A worked example is given below.

Figure 2.8: Embankment Fill Volume

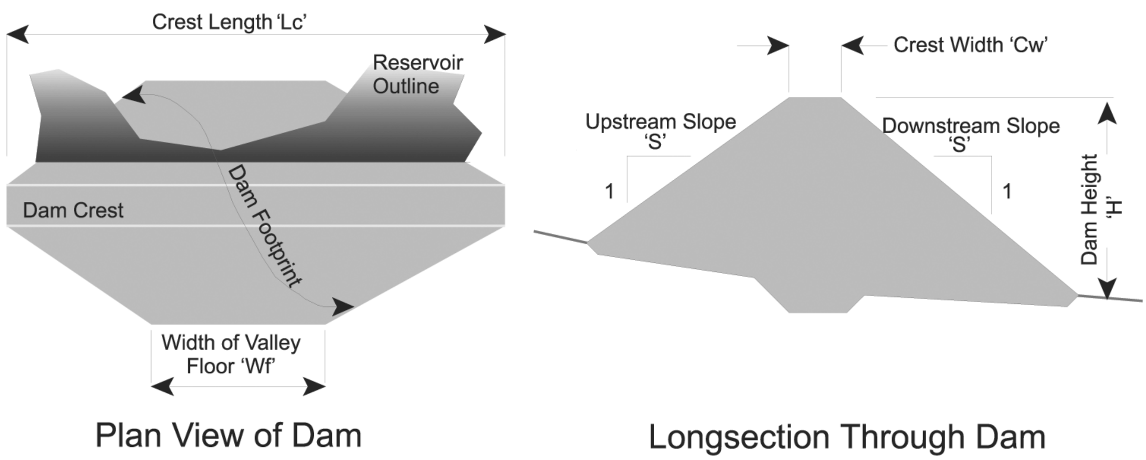


Figure 2.9: A Worked Example of Embankment Fill Volume

Dam fill volume and footprint area calculation				
Data			***Worked example***	**My Dam**
Crest Length		'Lc' (metres)	40	
Crest Width		'Cw' (metres)	3.5	
Dam Height		'H' (metres)	4.0	
Width of Valley Floor		'Wf' (metres)	*10 metres*	
Batter Slope (Upstream & Downstream)		'S'	*2.5*	
Footprint Area		A = Cw*Lc + H*S*(Lc + Wf)	*3.5*40+4*2.5*(40+10) = 640m²*	
Volume	Central Section	Vc = H*(H*S + Cw)* Wf	*4*(4*2.5 + 3.5) * 10 = 540m³*	
	End Sections	$Ve = H * \frac{(H*S + Cw) * (Lc-Wf)}{3}$	$\frac{4*(4*2.5 + 3.5) * (40-10)}{3} = 540m^3$	
	TOTAL	V = Vc + Ve	*540 + 540 = 1080 m³*	
Add allowance for Fill Settlement		+0.1*V	*add 108 m³*	
Site Stripping & Foundations		+0.5*A (For H < 2.5m) +0.7*A (For H > 2.5m)	*add 0.7 * 640 = 448 m³*	
Total Dam Fill Volume			***1080 + 108 + 448 = 1636 m³***	

dam safety guidelines

Guidelines for construction, maintenance and monitoring

Spillway

1 Flood spillway width calculation

The following method can be used to determine the minimum width required for the flood spillway of a small dam. A worked example is given below.

Figure 2.10: Flood Size and Spillway Width Calculations

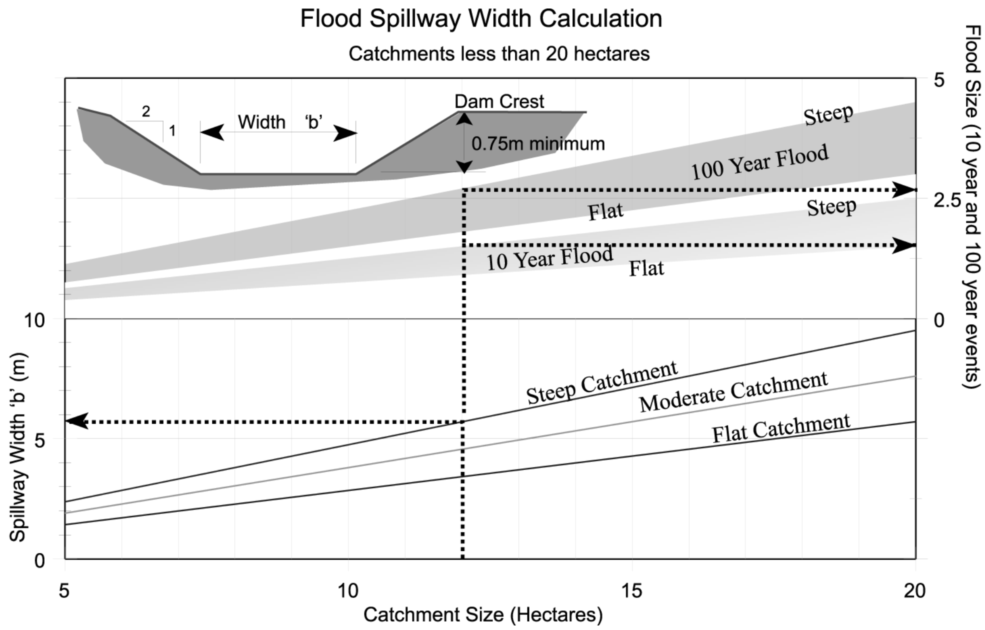


Figure 2.11: A Worked Example of Flood Size and Spillway Width Calculations

Flood size and spillway width calculation				
Data		***Worked example***	**My Dam**
Catchment Area	'Ac' (hectares)	*12*	
Catchment Type	'Steep / Moderate / Flat'	*Steep*	
Flood Size	10 Year Event	*1.4 m^3/sec*	
	100 Year Event	*2.6 m^3/sec*	
Spillway Width Required	'b' (from graph)	*6.0 metres*	

Note: Specialist input would result in a more optimised design solution.

Dam inspection checklist

The table below lists the key items that should be inspected on small earth dams. Not all items will apply to all dams.

Overpage is a sketch of a typical dam. Particular observations can be noted on this plan for comparison with future observations.

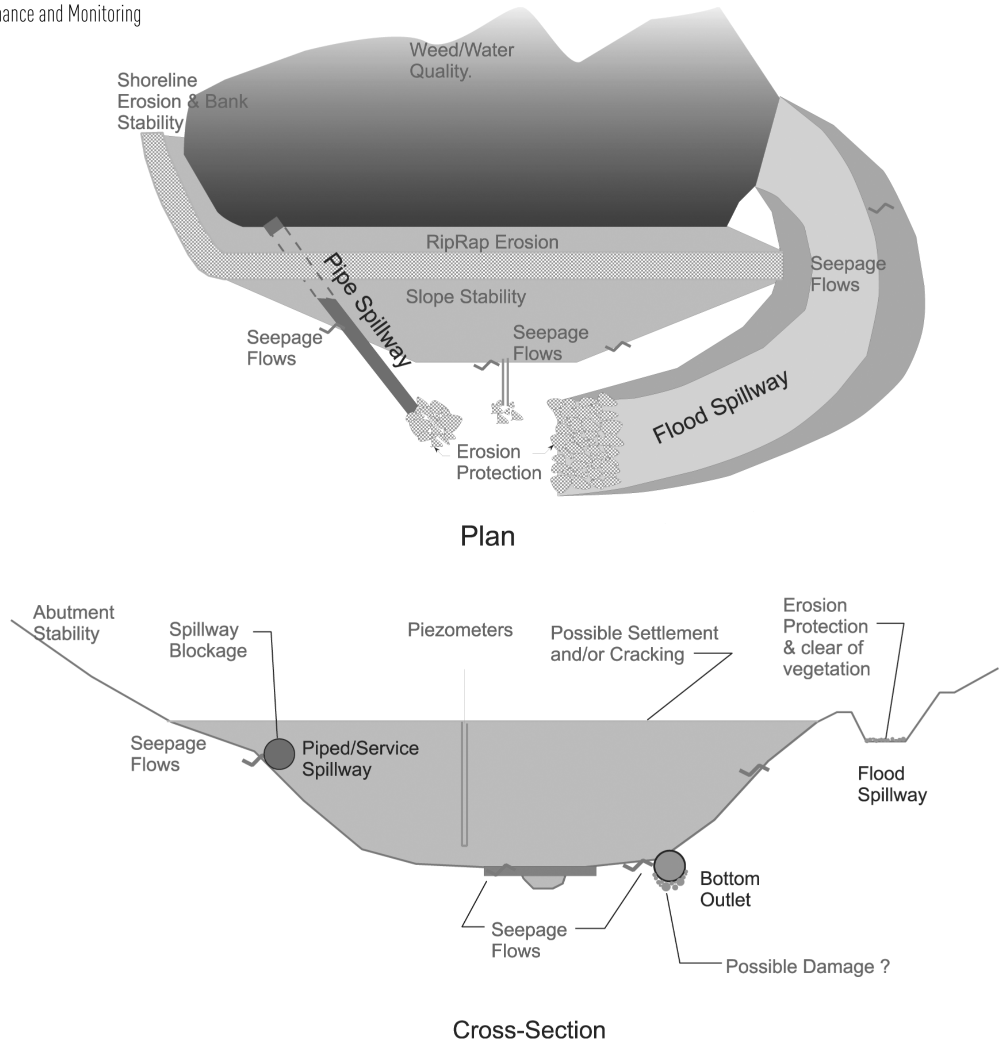
Figure 2.12: Checklist – Dam Maintenance and Monitoring

Location		What to Look For	Notes	Action
Dam	Upstream slope	Slope stability		
		Erosion protection (riprap)		
	Crest	Settlement		
		Cracking		
		Protection		
	Downstream slope	Seepages		
		Slope stability		
	Downstream toe	Seepages		
		Bulging		
		Erosion		
	General	Tree/shrub growth		
Spillways	Piped or Service Spillway	Inlet blockage/damage		
		Outlet erosion		
		Drainage flows		
	Flood spillway	Erosion		
		Blockage		
Low Level Outlet	Inlet (if visible)	Blockage		
	Outlet	Erosion		
		Drainage flows		
Reservoir	Sides	Slope stability		
		Weed growth		

Date: Inspected by:

Notes:

Figure 2.13: Schematic Checklist – Dam Maintenance and Monitoring



Notes: