Farm Dams



Catchments & Creeks

Version 1, 2026

Farm Dams

Version 1, August 2026

Written and illustrated by: Grant Witheridge, *Catchments and Creeks*, Queensland, Australia.

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Witheridge, G.M. 2026, *Farm Dams*. Catchments & Creeks, Bargara, Queensland.

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Cover image: A farm dam, Leadville, NSW, photographed on 5 November 2010.

Purpose of field guide

This field guide has been prepared specifically to:

- provide landowners with guidance on the design and maintenance of small farm dams
- provide guidance on the hydraulic design of bywash and spillway structures for small dams.

The focus of this field guide is on those aspects of farm dam design and operation that most closely aligns with the author's work experience. Consequently, there are some aspects of farm dam design that are not covered to the extent that the reader may have desired.

The photos presented within this document are intended to represent the current topic of discussion. The photos are presented for the purpose of depicting either a preferred or discouraged outcome (as the case may be). In some cases, the photo may not represent current best practice, but is simply the best photo available to the author at the time.

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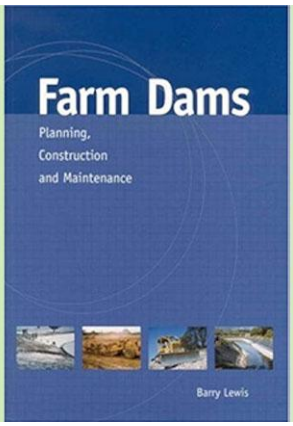
Author's background

Grant Witheridge is a retired civil engineer with both Bachelor and Masters degrees from the University of NSW (UNSW). He has 40 years experience in the fields of hydraulics, creek engineering, and erosion & sediment control, during which time he has worked for a variety of federal, state and local government bodies, as well as private organisations.

Grant commenced his career at the UNSW Water Research Laboratory (1981) constructing and operating physical flood models of river floodplains. He later worked for Brisbane City Council on creek engineering and stormwater management issues. He ended his carer working through his own company Catchments & Creeks Pty Ltd.

Grant is the principal author of more than 80 engineering publications covering the topics of creek engineering, fish passage, stormwater management, and erosion and sediment control.

Principal reference documents:



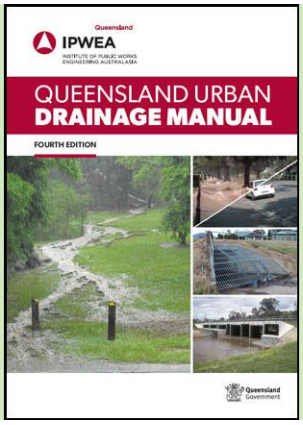
Farm Dams, 2002

Farm Dams

Lewis, B. 2002, *Farm Dams – Planning, Construction and Maintenance.*

Landlinks Press, Collingwood Victoria, 3066, Australia.

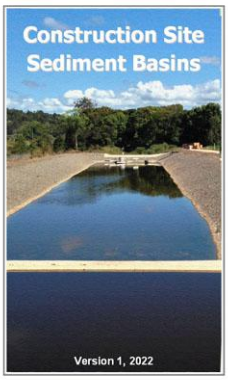
ISBN 0 643 06576 8.



Queensland Urban Drainage Manual

Queensland Urban Drainage Manual (QUDM)

Institute of Public Works Engineering Australia, Queensland Division and the Department of Energy and Water Supply. Brisbane, Australia, 4th edition, 2017.

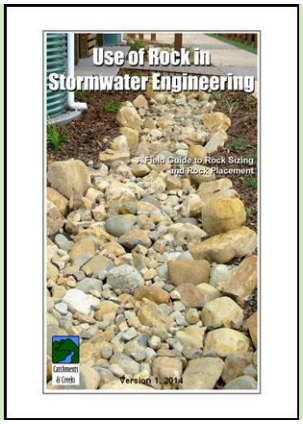


Construction Site Sediment Basins

Construction Site Sediment Basins

Witheridge, G., 2022, *Construction Site Sediment Basins,* Catchments & Creeks Pty Ltd., Bargara, Queensland

Version 2, July 2022.



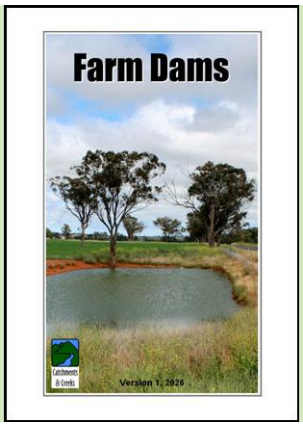
Use of Rock in Stormwater Engineering

Use of Rock in Stormwater Engineering

Witheridge, G., 2021, Catchments and Creeks Pty. Ltd., Brisbane, Queensland.

First released in 2014, with several updates

Layout of this document



Farm Dams, 2026

Introduction

- This field guide has been drafted on the assumption that most readers will be reading the document after they had built their dam, or had purchased a property that with a working dam.
- Consequently, there is minimal information presented on the planning stage and the design of storage basins.
- Instead, the focus in on spillway design and repair of damaged spillways.



Catchment hydrology

Catchment hydrology (Chapter 4)

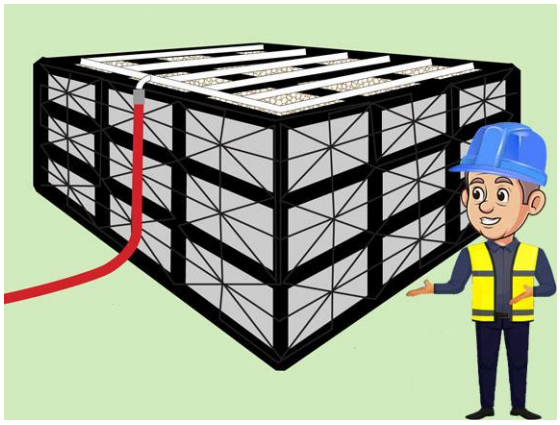
- The science of catchment hydrology is similar to the science of weather prediction—there is never an absolute 'correct' answer.
- Catchment hydrology is just a prediction tool, and the accuracy of your prediction depends on how sophisticated you want to be with your modelling.
- Chapter 4 provides a simplified flow prediction method that has low accuracy, but may be good enough for a low-risk dam site.



Dam spillway crest

Bywash and spillway design

- Chapters 6, 7, 10 and 11.
- Within this field guide, a bywash is defined as an all-grass spillway.
- The term 'spillway' is generally used only when referring to non-grass spillways.
- Chapter 6 contains worked examples of a bywash design, a spillway design, and the design of an energy dissipation zone.
- Chapters 10 and 11 focus on the repair options for damaged bywash spillways.



Modular trickling filter system

Water quality issues and leaking dams

- Chapters 8 and 9.
- Farm dams are not swimming pools, and as such they are managed differently from swimming pools.
- Landowners can of course seek expert advice from their local produce store on how best to manage water quality.
- Meanwhile, Chapter 8 provides some alternative water treatment options that are based on common water treatment and wastewater treatment processes.

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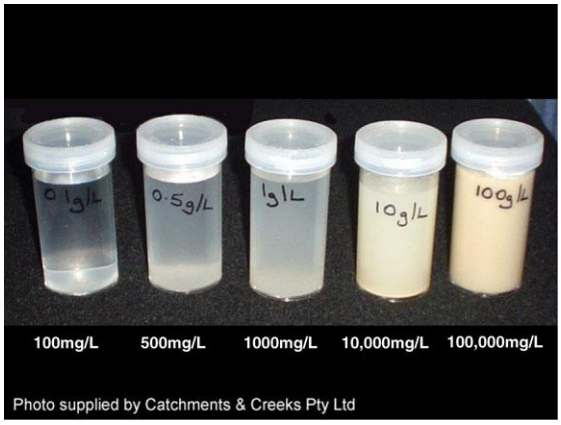
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1. Site Planning and Estimating Catchment Yield

Planning

Introduction

- The planning of a new farm dam typically follows one of the following pathways:
  - a scientific analysis to optimise water quality outcomes
  - planning how to achieve the maximum storage volume at a specific location on the property
  - trying to achieve the maximum storage volume for a given budget.



Turbidity levels in water samples

Planning to optimise water quality

- Planning issues could include:
  - What water quality do you require; and therefore, what animals are you going to allow to occupy, and possibly contaminate, the dam's drainage catchment?
  - Do you plan on drinking the water?
  - If the water is going to be used for laundry activities, then do you expect to use a filtration system to control water turbidity?



A small recessed dam/pond (Qld)

Planning to optimise the storage volume

- Planning issues include:
  - When planning the layout of the dam, don't forget to allow space for the bywash or spillway, and the land needed to dissipate the flow energy before the water leaves your property.
  - From the author's experience, the land needed for the spillway can be equal to the width of the storage basin.
  - Also, the more recessed the basin is, the smaller the embankment needs to be.



Ring tank (Qld)

Sizing a dam based on construction cost

- Planning issues include:
  - Costs can be minimised by balancing the volume of excavation with the volume of the embankment; however, always allow for some of the excavated soil to be considered unfit for use.
  - Think about the cost of scour protection on the spillway (i.e. rock can be very expensive in some regions)—and again, the more recessed the storage basin is, the cheaper the potential cost of the embankment and spillway.

Setting your priorities



Setting priorities

Introduction

- The only person that can determine your priorities will be yourself.
- Consequently, the author has no intension of dictating to you what your priorities should be.
- Instead, the following are just the priorities that the author would apply to the location of a small dam on a typical rural-residential property (the priorities for a dam on an open farmland property would be different).



Memorial

Safety

- Safety would be the author's highest priority.
- If the failure of the dam could result in the loss of life, then this would be a major concern.
- The risk to life could make the dam a referrable dam, even a small farm dam, which would bring added regulations and expenditure into the design of the dam.
- These risks not only refer to the failure of the dam, but also the risk of a person (child) drowning in the dam.



Duck faeces (poo)

Water quality

- The author's next priority would be to consider the level of water quality that is require, which should make the landowner consider what pollutants are likely to wash-off the drainage catchment.
- What animals, wild or livestock, will inhabit the drainage catchment from time-to-time.
- Even possums living in/on the roof of buildings and sheds within the catchment can have an effect.



Money

Cost

- If the dam can be constructed with a grassed bywash instead of a formal spillway, then this could save dollars in design fees and construction costs.
- If the dam requires a formal spillway, then the biggest cost in building the dam could become the construction of the spillway.
- Your choice of the location of the dam could significantly affect the cost of building the dam.

Planning the location of a farm dam



No room for an energy dissipater

Introduction

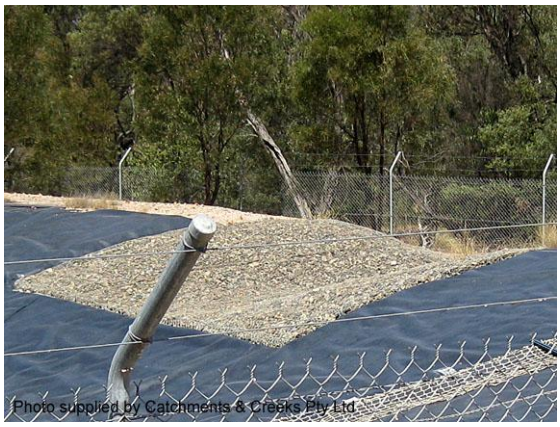
- Based on the author's experience, the most expensive mistakes are those made during the planning of a farm dam—not during its design or construction.
- The most common mistake is for the designer to focus on maximising the storage volume of the dam, with minimal regard given to the land requirements of the spillway.
- Unfortunately, as the dam gets larger, the space available for the spillway often gets smaller.



Acid sulfate soil

Locations to be avoided

- Avoid locations where there could be sand or gravel sub-layers within the soil.
- If there are existing springs releasing water downstream of your proposed dam site, then you will need bore hole testing to check if the spring is passing under the location of your dam.
- Avoid locations where the soils are potential acid sulfate, limestone, gravely, sandy, dispersive, or highly dispersive.



Dam spillway

Planning for a spillway

- Don't let the spillway become an after-thought.
- If the outflow crosses a property boundary, then common law rules may apply (refer to Chapter 2).
- There must be sufficient room to construct both the spillway and the energy dissipation zone, before the water crosses a property boundary.



Pumping water to rainwater tanks

Planning for more than one dam

- Don't limit your considerations to building one big dam—two well-designed dams are usually better than one large poorly-designed dam.
- Always consider the option of using fire fighting pumps to pump water from an on-line dam to an off-line dam, or even to a series of rainwater tanks.
- An 'on-line' dam is a dam that is located along the flow path of concentrated stormwater runoff, such as a swale.

Government and environmental issues



What you didn't what to hear

Introduction

- Dealing with governments and be a pain in the proverbial.
- I know what you are thinking—what they don't know won't hurt them, and it is your runoff, so why can't you capture and use it?
- Well, in most cases, the 'resources' of the State belong to the State, which means if you find a coal seam on your property, it belongs to the State, and similarly, the rain that lands on your property, in theory, belongs to the State!

Department of the Environment (SA)

Department of the Environment (or similar)

- Issues that they are likely to consider:
  - Will you be taking all reasonable and practicable measures to prevent or minimise environmental harm during the construction of your dam?
  - Will you be taking all reasonable and practicable measures to prevent or minimise environmental harm during the operation of your dam?
  - Will you be interfering with environmental flows within a waterway?

Fisheries Authority (Tas)

Department of Fisheries (or similar)

- Issues that they are likely to consider:
  - Will you be interfering with the habitat of threatened species?
  - Will you be interfering with the migration of fish?
  - Will you be damaging or removing native vegetation from a waterway?
- The definition of what is, and is not, classified as 'fish' will be in your State or Territory Fisheries legislation.
- This usually only affects instream dams.

Department of Natural Resources (NSW)

Department of Natural Resources (or similar)

- Issues that they are likely to consider:
  - Will you be interfering with a downstream landowner's rights to a natural supply of water?
  - Will you be interfering with existing licensed activities?
  - Will you be damaging or removing native vegetation from a waterway?

Note: Waterway vegetation may be protected by both Fisheries and Natural Resources legislation.

Assessment of the catchment yield



Overland flow (Qld)

Introduction

- Catchment yield is the annual volume [m^3] of stormwater runoff expected from the contributing drainage catchment.
- This catchment yield may, or may not, include dry weather spring flows; however, it is typical for the up-slope drainage catchment to be so small that spring flows are usually absent.



Approaching thunder storm (Qld)

Factors affecting catchment yield

- On a typical farm, the factors that will most likely affect the annual volume of storm runoff include:
  - annual rainfall (i.e. is it a 'wet' year, or a period of drought)
  - the type of storms
  - the type of vegetation within the drainage catchment
  - the occurrence of fire
  - the type of soil
  - the slope of the drainage catchment.



A full dam (Qld)

The volume of runoff from a single storm

- Some publications present 'volumetric runoff equations' that can be used to estimate the volume of runoff expected from either a single storm, or from the total annual rainfall.
- The actual volume of runoff from a single storm depends on the type of storm.
- For a single storm event, a long period of light rainfall can generate less runoff than a thunderstorm that releases the same total rainfall.



Ploughed field (Qld)

Factors affecting surface runoff

- Dense bushland generates less runoff than crop land, which generates less runoff than pasture (grass land).
- Green bushland generates less runoff than burnt bushland.
- Sandy soils generate less surface runoff than clayey soils.
- Ploughed crop land generates less runoff than undisturbed soil.
- Flat land generates less runoff than steep land.

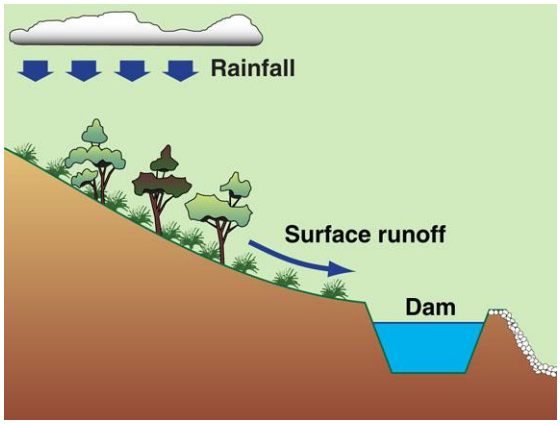
Understanding the movement of surface and sub-surface water



Spring-fed water storage (Qld)

The source of inflows into a farm dam

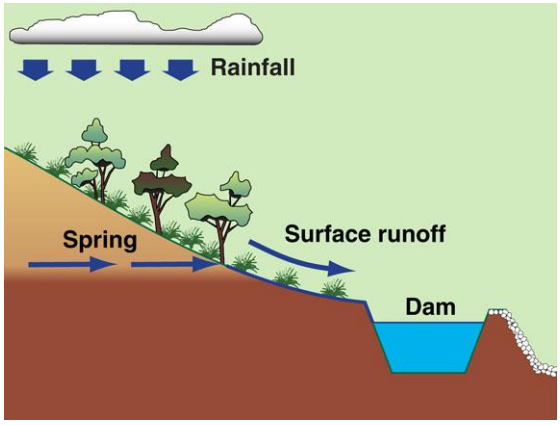
- In order to manage the catchment yield, it is important for the landowner to know where the water is coming from.
  - Does the dam only receive surface runoff, or does the dam receive inflows from groundwater (i.e. sub-surface flows entering the dam through the sidewalls of the dam?
  - Does the surface flow only occur during storms, or are there 'springs' feeding this surface flow?



Surface flow <u>without</u> springs

Surface flow <u>without</u> springs

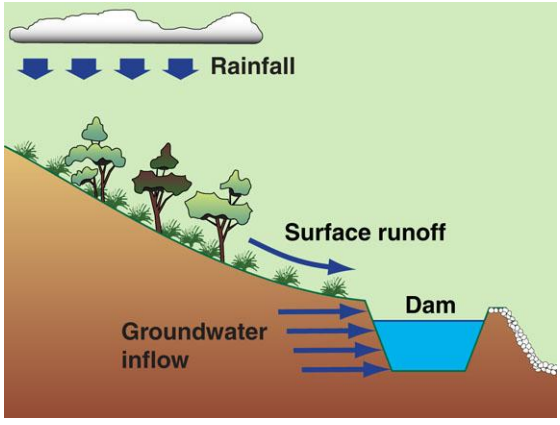
- Most small drainage catchments will operate without spring flows.
- However, even though spring flows do not exist, it is common for dams to receive inflows from groundwater entering the dam via the sidewalls of the dam.
- The dam will receive most of its inflows from surface runoff and direct rainfall.



Surface flow fed with some springs

Surface flow fed with some springs

- Having a spring flow can mean that a dam receives minor inflows for long periods after a storm.
- Typically, these spring flows will have a reduced concentration of phosphates because the water has passed through a soil on its way to the dam.



Combined surface and groundwater inflow

Combined surface and groundwater inflow

- If there is significant groundwater inflow, then those factors that can reduce surface runoff may no longer be important.
- It may not matter if the water arrives as surface flow, or if the stormwater is allowed to infiltrate the soil and then enter the dam as groundwater.
- However, such cases are rare, and there can still be significant 'deep' groundwater flow that can pass under the dam.

The effects of bushfire on catchment yield



Active bushfire (NSW)

Introduction

- Most hydrology text books will tell you that stormwater runoff reduces with an increase in tree density, but the 'science' is a little more complicated that simply counting trees.
- Vegetation can reduce runoff in two ways:
  - it increases the total surface area of the catchment that needs to be made 'wet' (i.e. leaves, branches, twigs and mulch)
  - trees extract water from the soil, which needs to be replaced during storms.



Recent burn (Qld)

The first few years following a bushfire

- Bushfires immediately reduce the effects of trees without necessarily reducing the density of trees.
- The effective surface area of the trees is reduced, and the ability of the trees to extract soil moisture is also reduced.
- Consequently, annual stormwater runoff is initially increased.
- Also, there can be an increase in the flow of nutrients (ash) into farm dams.



Recovering bushland (Qld)

A decade after a significant burn

- Within a few years, vegetation recovery begins.
- Bushland can achieve its greatest 'density' (i.e. maximum effective surface area of leaves, etc.) some 10 years after a major fire (shorter times for tropical regions).
- This period can represent the period of lowest stormwater runoff.

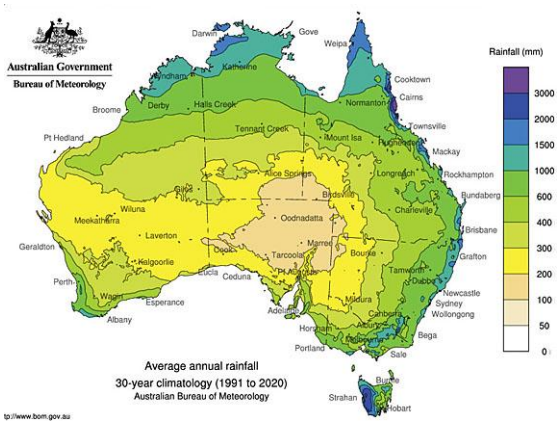


Mature bushland (Qld)

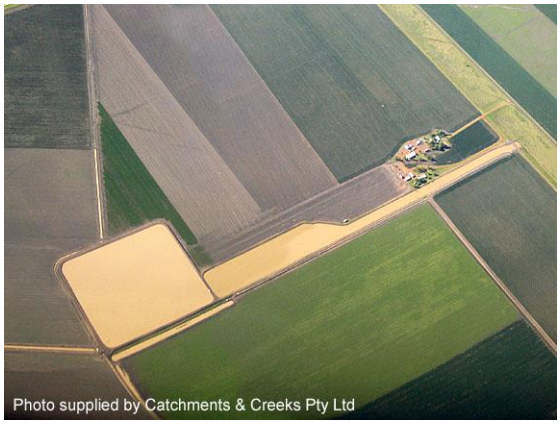
Two decades after a significant burn

- Beyond a ten-year period, bushland can reach maturity, and stormwater runoff will slightly increase as shading from the established tree canopy begins to thin-out the volume of middle storey and ground cover vegetation.

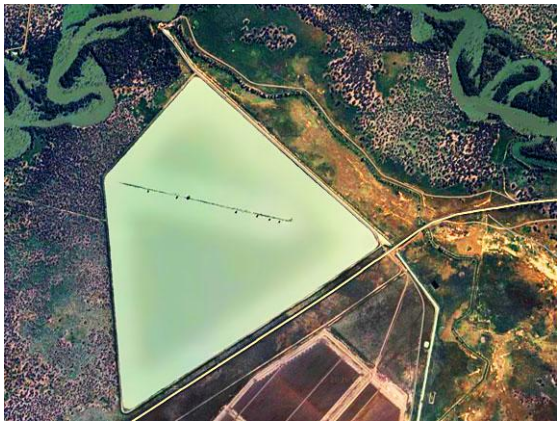
Determination of the required storage volume



Average annual rainfall for Australia



Farm dam (Qld)



Large ring tank (NSW)



Newly excavated dam (Qld)

Recommended storage period

- The following is a recommendation of the storage capacity (in months) for a farm dam relative to the annual rainfall depth.
  - 12 months for > 650 mm
  - 18 months for 450 to 650 mm
  - 24 months for 250 to 450 mm
  - 30 to 36 months for < 250 mm.
- The required storage volume [m^3] = (expected monthly usage of water in m^3/month) x (storage period in months).

Factors affecting the actual storage volume

- The above recommendation refers to the total storage of all the dams and tanks on a property.
- The volume of any single dam depends on several factors, including:
  - assessed safety risks
  - physical limits of the area (i.e. the capabilities of a given location to form a dam, embankment and spillway).
  - construction budget.

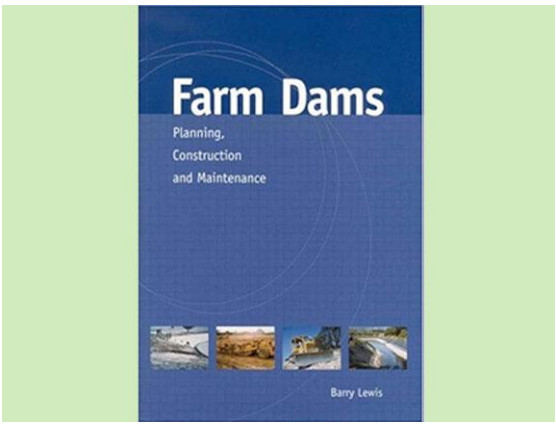
The risk of a dam being <u>too</u> big

- Dams are often smaller than the landowner may desire, but they can also be bigger than the catchment can support.
- A dam can be considered too big for the following reasons:
  - too many lives could be placed at risk if the dam were to structurally fail
  - excessive cost (e.g. cost of spillway)
  - insufficient water inflow
  - the catchment cannot deliver enough sediment to 'seal' the dam (see below).

Controlling the leakage from a dam

- Most soils are permeable to the flow of water.
- Controlling leakages from a new dam is not just a case of building an impermeable embankment (dam wall), but it also requires the sealing of the storage basin (i.e the basin's floor and walls).
- It can take many years for fine silts and clays to enter a dam as part of the natural inflow, and slowly 'seal' the many pores within the exposed soil surface.

Estimating catchment yield (annual runoff volume)



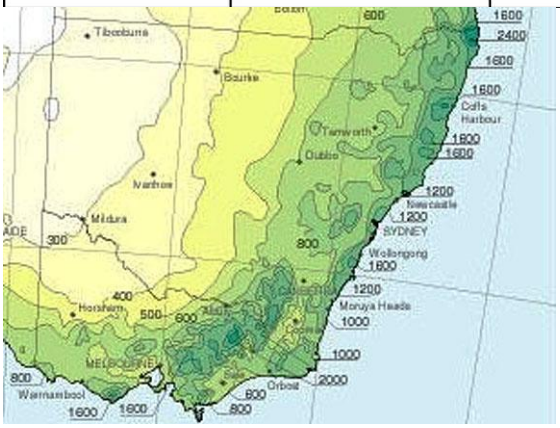
Farm Dams, 2002

Introduction

- The following method for estimating catchment yield is a modification of that presented in ***Farm Dams*** (Barry Lewis, 2002), which was modified from:
  - The Water Research Foundation of Australia, Bulletin No. 9 Vol. 1 (Burton J.R. 1965), and
  - Journal of the Department of Agriculture, Victoria (Nelson,K.D. 1983)
- Annual runoff volume [m^3] = (Annual rainfall, mm) x (Annual volumetric runoff coeff.) x (Catchment area, km^2) x 1000.

Table 1.1 – Estimating the annual volumetric runoff coefficient

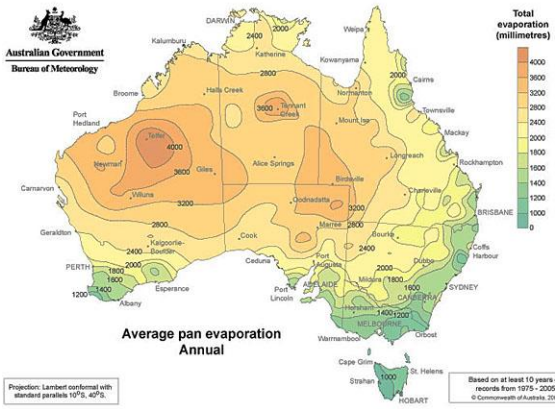
Annual rainfall (mm)	Annual evaporation (mm)	Type of catchment soil		
		Sandy loam	Sandy clay	Clayey soil
> 1100 mm	< 1000 mm	0.10 to 0.15	0.12 to 0.20	0.15 to 0.30
900 to 1100	< 1000 mm	0.10 to 0.15	0.10 to 0.20	0.12 to 0.25
500 to 900	1000 to 1300	0.05 to 0.08	0.07 to 0.12	0.08 to 0.15
500 to 900	1300 to 1800	0.05 to 0.08	0.05 to 0.12	0.05 to 0.15
400 to 500	1300 to 1800	0.03 to 0.04	0.03 to 0.07	0.04 to 0.12
250 to 400	< 1800 mm	0.01 to 0.03	0.02 to 0.05	0.02 to 0.05
< 250 mm	> 1800 mm	0.01 to 0.02	0.02 to 0.03	0.02 to 0.05



Annual rainfall (mm)

Example: Farm dam in regional Sydney:

- Annual rainfall = 1200 mm
- Annual evaporation = 1500 mm
- Catchment soil is a sandy loam.
- Annual volumetric runoff coefficient is estimated from the table to be 0.13
- Catchment area = 0.5 km^2
- An estimate of the annual runoff volume = 1200 x 0.13 x 0.5 x 1000 = 78,000 m^3 = 78 ML (note: 1000 m^3 = 1 mega litre).

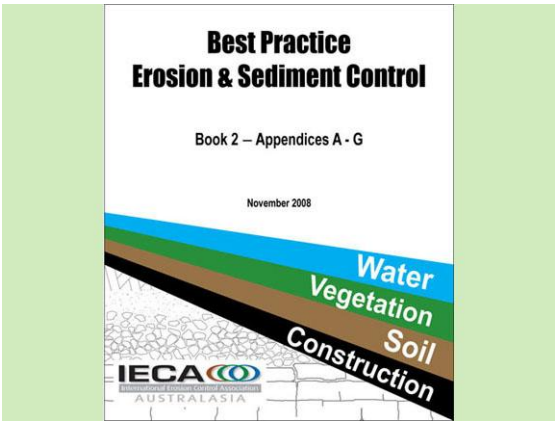


BoM Average annual evaporation (mm)

Another example:

- Annual rainfall = 1000 mm
- Annual evaporation = 1000 mm
- Catchment soil is a sandy clay.
- Annual volumetric runoff coefficient is estimated from the table to be 0.10
- Catchment area = 50 ha = 0.5 km^2
- An estimate of the annual runoff volume = 1000 x 0.10 x 0.5 x 1000 = 50,000 m^3 = 50 ML.

Estimating runoff volume from a single storm



IECA (Australasia), 2008



Soil properties

Introduction

- For whatever reason, a landowner has chosen to size a dam so that it is able to capture the runoff from a single historical storm event (i.e. a known rainfall event).
- This single storm may have occurred over a few hours, or a few days.
- In such cases, the analysis needs to be based on the volumetric runoff coefficient for a single storm event (which is significantly different from the annual average coefficient used on the previous page).

Soil properties

- Sandy soils usually consist of deep, well-drained sandy loams, sands or gravels.
- Sandy loams usually consist of well-drained medium loamy texture sandy loams, loams or clay loam soils.
- Loamy clays usually consist of moderately fine clay loams, or loamy clays.
- Clayey soils usually consist of fine-textured clays, soils with poor structure, surface-sealing (dispersive/sodic) soils, or expansive clays.

Table 1.2 – Volumetric runoff coefficient for a single storm event [1]

Rainfall (mm)	Type of catchment soil			
	Sand	Sandy loam	Loamy clay	Clayey soil
10	0.02	0.10	0.09	0.20
20	0.02	0.14	0.27	0.43
30	0.08	0.24	0.42	0.56
40	0.16	0.34	0.52	0.63
50	0.22	0.42	0.58	0.69
60	0.28	0.48	0.63	0.74
70	0.33	0.53	0.67	0.77
80	0.36	0.57	0.70	0.79
90	0.41	0.60	0.73	0.81
100	0.45	0.63	0.75	0.83

[1] Sourced from Fifield (2001) and Landcom (2004).

Fifield, J.S. 2001, Designing for Effective Sediment and Erosion Control on Construction Sites. Forester Communications, California. ISBN 0-9707687-0-2.

Landcom 2004, Managing Urban Stormwater: Soils and Construction – Volume-1, Landcom, New South Wales Government, ISBN 0-9752030-3-7.

Water quality issues



Water samples

Introduction

- How you plan a farm dam depends on what you wish to use the dam for:
  - irrigation
  - watering of stock
  - non-drinking domestic use
  - drinking
  - swimming pool.
- The difference between each of these uses is the required (or desired) water quality.



Domestic use of water

Dam water intended for human consumption

- Consider the risk of road runoff entering the dam—road runoff can contain metals from tyre and brake pad wear, plus oils.
- Runoff from pastures can be contaminated with animal faeces.
- Drainage from areas containing horses, pigs, dairy cattle, sewerage disposal will require special consideration with regards its ability to be treated before the water can be used for human consumption.



Water trough

Dam water used for irrigation

- If the farm has an ‘organic produce’ rating, then caution the capture and use of any road or domestic runoff.



Algae problem

Brown water vs green water

- It is understandable that farmers would prefer to have clear water in a dam that is used for domestic purposes.
- Brown water can cause problems when used for laundry purposes, and it may have a poor taste.
- However, clear water allows the penetration of heat and light into the water, which can lead to algae problems, which can lead to health problems—in general, ‘brown’ water is better than ‘green’ water (personal opinion!).

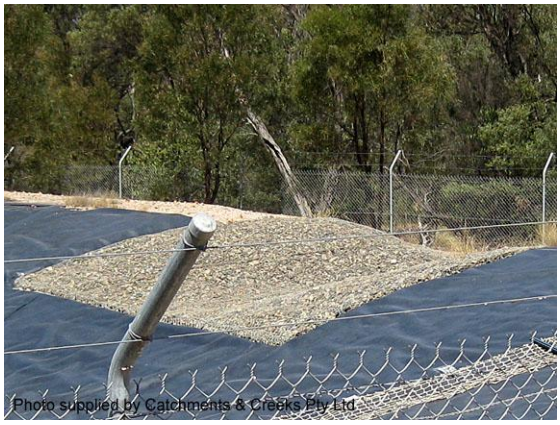
Emergency spillway issues



Grass bywash

Bywash vs spillways

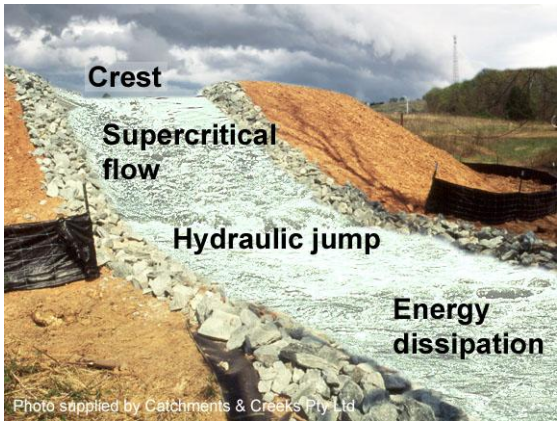
- An important step in the planning of a farm dam is the choice between a bywash-type spillway, and a structural spillway (sometimes referred to as a 'formal spillway').
- The term 'bywash' normally refers to a low-gradient grassed spillway.
- The term 'spillway' is more commonly associated with a rock-lined or concrete-lined spillway, which may, or may not, be formed over the fill embankment.



Formal spillway

Minimising the risk to life

- A grassed bywash is cheaper to build, but there is often a higher risk of failure (see examples in Chapter 11).
- A grassed bywash is highly susceptible to head-cut (gully) erosion that can migrate up to the bywash from a downstream channel.
- If the failure of the bywash could cause a rush of water that could risk life, then a formal spillway should be designed by a suitably qualified engineer.



Hydraulic conditions on a spillway

Allowing space for energy dissipation

- Based solely on the author's observations, it would appear that most bywash and spillway failures are triggered by erosion within the energy dissipation zone that exists immediately downstream of the bywash/spillway chute.
- From the author's observations, many landowners focus solely on scour protection on the 'sloping' section of the spillway chute, but not on the downstream end of the chute where energy dissipation is expected to occur.

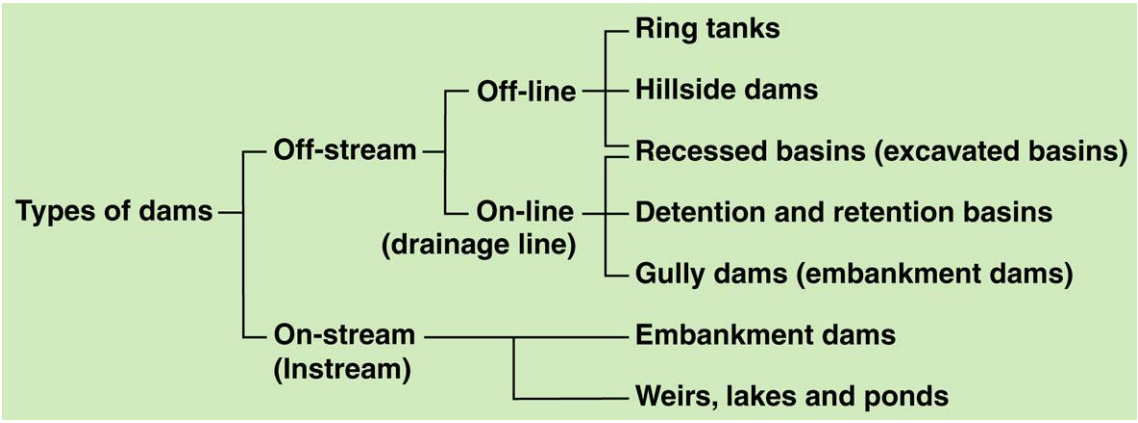


Spillway just upstream of property line

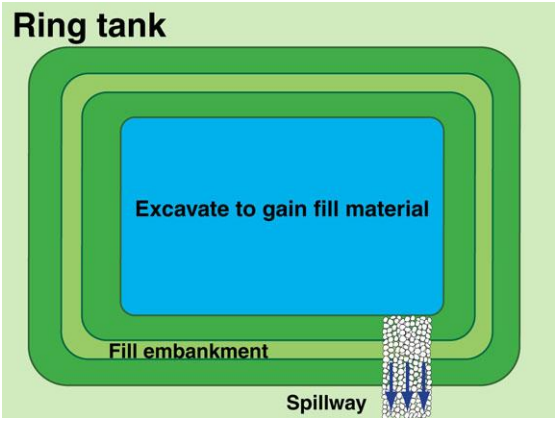
Releasing flows near a property boundary

- If the farm dam is located just upstream of a property boundary, then under 'common law' it is essential for all energy dissipation to have occurred before the flow crosses the property boundary.
- The farm dam must allow sufficient space for the discharged flows to return back to a 'normal' flow condition (i.e. a flow condition that does not increase the level of nuisance or harm on the downstream properties above that which would have occurred in absence of the dam).

Types of farm dams – Ring tanks



Types of dams



Ring tank (sectional view)

Ring tanks

- Ring tanks consist of a continuous (ring) embankment built from earth extracted from the centre of the tank.
- The storage volume is partially above and partially below natural ground level.
- The inflow of water is either from pumping or direct rainwater inflow.
- The surface area of the tank does not alter the hydraulic pressure placed on the embankment, which is controlled only by the depth of the water.



Recently constructed ring tank (Qld)

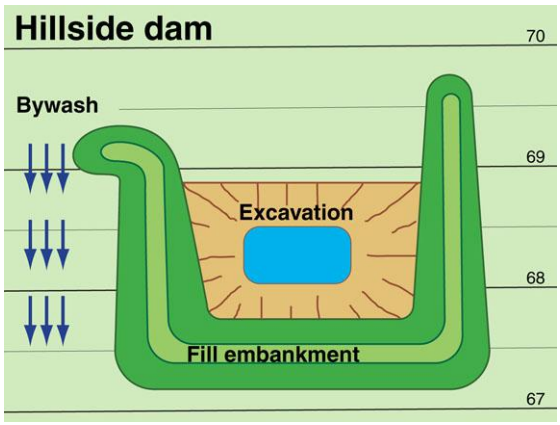


Aerial view of above ring tank, now full

The need a spillway

- The installation of a spillway on some ring tanks is recommended by the author (refer to Chapter 6).
- Ring tanks have been known to overtop during extended periods of wet weather when direct rainwater inflow can lift the water level above the nominated maximum water level.

Types of farm dams – Hillside dams & recessed basins



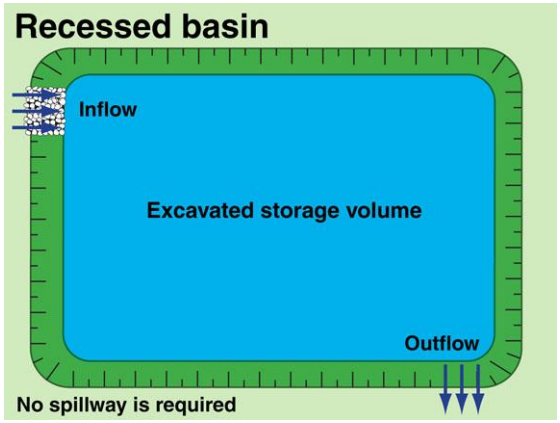
Hillside dam (plan view)

Hillside dams

- Hillside dams are constructed on a valley's side-slope, well away from the valley floor.
- Hillside dams receive storm runoff from:
  - the hill slope above the dam
  - a zero-gradient catch drain that collects runoff from other parts of the hill slope.
- The careful design of these lateral catch drains is critical in order to ensure the safe operation of the dam during severe storms (refer to Chapter 7).



Hillside dam (Qld)



Recessed basin

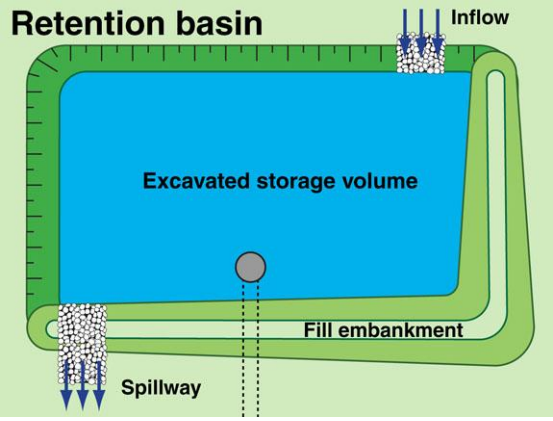
Recessed basins (excavated basins)

- The benefit of a fully recessed (excavated) basin is the absence of a fill embankment and any risk of an embankment failure.
- The overflow point (or spillway) is at natural ground levels, which results in a low risk of failure.
- The deeper the basin, the lower the evaporation percentage; however, the depth could be limited by the existence of the underlying bedrock.



Small recessed dam (pond)

Types of farm dams – Retention basins & gully dams



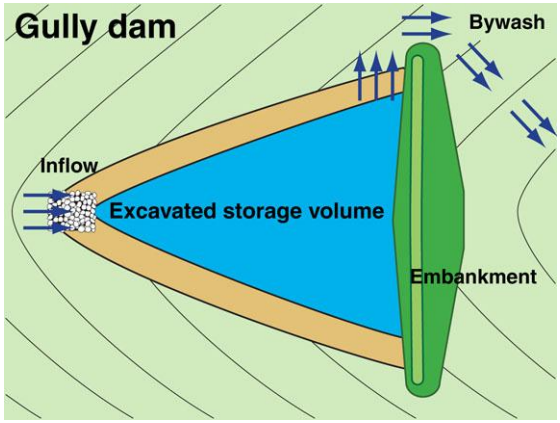
Retention basin

Retention basins

- A retention basin is a large open basin designed to retain a portion of the stormwater runoff either for water quality benefits, or to assist in reducing the volume of runoff discharged from a property.
- The need for a retention basin would be governed by local government rules associated with a local flooding study.
- These basins can be used as part of a farm's water storage system.



Retention basin



Gully dam

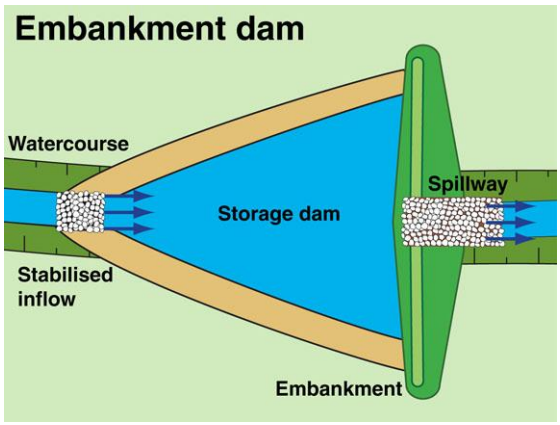
Gully dams

- Gully dams are formed across the flow path of a drainage depression, valley, gully, or unnamed watercourse.
- A gully dam should not be constructed across a State-recognised waterway.
- Bypass flows may be managed via a grassed bywash, or a formal spillway, depending on the site conditions (see Chapter 6).



Gully dam (Qld)

Types of farm dams – Embankment dams, weirs, lakes and ponds



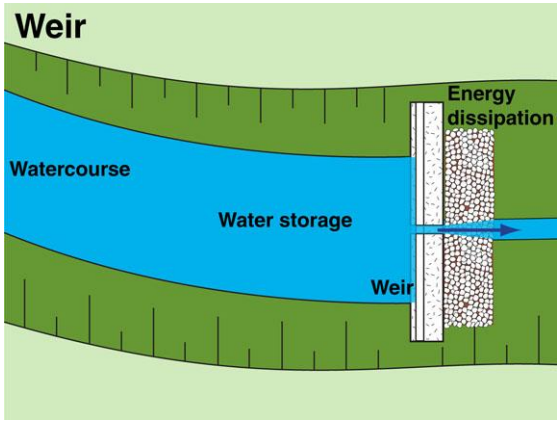
Embankment dam

Embankment (on-stream, instream) dams

- The term: 'embankment dam', has been used in this field guide to identify dams built over a watercourse that has well-defined bed and banks, whether or not the watercourse has been recognised by the State or Territory.
- This type of dam is basically the same as a 'gully dam', except that there may be a regular dry-weather inflow (stream flow) entering the dam, and embankment dams normally require a formal spillway, instead of a bywash.



Instream embankment dam (Qld)



Weir

Weirs, lakes and ponds

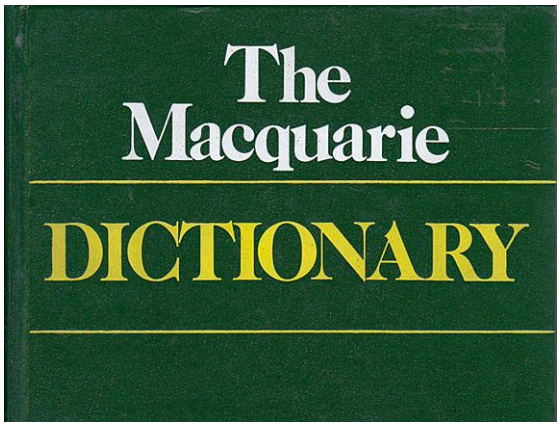
- The author is unaware of any 'official' naming convention, but lakes are typically found along a watercourse, while ponds are normally located off-stream.
- Ponds are normally fully recessed basins, while lakes often have a downstream weir to control water levels.
- Weirs are often found in waterways as a means of providing water storage for a single property (below), or a local community.



Instream weir (NSW)

2. Legal Issues and Risk Assessment

Introduction



Dictionary

Terminology

- Use of the term 'legal' usually means that the topic has something to do with the legal profession (e.g. 'legal papers').
- Use of the term 'lawful' usually means that the topic has something to do with the law (e.g. 'lawful conditions').
- In this chapter, the term 'waterway' shall refer to a watercourse recognised by a State or Territory (i.e. it will be identified on official waterway maps).



Stormwater runoff (Qld)

Stormwater runoff vs waterway

- The legal system treats stormwater runoff, stormwater drains, and gullies, differently from recognised waterways and watercourses.
- Common law is typically used when resolving disputes regarding the interference of stormwater runoff, stormwater drains, or gullies.
- It is State legislation that usually controls the management of waterways.

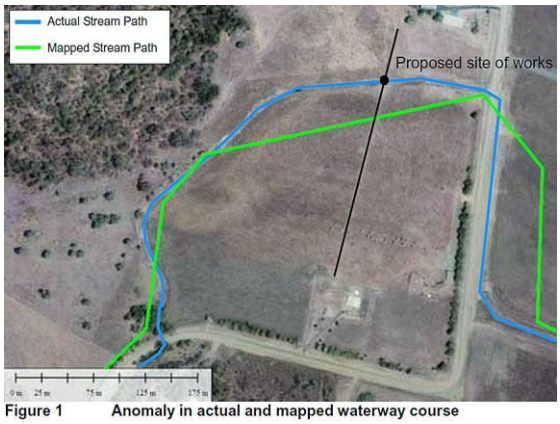


Figure 1 Anomaly in actual and mapped waterway course

Waterway map (Qld)

Your first action

- When planning a new farm dam, your first step should be to determine if the location of the proposed dam is:
  - across a gully, overland flow path, or an unrecognised watercourse
  - across an existing drainage easement
  - across a State recognised waterway or watercourse, or
  - located well off-stream (i.e. water needs to be pumped to the storage basin).

NSW GOVERNMENT Natural Resources Commission

State authority (NSW)

When is 'permission' required?

- If located across a gully: Permission is required only if the works are recognised within a local government planning scheme, or State legislation.
- If located across an easement: Permission is required from the easement owner.
- On a recognised waterway:
  - Department of Water, or Natural Resources, or Primary Industry, etc.
  - Department of Fisheries (possible)
  - Department of Environment (possible).

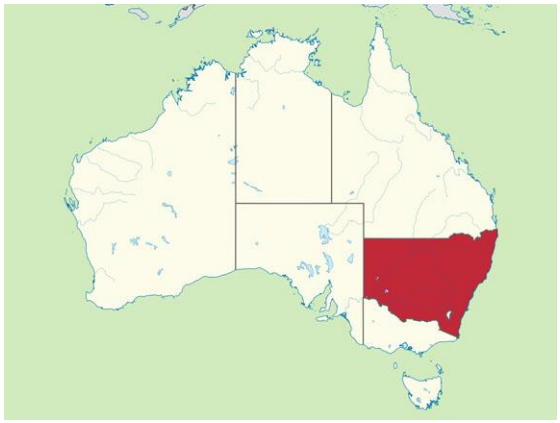
Referable dams



Referable dam (Qld)

Introduction

- If the sudden failure of a dam or weir could result in the loss of life, then the structure becomes a ‘referable dam’ or ‘prescribed dam’.
- The construction, inspection, and maintenance of these structures fall under the control of the State or Territory government.

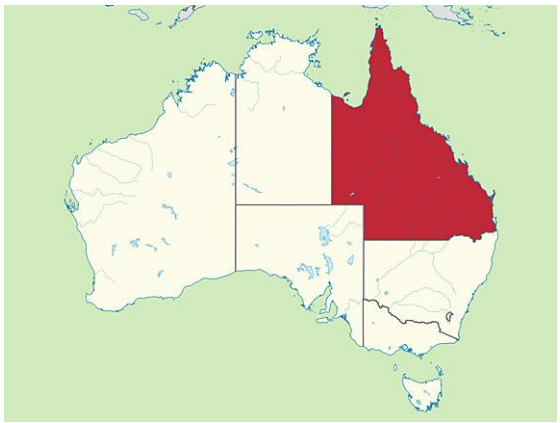


NSW

New South Wales

- Barry and Lewis (2002) report that in 2002 a ‘Prescribed Dam’ in New South Wales was defined as being:
  - 5 m or more high with a capacity of at least 50 Megalitres, or
  - 10 m or more high with a capacity of at least 20 Megalitres.

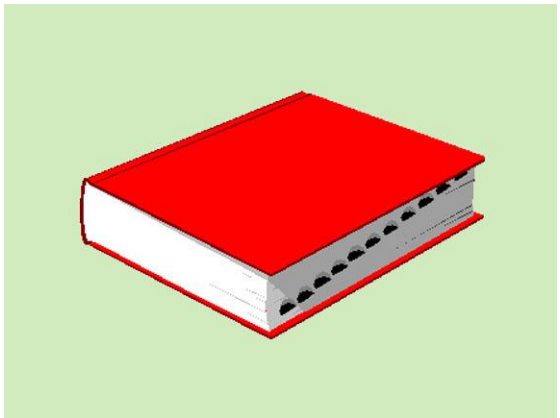
The above information is very dated (2002), so readers should check the latest information.



Queensland

Queensland

- In Queensland, as of 2017, a dam was referable if:
  - a failure impact assessment is required to be carried out under the Water Supply Act
  - that assessment states that the dam has or will have a Category 1 or Category 2 failure impact rating
  - the Chief Executive has, under the Water Supply Act, accepted the assessment.



Rules and regulations

Typical requirements of referable dams

- The dam must be designed by a suitably qualified engineer, who is experienced in the design of small dams (i.e. not an engineer with experience only on the design of large regional dams).
- Detailed engineering plans must be submitted with calculations and supporting documentation.
- Construction must be supervised.
- As-constructed plan must be submitted to the relevant authority.

Statutory requirements in Queensland (as of 2017)

Works constructed within a watercourse generally require approval under the *Water Act 2000* and need to satisfy all legal requirements of this Act. When applying this Act, the definition of a 'watercourse' as presented within the Act must be applied, not the definition provided within this Manual.

Under the *Water Supply (Safety and Reliability) Act 2008* (**Water Supply Act**) and under common law, responsibility for the safety of a dam rests with the dam owner. Dam owners may be liable for harm, loss and damage caused by the failure of a dam or the escape of water from a dam. Consequently, dam owners need to be committed to dam safety and have an effective dam safety management program. A dam safety management program is intended to minimise the risk of a dam failing and to protect life and property from the effects of such a failure, should one occur.

In addition, the embankment for a detention basin may require a failure impact assessment under the Water Supply Act and development approval from the State Assessment and Referral Agency under the *Sustainable Planning Act 2009* (Qld) if:

- the dam will be more than 10 m in height and have a storage capacity of more than 1500 ML; or
- the dam will be more than 10 m in height and have a storage capacity of more than 750 ML and a catchment area that is more than 3 times its maximum surface area at full supply level; or
- the Chief Executive gives the dam owner a notice to have a dam failure impact assessed (regardless of its size) because the Chief Executive reasonably believes the dam will have a Category 1 or Category 2 failure impact rating; or
- if works resulting in dams exceeding certain thresholds are proposed to an existing dam (see Section 343 of the Water Supply Act for details).

Referable dams are classified according to categories which are based on the population at risk if the dam fails, that being:

- dams with a Category 1 failure impact rating have 2 or more persons and not more than 100 people at risk
- dams with a Category 2 failure impact rating have more than 100 persons at risk.

If less than 2 people are at risk by the dam failing then the dam is not referable under the Water Supply Act. People are considered to be part of the population at risk if there is a 300 mm incremental rise in water level at a place of occupation in the event of dam failure.

A dam is referable if:

- a failure impact assessment is required to be carried out under the Water Supply Act
- that assessment states that the dam has or will have a Category 1 or Category 2 failure impact rating
- the Chief Executive has, under the Water Supply Act, accepted the assessment.

In addition, some dams were made referable by the transitional provisions in the Water Supply Act. Once a dam is accepted as being referable, the Chief Executive may impose safety conditions on the dam. These safety conditions effectively require a dam safety management program to be developed and implemented for the dam.

The legal system



Caution

Introduction

- **Note:** The author of this field guide is an engineer, not a lawyer.
- The author has had no training in legal matters.
- Therefore, the author cannot provide 'legal' advice.
- What is presented below are some observations of the legal system as made by the author during his time working as an engineer within the water engineering profession.



Money

The cost of legal action

There are typically three parts to the cost:

1. The cost of your legal team—in some courts, if you win, the opposition will pay your court costs, in other courts, no!
2. The fine for doing something wrong—if a dam fails, and damage is done, but you were not shown to have been negligent, then there should be no fine.
3. The 'clean-up' costs—even if you were shown not to be negligent, you still have to pay for the damage your dam has done to other properties.



Law courts

Who is to blame?

- It is common for people to identify the one person that is most at fault; however, the courts don't work that way.
- Court cases typically like to bring everyone into the case, and then the court assigns a percentage of the blame and a percentage of the 'costs' to each of the people or organisations found to be a fault.
- What should matter to **you** is **your** involvement, not the actions of others.

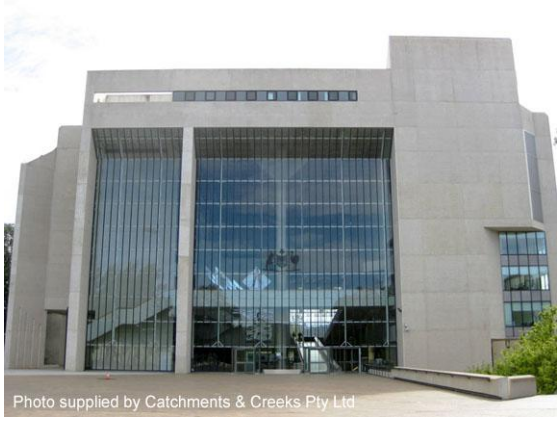


Embankment failure

What can go wrong?

- Dam failures, and dam construction, can cause many problems, including:
  - drowning
  - loss of life cause by the rush of water
  - cars washed-off a road cause by the sudden release of water from a dam
  - rising salt levels on an adjacent property
  - interference with the natural movement of fish cause by a dam's construction across a watercourse.

The application of ‘common law’ rights in drainage disputes



Australia’s High Court, Canberra



Concrete weir (Qld)



Overland flow



Flows caused by a water pipe failure

Common law

- Common law is a legal system that gives weight to the principle that it is unfair to treat similar facts differently on different occasions—meaning: judges’ decisions in active cases are informed by the decisions of previously settled cases.
- The common law system (known also as ‘case law’) forms the basis of the Australian legal system.
- **Note:** common law is only applicable in the absence of relevant ‘statute laws’, including local building codes.

Laws applicable to ‘watercourses’

- In most States the laws applicable to watercourses have been modified by statute law, and thus the principles of common law are unlikely to apply.
- Each State has its own definition of what constitutes a watercourse—in some cases, these definitions vary from region to region within the State.
- Approval is usually required from the State before a weir or dam is constructed across a watercourse (separate from any local government approvals).

Laws applicable to ‘overland flow’

- Common law principles typically apply to the interference of overland flows (i.e. stormwater runoff).
- The leading court case that outlines the common law principles applicable to the management of overland flows passing across a property boundary is *Gartner v Kidman* (1962) 108 CLR 12.
- An overview of how these common law principles **may** apply to farm dams is provided over the following pages.

Application of the common law principles

- The following common law principles relate only to surface waters that come naturally upon the land from which it flows, as distinct from water artificially brought or concentrated there and allowed to escape.
- These laws are therefore not applicable to cases such as a burst water pipe, or the failure of an up-slope or upstream property dam.

Common law principles applicable to overland flows

Common law principle #1

- **The owner or occupier of an up-slope property is not liable merely because surface water flows naturally from their land on to lower land.**

This means:

- Unless otherwise required by statute laws, it is acceptable for stormwater run-off to flow naturally down a slope.
- The existence of a property boundary does not necessarily make this 'natural' passage of surface water unlawful.
- This common law principle does not necessarily apply if statute laws (government enacted laws) exist that stipulate an alternative stormwater management outcome.

Common law principle #2

- **The owner or occupier of an up-slope property may be liable if such water is caused to flow in a more concentrated form than it naturally would.**
- **The proprietor of the down-slope land may recover damages from, or in appropriate cases obtain an injunction against, the proprietor of the higher land who is liable to an action because he has concentrated or altered the natural flow.**

This means:

- This means that the focus is on taking all reasonable and practicable measures to maintain the 'natural' flow conditions of stormwater run-off as it passes from one property to another.
- After flows leave a farm dam, these flows must be given sufficient space to return to a flow condition (i.e. velocity width and depth) that would be considered 'natural' for the land contours.
- Stormwater may be considered to have been 'caused to flow in a more concentrated form than it naturally would' if the flow has increased in peak discharge, peak velocity, flow volume, or flow per unit width, at any particular point, relative to the flow conditions that would naturally occur.
- The fact that an up-slope dam reduces the volume of water entering a down-slope property does not mean that this flow could not be considered to be concentrated if there is an unnatural change in velocity, width, duration of flow, etc.
- This does **not** mean that any form of flow concentration is unlawful.
- Some minor flow concentration may be considered to be lawful if it is the direct result of the 'normal use of the land', and this flow concentration does not cause harm to the down-slope land that would not naturally have otherwise occurred.
- For example, a reasonable property fence between two properties may cause a reasonable concentration of flows.
- It is noted that if a concentration of flow has been tolerated in the past by a down-slope property owner/occupier, this does not mean that corrective measures may not be required some time in the future to minimise the risk of future impacts.

Common law principles applicable to overland flows

Common law principle #3

- **If a more concentrated flow occurs simply as the result of the 'natural' use of an up-slope property, then generally speaking, the owner or occupier of that property is not liable.**
- **What is a natural use is a question to be determined reasonably having regard to all the circumstances, including the purposes for which the land is being used and the manner in which the flow of water was increased: as for example whether it is agricultural land drained in the ordinary course of agriculture, whether it is timbered land cleared for grazing, whether it is a mining tenement, or is used for buildings and so forth.**

This means:

- These statements reinforce the previous discussion that some forms of flow concentration may be considered lawful if they are no more than what would be expected from the normal use of the land.
- The 'normal use of the land' depends on issues such as:
  - the 'zoning' of the land as defined within a council planning scheme
  - the types of lawful land use activities commonly associated with the land
  - the normal changes, from time to time, that exist in the operation of the land as a result of the normal maintenance of those items that can influence the flow or concentration of stormwater run-off.
- This means that the owner/occupier of an up-slope property would not necessarily be held liable for damages caused to a down-slope property as a result of the normal operation of a farm dam on a rural property that would normally contain an operational farm dam.
- However, the owner/occupier of an up-slope property **may** be held liable for damages caused by the concentration of flows resulting from the 'negligent' maintenance of a farm dam.
- In essence, this means that there is an obligation on the up-slope property owner and/or occupier to:
  - take all reasonable measures to minimise any adverse impacts on down-slope properties caused by the normal use of their up-slope land.
- Similarly, there is an obligation on the down-slope property owner and/or occupier to:
  - take all reasonable measures to design, manage and defend their property in a manner that allows existing and future owners and occupiers of up-slope lands to operate their land for normal lawful purposes.
- The fact that a down-slope property has, for some time, relied upon the flow of water into their farm dam, does not prevent an up-slope property from constructing a new farm dam on their up-slope property, which would reduce the flow of water into the down-slope property from time to time, if the operation of such farm dams represents the normal use of the land.

Common law principles applicable to overland flows

Common law principle #4

- **Stormwater is considered to be flowing in a more concentrated form than it naturally would if, by the discernible work of man, the levels or conformations of land have been altered, and as a result the flow of surface water is increased at any particular point.**

This means:

- This statement outlines **one** example of circumstances that could result in the unnatural concentration of flow.
- This example relates specifically to the land form changes applicable to the High Court case of *Gartner v Kidman* (1962) 108 CLR 12 to which these common law principles were applied.
- However, this does not imply that this is the only means by which stormwater can be flowing in a more concentrated form than it naturally would.
- The trial judge in the case of *Alamdo Holdings Pty Ltd v Bankstown City Council* (2003) 134 LGERA 114, found that even a significant increase in the frequency with which land will be inundated can constitute a significant interference with the use and enjoyment of land, and hence could give rise to an actionable nuisance.

Common law principle #5

- **The proprietor of higher land is not liable for a more concentrated flow from their land if it is the result of work done outside their land by someone else, and for the doing of which they are not responsible, as for example by the paving and guttering of public roads by municipal authorities.**

This means:

- This statement acknowledges that the owner or occupier of an up-slope property cannot be held liable for an increase in stormwater flow, or a concentration of such flow, if such changes have resulted from flows entering their property from a third property, or from an adjoining roadway.
- This means that complaints about the concentration of stormwater run-off entering a down-slope property can become very complex if the immediate up-slope property is not the sole source of this stormwater run-off.
- For example, an up-slope property owner should not be held liable for damages caused by an increase in stormwater run-off if the source of this increase in flow can be directly linked to the operations of a farm dam on a third property.
- However, the above statement is only applicable if the third property is not under the management or ownership of the owner or occupier of the immediate down-slope property through which it flows before damaging a further down-slope property. For example, if several up-slope properties were owned or managed by a single person or entity.

Common law principles applicable to overland flows

Common law principle #6

- **The previous statements concerning the concentration of surface waters relate to cases when the increased flow results from work done when the higher land and the lower land were held by separate proprietors.**
- **Different considerations apply when the lower land receives a concentrated flow as the result of work which was done when it and the higher land were in the same ownership and possession.**

This means:

- An up-slope property owner cannot claim immunity from prosecution simply because the increased stormwater flow originated from an adjoining up-slope property if both properties are owned by the same person.
- This common law principle highlights that the resolution of stormwater disputes is critically linked to two factors:
  - the current ownership of the associated allotments, and
  - the ownership of the allotments at the time that the farm dam and associated drainage systems were installed, and/or the stormwater-altering activities were conducted.
- Consequently, when documenting a stormwater complaint, it is very important for the complainant to establish a time-line of activities, and to identify the ownership of each of the associated properties at each stage of this time-line.
- This common law principle also highlights that the owner or occupier of a down-slope property is unlikely to have a legitimate complaint about the damages caused to their property as a result of stormwater flows discharging into their property from an up-slope property or council roadway if:
  - the drainage system was established at the time of the original land subdivision when both properties existed as a single property, or
  - the drainage system was established at a time when both the roadway and down-slope property were owned or managed by a single entity.
- It is therefore advantageous for councils to ensure that all stormwater infrastructure is constructed during the initial subdivision of the land while all affected properties are under the control of a single entity.

Common law principles applicable to overland flows

Common law principle #7

- **Although the lower proprietor has no action against the higher proprietor because of the natural non-concentrated flow of water from the up-slope land, they are not bound to receive it.**
- **The lower proprietor may put up barriers and pen it back, notwithstanding that doing so damages the upper proprietor's land, at all events if the lower proprietor uses reasonable care and skill and does no more than is reasonably necessary to protect the enjoyment of their own land.**
- **But the lower proprietor must not act for the purpose of injuring their neighbours.**
- **It is not possible to define what is reasonable or unreasonable in the abstract. Each case depends upon its own circumstances.**

This means:

- In effect, these common law principles set out two important outcomes:
  - the owner or occupier of a down-slope property must design, maintain and defend their property in a manner that does not unreasonably prevent the owner or occupier of an up-slope property enjoying the normal use of their up-slope land, and
  - the owner or occupier of an up-slope property must design, maintain and defend their property in a manner that does not unreasonably prevent the owner or occupier of a down-slope property enjoying the normal use of their down-slope land.
- This means that:
  - the existence of a drainage problem within a down-slope property should not necessarily prevent further development, or the conducting of stormwater-altering activities, within an up-slope property, and
  - when building a home or landscaping a property, the owner or occupier of that property must consider, and account for, likely changes in stormwater flows caused by their neighbour's normal use of their land, and
  - a down-slope property owner or occupier can take reasonable steps to defend their home, swimming pool, or other normal uses of their land against stormwater run-off even if this causes unavoidable adverse impacts on the up-slope property from which the stormwater was discharged.
- A very important principle noted here is that while defending your property from the effects of stormwater run-off, you can **do no more than is reasonably necessary** to protect the enjoyment of your land.
- No property owner or occupier should be allowed to act in a malicious manner, or adopt a damaging course of action, if a reasonable alternative exists that allows their neighbour the continued enjoyment and use of their land.
- **Warning:** this clause is easy to misinterpret, and readers are advised to seek professional legal advice if they feel this clause is relevant to their situation.

Common law principles applicable to overland flows

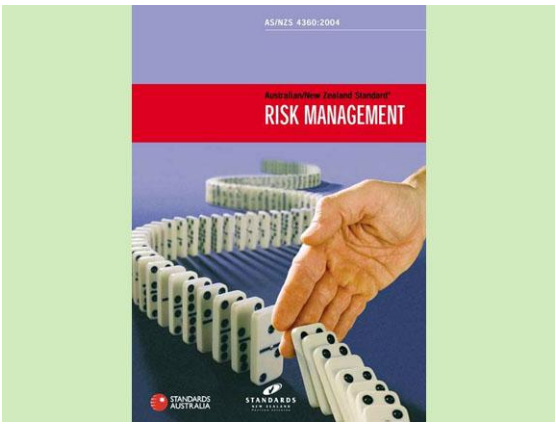
Common law principle #8

- **It may be added that the proprietor's right to defend their land against water coming upon it by erecting barriers, is generally speaking restricted to penning it back on to the higher land whence it would otherwise have naturally come.**
- **It does not entitle them to divert it on to the land of a third proprietor to which it would not have naturally gone to the damage of that proprietor.**

This means:

- This final principle is very important in an urban context because stormwater run-off often flows naturally, in a diagonal alignment, across several residential properties, and as a result, can cause disputes between the numerous property owners.
- The owner or occupier of a down-slope property can defend their property and the enjoyment and use of their land from the adverse impacts of stormwater run-off provided they:
  - cause the flow conditions of the stormwater run-off to be altered only on their land, and/or on the land from which the stormwater run-off would otherwise have naturally come
  - do no more than is reasonably necessary to protect the enjoyment of their own land
  - do not cause the stormwater to be diverted onto the land of a third proprietor to which it would not have naturally gone
  - do not cause the stormwater to be diverted in a manner that causes the flow to be unnaturally concentrated, or to travel along an unnatural flow path.
- Of course, almost any change in the management of stormwater flows can occur lawfully if all affected parties (including regulatory bodies) agree to the proposed changes.
- However, it is noted that a verbal or even a written agreement can be lawfully withdrawn at any future date, and that such agreements are not necessarily binding after a change of ownership of the land.
- Consequently, residents are advised to obtain agreements in the form of a registered easement that is attached to the land, rather than a verbal or even written agreement that is linked only to the landowners that made the agreement.
- This means that a property owner wishing to construct a new dam that may alter the flow conditions on a neighbouring property should get written agreement of the fact by the affected property owner while good interactions exist, and before any change in ownership of the land.

Assessing the risk of a drowning



AS 4360:2004 Risk Management

Reference document

- Australian Standard AS 4360 *Risk Management,* provides guidance on:
  - assessing risks
  - ranking risks
  - establishing an internal framework to manage risk.
- AS 4360 was used as the basis for the development of the risk assessment matrix as presented in the *Queensland Urban Drainage Manual*, which has been further modified for this field guide.



Inspection of the dam

Consideration of 'likelihood' and 'consequence' issues

- Within the Australian Standard AS 4360, the final risk matrix considers the two main issues of 'likelihood' and 'consequence'.
- The first risk assessment table (Table 2.3) considers the risk of a child drowning in the dam.
- The second risk assessment table (Table 2.6) considers the risk of a dam failure potentially resulting in a loss of life.



Accessible to children

Proposed risk assessment procedure

- The risk assessment procedures presented over the page were developed as part of the original 2026 production of this field guide.
- The risk assessment procedures are presented only as a guide, and as of August 2026, neither are recognised by any authorities.
- Landowners are required to seek information on the current risk assessment procedures.



Consideration by the landowner

Consequences of the assessment outcome

- The following risk assessment procedures do not present any specific 'actions' for a landowner.
- The actions taken by a landowner will depend on local values and concerns, and will likely vary from region to region across the country.
- The key outcome of this process is for the owners of farm dams to at least go through a process of considering the safety risks associated with any existing or proposed water storage.

Tables 2.1 to 2.3 present an unofficial risk assessment process developed by the author for assessing child safety around farm dams.

Table 2.1 – Location classification

Location class	Location description
Class A	Within or immediately adjacent to a school or childcare centre, including the adjoining road reserve.
Class B	Within 100 metres of an existing or future urban residential area, or public gathering area, such as a park, shopping centre, business centre, entertainment, or sporting facility (i.e. near the boundary between urban and rural, commercial and rural, or industrial and rural), but not just a roadway.
Class C	More than 100 metres from a school, park, childcare centre, existing or future urban residential area, or public gathering area, such as a park, shopping centre, business centre, entertainment, or sporting facility.
Class D	More than 1000 metres from a school, park, childcare centre, existing or future urban residential area, or public gathering area, such as a park, shopping centre, business centre, entertainment, or sporting facility.
Class E	Within an area surrounded by heavily trafficked arterial roads, or is otherwise considered inaccessible to a child.

Table 2.2 – Access classification

Access class	Fencing description
Class 1	Water storage has no fencing, broken or incomplete fencing, or is surrounded by open boundary fencing.
Class 2	Water storage is surrounded by open barbed wire fencing.
Class 3	Water storage is surrounded by exclusion fence less than 1200 mm high.
Class 4	Water storage is surrounded by exclusion fence less than 1800 mm high.
Class 5	Water storage is surrounded by pool safety fence or an exclusion fence more than 1800 mm high.

Table 2.3 – Suggested child safety ranking

Location class	Access class				
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**
Class A	**Very high**	**Very high**	High rank	High rank	Medium rank
Class B	**Very high**	High rank	High rank	Medium rank	Low rank
Class C	High rank	High rank	Medium rank	Medium rank	Low rank
Class D	Medium rank	Medium rank	Low rank	Low rank	Low rank
Class E	Low rank	Low rank	Low rank	Low rank	Low rank

This table is not to be confused with the 'risk rating' presented in Table 2.6. The above 'ranking' categories are not used for any specific purpose throughout the rest of this field guide. Unless otherwise stated within government regulations, the purpose of the above assessment is solely to provide information for the landowner.

Description of fencing options



Open timber fence (NSW)

Open boundary fencing

- These fences can be used to identify a property or field boundary, but they will not stop access by a determined individual.



Barbed wire fencing (Qld)

Open barbed wire fencing

- These fences can be used to identify a property boundary, but they will not stop access by a determined individual, especially a small child.



Protection of a stormwater inlet (NSW)

Pool safety fencing

- These fences are designed to prevent a child climbing over the fence.
- Included in the fence design are special gate and locking mechanisms.

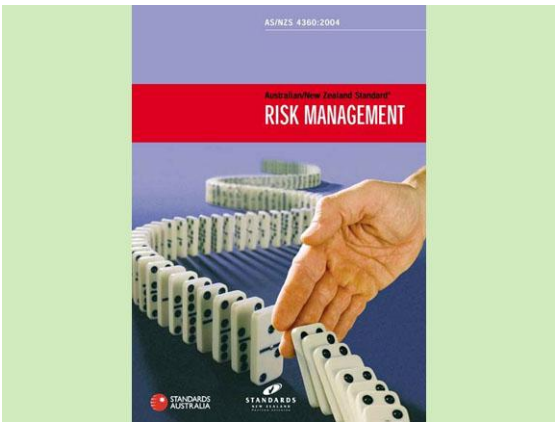


Exclusion fence (Qld)

Exclusion fencing

- Exclusion fencing is used to exclude all but the most determined adult (excluding authorised personnel) from accessing an area.
- The fencing typically includes chain-locked gates.

Assessment of low, medium and high-risk dams (small dams only)



AS 4360:2004 Risk Management

Reference document

- Australian Standard AS 4360 *Risk Management,* provides guidance on:
  - assessing risks
  - ranking risks
  - establishing an internal framework to manage risk.
- AS 4360 forms the basis for the following risk assessment procedure.



Risk assessment

Application of the risk assessment

- Tables 2.4 to 2.6 present an unofficial risk assessment process developed by the author for assessing general safety risks downstream of small farm dams.
- The purpose of Table 2.4 is to classify the risk of the flow from a failed dam coming into contact with one or more persons downstream of the dam.
- The purpose of Table 2.5 is to classify the risk of the flow conditions causing material damage, physical injury, or loss of life.



Design

Low and medium risk dams

- Table 2.6 presents a risk assessment matrix associated with the risk of damage or harm resulting from a dam failure.
- For a low risk site, this field guide suggests that the dam/s bywash or spillway can be designed by an unqualified person, possibly using the simplified procedures as presented within this field guide.
- For a medium risk site, it is recommended that the design is performed by a suitably trained professional.



Caution

High risk dams

- High risk sites are considered referable dams.
- These dams need to be registered with the State or Territory.
- The design procedures presented within this field guide are **not** suitable for such structures.

Table 2.4 – Contact classification

Contact class	Description of site conditions
Class A	The dam is located less than **X** metres upstream of a childcare centre, school, church, community centre, or retirement village, where the waters released from the dam would pass through such a location. X = 1000 + 100 times the square root of the potential water storage volume above natural ground level (measured in ML). **X** = 1000 + 100.(volume)$^{0.5}$ Thus; for 25 ML volume, **X** = 1000 + 100(25)$^{0.5}$ = 1500 metres.
Class B	The dam is located less than **X** metres upstream of an urban/residential area where the waters released from the dam would pass through such a location.
Class C	The dam is located less than **X** metres upstream of a commercial or industrial area where the waters released from the dam would pass through locations occupied from time to time by people.
Class D	The dam is located more than **X** metres upstream of a childcare centre, school, church, community centre, or retirement village, urban/residential area, commercial or industrial area where the waters released from the dam would pass through such a location. OR The dam is located less than **X** metres upstream of a roadway where the waters released from the dam would pass over the roadway.
Class E	The dam is located more than **X** metres upstream of a roadway where the waters released from the dam would pass over the roadway.

The factors that are likely to affect these risks include: (i) the amount of warning a person may have of a sudden change in flow conditions, (ii) the likely depth of flow at the point of contact, (iii) the likely velocity of flow at the point of contact, (iv) the coefficient of friction of the land surface at the point of contact, (v) the likely stability of the land surface at the point of contact, (vi) any safety risks associated with the waters or land into which a person would be swept by the released flow, (vii) the persons being either very young or very old.

Table 2.5 – Flow classification

Flow class	Description of likely flow conditions
Class 1	The dam is classified as a 'referable dam' (or similar terminology).
Class 2	The dam has a bywash or spillway passing through or over a constructed earth embankment.
Class 3	The dam has a bywash or spillway passing around a constructed earth embankment, and part of the water storage rests above natural ground level from time to time.
Class 4	The storage basin is fully recessed below natural ground level, but there is the risk of bywash/spillway failure (includes the risk of gully erosion migrating up to the dam).
Class 5	The storage basin is fully recessed below natural ground level (i.e. no risk of embankment or spillway failure).

Table 2.6 – Suggested risk rating (damage or harm resulting from a dam failure)

Contact class	Flow class				
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**
Class A	**High risk**	**Medium risk**	**Medium risk**	**Medium risk**	Low risk
Class B	**High risk**	**Medium risk**	**Medium risk**	**Medium risk**	Low risk
Class C	**High risk**	**Medium risk**	**Medium risk**	Low risk	Low risk
Class D	**High risk**	**Medium risk**	Low risk	Low risk	Low risk
Class E	**High risk**	Low risk	Low risk	Low risk	Low risk

3. Soils

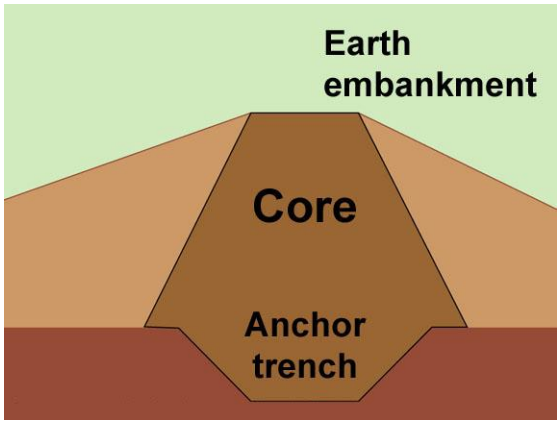
Introduction



pH testing

Introduction

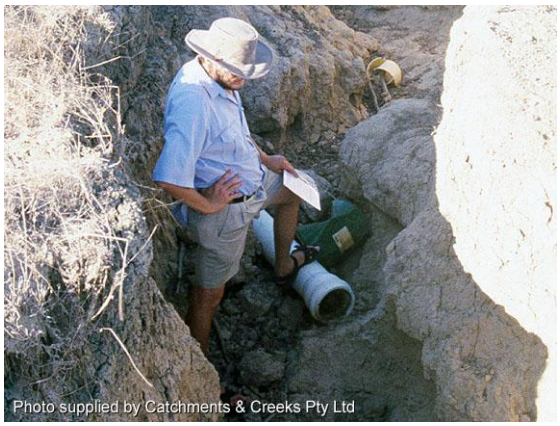
- In the civil construction, the official testing of soils for their structural properties is normal practice.
- In agriculture, the testing of soils for their chemical properties and nutrient content is essential if soil additives are to be applied.
- In the planning of farm dams, there are several laboratory-based soil tests that can be performed, as well as a few (unofficial) in-field soil tests.



Embankment with a central core

Dam embankment with a central core

- If an embankment is constructed from different soils (e.g. a dam with a central core), then:
  - all the soil zones must be compacted to an equal standard; otherwise, uneven settlement can occur resulting in cracking, and potentially, tunnel erosion
  - the outer, more permeable zones, are required to provide structural stability to the central core, and be able to drain excess soil moisture without slumping.



Site inspection and soil sampling

Soil testing

- For a farm dam, the soil properties of greatest interest are:
  - soil texture
  - susceptible to tunnel erosion
  - dispersive properties
  - soil permeability
  - shrink–swell potential
  - optimum moisture content for soil compaction.



Particulate components of soil

Soil texture (clay and silt content)

- Once disturbed by an erosion process, soil quickly breaks down into its constituent components, which includes:
  - clays
  - silts
  - sands, and
  - gravels.
- Soil testing can provide the percentage of each particle size.
- The desired clay content for use in dam construction is 25–40%.

Soil properties



Tunnel erosion (outlet of the tunnel)

Soils that are susceptible to tunnel erosion

- To minimise the risk of tunnel erosion, the soil should have less than 30 percent dispersion of those particles smaller than 5 microns (Ritchie, 1963).
- Based on the EAT assessment, it is unlikely that earth embankments formed from Class 3 aggregates will leak (Charman & Murphy, 2007).
- Class 4, 5, 6, 7 and 8 aggregates are not susceptible to tunnel erosion.
- EAT = Emerson Class aggregate test.



Eroding (rilling) of earth bank (Qld)

Soils with dispersive properties

- Soil dispersion is the ability of some clay particles to freely disperse and enter passing water, or the water column, when the soil becomes wet.
- Soil dispersion can be both a dam owner's best friend, and worst enemy.
- A minor degree of soil dispersion is essential to allow a soil to become impervious, and thus to control leakage.
- However, major soil dispersion can cause tunnel erosion, the rilling of sidewalls, and the total failure of the spillway.



Sandy soil with minimal clay (EAT test)

Soil permeability

- Soil permeability is a measure of how well water can percolate through the soil.
- A dispersion percentage less than 10% is likely to result in a soil with good permeability (therefore avoid these soils).
- Highly permeable soils should not be used in the construction of farm dams.
- **Warning:** Class 4 to 8 soils (EAT test), particularly Class 6 soils, can be too permeable for dam construction.

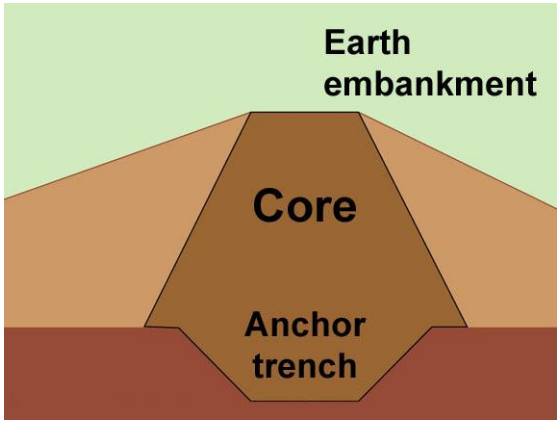


Cracking clay (SA)

Shrink–swell potential

- The shrink-swell potential of a soil relates to the capacity of a soil to expand and shrink in volume as a result of changes in moisture content.
- Soils with < 12% shrinkage values may not seal, and may experience tunnel erosion if dispersive.
- Soils with shrinkage values of 12 to 22%, that are not dispersive, can aid the sealing of a farm dam.

Desirable soil properties for the dam's core



Central core of the embankment



Clayey soil

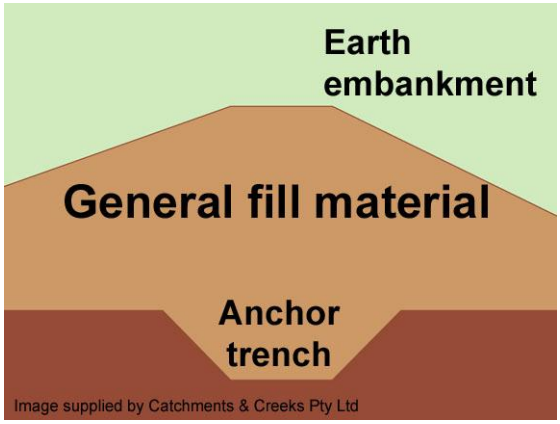
Desirable soil properties of the core

- Suitable soil groups include Unified Soil Classification (USC) Groups GC, SM (with good compaction), SC, CL (caution), CH (caution).
- The preferred soils suggested in Barry Lewis (2002) are: GC, SC, CL or CH—these soils are stable and impervious when well compacted, to at least 85% of Proctor Maximum dry density.
- To achieve this, the soil should be close to the optimum moisture content for the compaction plant, be placed in layers less than 15 cm thick, and be compacted with four complete passes of a crawler tractor or roller.
- For crawler tractors, the soil should be sufficiently moist to be made to be made into a thread 10 mm thick, but not moist enough to be rolled thinner than 3 mm without breaking.
- Minimum batter grades are 1:3 (V:H) upstream, and 1:2.5 downstream.

Table 3.1 – Desirable soil properties of the core

USCS	Clay %	Silt + Fine Sand %	Emerson EAT Class	Dispersion	Expansion	Shrinkage
				< 5 um (%)	%	%
CH	>40		1 or 2	50-65	0-20	0-12
CH	"		2 or 3	30-50	0-20	0-12
CH	< 40 %		2 or 3	30-50	0-20	0-12
MH	< 25 %		2 or 3	30-50	0-20	0-12
MH	"		3	10-30	20-30	12-17
MH	> 25 %		2 or 3	30-50	0-20	0-12
CL		< 50 %	2 or 3	30-50	0-20	0-12
CL		"	2 or 3	30-50	20-30	12-17
CL		> 50 %	3	10-30	0-20	0-12
CL		"	3	10-30	20-30	12-17
ML			2 or 3	30-50	0-20	0-12
ML			2 or 3	30-50	20-30	12-17
SC			2 or 3	30-50	0-20	0-12
SC			2 or 3	30-50	20-30	12-17
SC			3	10-30	0-20	0-12

Desirable soil properties for general fill material



General fill material



Fill material

Desirable soil properties of the outer zones

- Suitable soil groups include Unified Soil Classification Groups: GW, SW, CL (requires good erosion protection).
- Second choice soils: GP, GM, GC, SP, SM, SC, CH.
- Barry Lewis (2002) suggests the following soil groups are considered suitable as general fill material: GW, GP, SW or SP.
- Take care to achieve good compaction, preferably with moist soil.
- Compaction should be equivalent to that achieved within the 'core' (if any).
- If the soil is dry (i.e. cannot be moulded), reduce layer thickness to less than 15 cm.
- Minimum batter grades 1:2.5 (V:H) upstream, and 1:2 downstream, except for CH and MH classifications when they should be decreased to 1:3 and 1:2.5 respectively.

Table 3.2 – Desirable soil properties for general fill material

USCS	Clay %	Silt + Fine Sand %	Emerson EAT Class	Dispersion	Expansion	Shrinkage
				< 5 um (%)	%	%
CH	> 40 %		3	10-30	0-20	0-12
CH	> 40 %		3	10-30	0-20	0-12
MH	< 25 %		3	10-30	0-20	0-12
MH	> 25 %		3	10-30	0-20	0-12
CL		< 50 %	3	10-30	0-20	0-12
CL		< 50 %	3	10-30	**20-30**	**12-17**
ML			3	10-30	0-20	0-12
ML			3	10-30	**20-30**	**12-17**
SC			3	10-30	**20-30**	**12-17**

Jar Settling Test (field test)

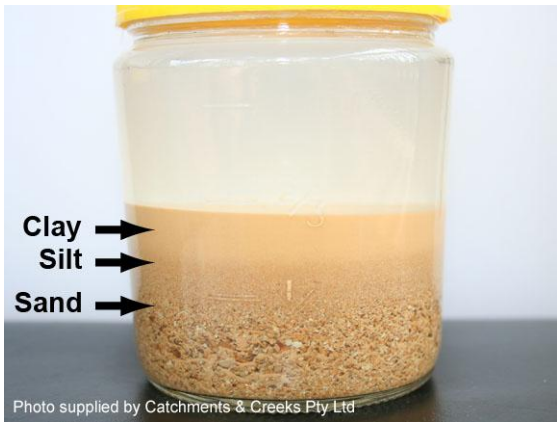


Photo 3.1



Photo 3.2



Photo 3.3



Photo 3.4

Test procedure

- The jar settling test is primarily used to indicate the settling qualities of a soil, but it can also identify a soil that may be dispersive.
- The test involves placing a crushed soil sample in a clear jar containing distilled (de-ionised) water.
- The sealed container is shaken vigorously to further break-up the soil sample.
- The jar is then left undisturbed for up to 5 days.
- If the suspended soil settles leaving the water clear, then there is a low risk that the soil is dispersive (Photo 3.3).
- If the settled soil sample leaves the water ‘slightly’ cloudy after 5 days, then the soil may be dispersive (Photo 3.2).
- If the water remains significantly cloudy after 5 days, then there is a high risk that the soil is dispersive (Photo 3.4).
- This test can also be used to obtain a visual indication of the proportions of clay, silt and sand, as shown in Photos 3.1 and 3.2.

Aggregate Immersion Test (field test)



Slightly dispersive soil

Test procedure

- The ***Aggregate Immersion Test*** can be used as an 'indicator' of dispersive soils.
- The test involves filling a dish with distilled water (generally available at petrol stations and supermarkets) to a depth sufficient to cover the soil samples.
- Several dry, hard clumps of soil are gently placed in the water.
- The water is then observed for colour changes (**after** all the air has escaped).



Non-dispersive, non-slaking soil

Non-dispersive soil

- If the water remains clear and the boundary of the soil clumps remains clearly defined, then the soil is likely to be non-dispersive.
- If the soil clumps are loose or otherwise heavily disturbed, then the soil clumps will likely separate into smaller pieces when first placed into the water—this does not indicate that the soil is dispersive.
- Air escaping from the soil can also cause the clumps to fall apart—this also does not indicate that the soil is dispersive.



Dispersive soil

Dispersive soils

- If the water discolours both horizontally and vertically around the soil samples, then the soil could be dispersive.
- Highly dispersive soils will collapse in less than 10 minutes.
- Caution: using tap, tank or groundwater can sometimes mask the dispersive reaction due to minerals and/or chemicals in the water.



Slaking soil

Slaking soils

- Slaking soils are soils that readily collapse in water, but do not necessarily cloud the water.
- If the water remains clear, and the clumps completely collapse and **spread horizontally**, then the soil could be a slaking soil.
- Slaking soils commonly occur within regions containing granite rock.
- These soils can be highly erodible, especially if disturbed by pipe trenching.

Visual identification of dispersive soils

Textured surfaces

- Dispersive and slaking soils often display textured patterns on those surfaces that are not directly exposed to rainfall.
- This textured pattern can result from raindrop splash bouncing off adjacent soil surfaces, or the result of light rainfall falling directly on the soil.
- The textured surface often looks similar to the surface of a white ant nest.



Textured surface not exposed to rain



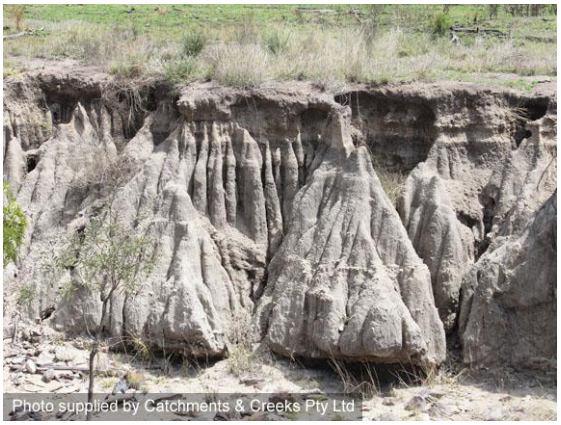
Textured surface of eroded soil



Textured surface

Fluting

- 'Fluting' is a type of rill erosion represented by a series of vertically elongated grooves (flutes) that form down the gully sides.
- In dispersive or sodic soils, these rills are normally deep, narrow and regularly spaced across the slope.
- When soils are dispersive, it is very common for the rills to be significantly deeper than they are wide.



Fluting erosion (Qld)



Fluting erosion (Qld)



Fluting and tunnel erosion (Qld)

Visual identification of dispersive soils

Tunnel erosion

- The existence of tunnel erosion is a common indicator of dispersive or sodic soils (a 'sodic soil' simply being a soil that disperses due to excess sodium).
- The outlets of these tunnels can often appear like normal rills, but further inspection should reveal the tunnel inlets up-slope of the rills.
- The inlets of the tunnels are often found close to the top edge of the gully bank; however, some tunnels can extend several metres into the gully bank.



Deep rilling and outlet of tunnels (Qld)



Entry to a tunnel (Qld)



Tunnel erosion along edge of gully (SA)

Deep rilling with near-vertical sides

- When dispersive soils first erode, the erosion is often (but not always) deeper than it is wide, and the sides of the erosion are often near-vertical.
- However, it is noted that this form of erosion can also exist if the soil has one or more of the following attributes:

– slaking
– non-cohesive (sandy)
– poorly compacted
– very low in organic matter.



Deep rilling along drainage lines



Lateral bank erosion (Qld)



Deep rilling/gully erosion (SA)

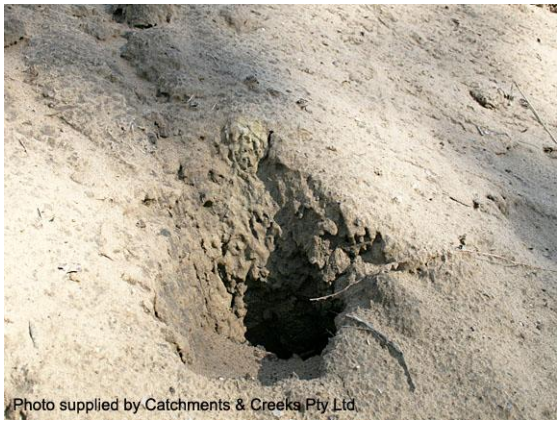
Visually identifying slaking soils



Deep rilling within a sandy soil

Deep rilling with near-vertical sides

- When slaking soils and non-cohesive (sandy) soils first erode, the erosion is often (but not always) deeper than it is wide, and the sides of the rill are often near-vertical.
- This form of erosion can exist if the soil has one or more of the following attributes:
  - slaking
  - non-cohesive (sandy)
  - poorly compacted
  - very low in organic content.



Inlet to tunnel erosion in pipe trench

Tunnel erosion

- Both dispersive and slaking soils are susceptible to tunnel erosion if used as backfill within a pipe or service trench.



Erosion of backfilled service trench

Erosion of compacted backfill

- Slaking soils can still be highly erodible even if firmly compacted, especially if the soil lacks sufficient organic matter, such as a very sandy soil.



Bank not exposed to direct rainfall

Textured surface

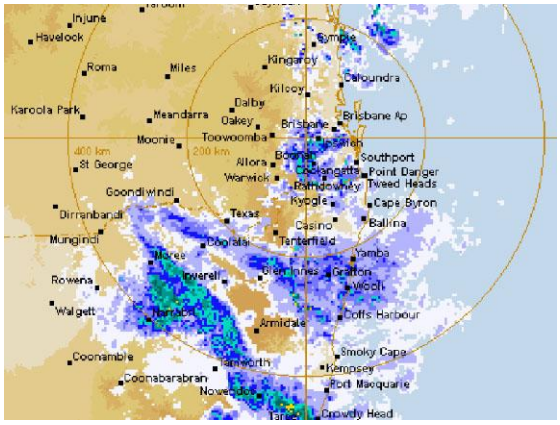
- Both dispersive and slaking soils can display textured patterns on those underside surfaces that are not directly exposed to rainfall.
- These surfaces become textured as a result of raindrop splash bouncing off adjacent surfaces.

4. Catchment Hydrology

Introduction



Approaching storm (Qld)



Weather radar map (BoM)



Storm analysis

Go to Chapter 1

Purpose of chapter

- The difference between this chapter, and hydrology presented in Chapter 1, is that this chapter focuses on estimating the peak discharge from a single storm, while Chapter 1 focuses on the expected annual runoff volume.
- Readers should not use this chapter as:
  - a general guide to storm hydrology; or
  - to determine catchment hydrology for large dams (i.e. dams that are not classified as 'small dams').

Terminology

- *Hydrology* is the study of the movement of water over or under the land, and it is this science that we use to calculate 'design discharges' (flow rates).
- A design discharge (Q) is the estimated peak discharge (flow rate) from a drainage catchment based on:
  - a specified storm frequency (Y), and
  - the critical storm duration (T_C) determined for the gully.

(BoM means the Bureau of Meteorology)

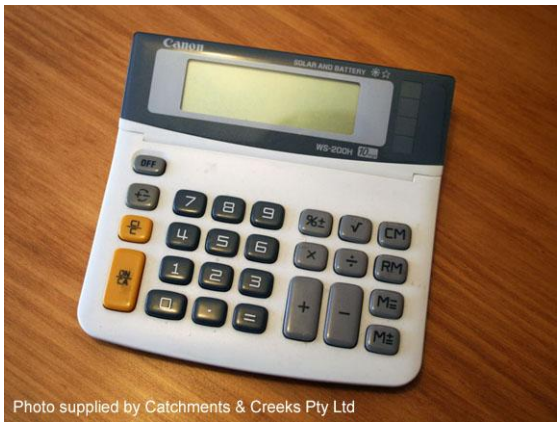
Estimating peak discharge

- This chapter provides a 'simplified' procedure for estimating the peak discharge (flow rate) for a single storm (a design storm).
- The procedure is considered to be simplified because it falls below the design standard outlined within *Australian Rainfall and Runoff*, and is therefore below normal engineering standards.
- A design storm is a short-duration storm typically used to size hydraulic structures.

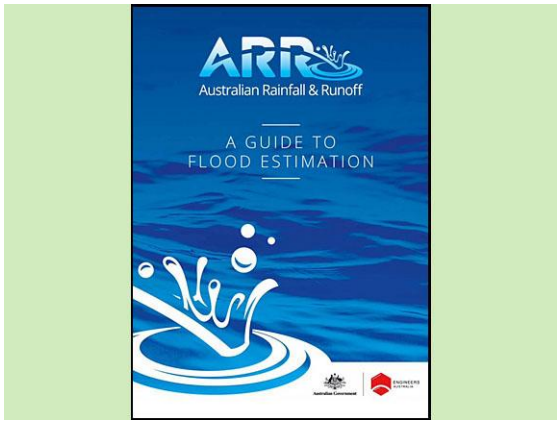
Estimating annual runoff volume (catchment yield)

- Readers that wish to determine the likely annual runoff from a drainage catchment should refer to Chapter 1.

Fit-for-purpose hydrology



Calculator



Australian Rainfall and Runoff (ARR)



The earth embankment of a gully dam

Low risk sites

- A site's risk assessment may be determined from the tables presented at the end of Chapter 2.
- If the proposed dam is considered to be a low risk structure, then the author suggests that landowners can follow the hydrologic procedure presented below in order to design a grassed bywash.
- However, always check with the regulating authority to confirm that this hydrologic procedure is considered acceptable.

Medium risk sites

- A site's risk assessment may be determined from the tables presented at the end of Chapter 2.
- If the proposed dam is considered to be a medium risk structure, then the author recommends:
  - use of the procedures presented in ARR to determine the site hydrology
  - landowners should seek the support of a suitably qualified engineer to design the bywash or stabilised spillway.

Fit-for-purpose hydrology

- The expression 'fit for purpose' is used in the engineering profession to describe a design procedure that is considered suitable for a specific purpose.
- The flow estimation procedure presented within this chapter is considered suitable for the design of small, low-risk, farm dams because:
  - the hydrologic procedure presented in this field guide apply only to low risk sites—medium and high risk sites are required to meet a much higher design standard
  - in the absence of a prescribed flow condition (specified with legislation of approval conditions), the design storm for a low-risk bywash or spillway structures is likely to be less than a 1 in 50 year event (Chapter 6 recommends a 1 in 10 year design for low-risk dams)
  - if a design storm greater than the 1 in 100 year storm is specified within the design conditions, then this simplified hydrologic procedure would not be considered appropriate.

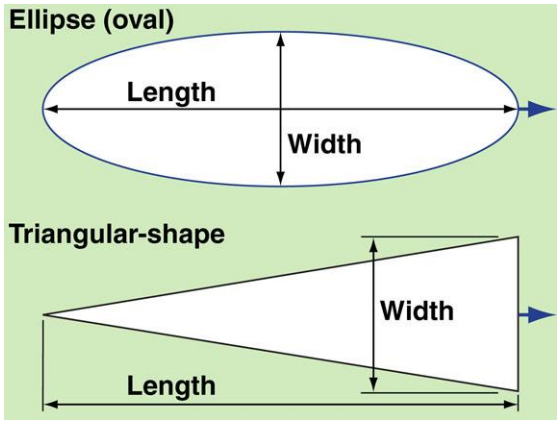
Modified Rational Method



Rural catchment (Qld)

Use of this modified Rational Method

- The hydrologic procedure presented in this chapter is considered suitable for estimating the design discharge (QY) for small rural catchments that have minimal (< 10%) impervious surface area.
- For urban or partial urban catchments, refer to your State's hydrology or urban drainage guidelines.
- QY = Q5, Q10, Q20, Q50, etc. were 'Q5' is the 1 in 5 year peak discharge.



Oval-shaped and triangular catchments

Determination of the catchment area (A)

- Determining the surface area (A) of the drainage catchment can be a simple task for some, but a difficult task for others.
- If accuracy is not critical, then for oval-shaped catchments, the area (in hectares) may be approximated as:

  A = (0.8 x length x width)/10,000
- For triangular or diamond-shaped catchments the area may be taken as:

  A = (0.5 x length x width)/10,000

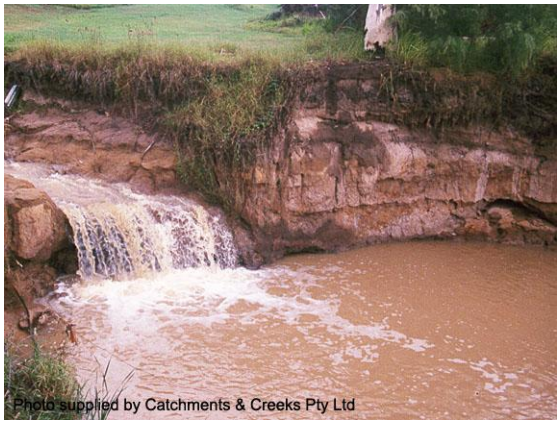
Length and width are measured in metres.



Field with contour banks (Qld)

Determination of catchment area for complex drainage catchments

- Contour banks and flow diversion banks can significantly alter the flow conditions within a rural drainage catchment.
- However, bywash and spillway structures should be designed for the worst-case outcome, i.e. the maximum possible catchment area, whether that is with or without these flow diversion structures.



Gully runoff from a minor storm (Qld)

Modified Rational Method

Step 1: Determine the storm duration, T_C

Step 2: Determine 10-year rainfall intensity, I_{10}

Step 3: Determine the catchment group

Step 4: Determine the 10-year coefficient, C_{10}

Step 5: Determine the catchment area, A

Step 6: Calculate the 10-year discharge, Q10

If Q1, Q2, Q5, Q20, Q50 or Q100 is required:

Step 7: Determine the coefficient multiplier, F_Y

Step 8: Determine the rainfall multiplier, R_Y

Step 9: Calculate the required discharge, QY

Approximation of the 1 in 10 year discharge for small rural catchments

Step 1: Obtain the critical storm duration (T_C) from Table 4.1 based on the distance from the dam to the top of the drainage catchment, and the average slope of this drainage path. Always select the shortest storm duration when interpolating between two values.

Table 4.1 – Critical storm duration 'T_C' (minutes)

Average land slope	Length of overland flow path to the top of the catchment (metres)									
	50	100	200	300	400	500	1000	2000	3000	5000
1 in 10	10	10	10	10	10	10	10	15	20	30
1 in 20	10	10	10	10	10	15	15	20	30	45
1 in 50	15	15	20	20	20	20	20	30	45	60
1 in 100	15	20	20	20	20	20	30	45	60	–
1 in 500	20	20	30	30	30	45	60	–	–	–
1 in 1000	20	30	30	45	45	60	–	–	–	–

Step 2: Using the critical storm duration (T_C) determined from Table 4.1, obtain the average rainfall intensity 'I_{10}' (mm/hr) for the 1 in 10 year storm from tables 4.5 to 4.13 based on the town nearest to your location. Note; the nearest town may be in a neighbouring State. Do not select a town that is on the opposite side of the Great Dividing Range. If necessary, you can average the values of two towns if the dam is located between these towns.

Step 3: Obtain the group number for the town (i.e. Group 1, Group 2, etc.) from tables 4.5 to 4.13.

Step 4: Obtain the discharge coefficient 'C_{10}' from Table 4.2 based on the site's group number, average vegetation cover, and the soil permeability for the catchment.

Table 4.2 – Discharge coefficient (C_{10}) for the 10-year storm

Group	Thick bushland, or timbered forest			Regularly burnt bush, tall crops, or tall grass			Poor grass cover, short crops, short grass		
	Soil 1	Soil 2	Soil 3	Soil 1	Soil 2	Soil 3	Soil 1	Soil 2	Soil 3
Group 1	0.08	0.24	0.32	0.16	0.32	0.40	0.24	0.40	0.48
Group 2	0.10	0.29	0.39	0.20	0.39	0.49	0.29	0.49	0.59
Group 3	0.12	0.35	0.46	0.23	0.46	0.58	0.35	0.58	0.69
Group 4	0.13	0.40	0.53	0.27	0.53	0.66	0.40	0.66	0.70
Group 5	0.15	0.44	0.59	0.30	0.59	0.70	0.44	0.70	0.70
Group 6	0.17	0.50	0.66	0.33	0.66	0.70	0.50	0.70	0.70
Group 7	0.18	0.53	0.70	0.35	0.70	0.70	0.53	0.70	0.70

Soil 1: is a soil with high permeability, such as a sandy soil, or a well-ploughed soil that can absorb a lot of rainwater. This is based on the average soil condition for the catchment.

Soil 2: is a soil with medium permeability, such as a silty soil, well-mixed low-clay soil, or a highly permeable topsoil sitting over a subsoil which has a much lower permeability.

Soil 3: is a soil with low permeability, such as heavy clay soil, a compacted soil, or a soil with a hardsetting or crusting surface.

Step 5: Determine the surface area of the drainage catchment 'A' (hectares) upstream of the structure being designed.

Step 6: Calculate the peak 1 in 10 year design storm discharge 'Q10' (m^3/s).

$$Q10 = (C_{10} \cdot I_{10} \cdot A)/360 \qquad (4.1)$$

Estimation of an alternative design storm discharge (Q5, Q20, Q50 etc.)

Step 7: Obtain the discharge coefficient multiplier 'F_Y' from Table 4.3.

Table 4.3 – Discharge coefficient multiplier (F_Y)

Y =	1 year	2 year	5 year	10 year	20 year	50 year	100 year
F_Y =	F_1 = 0.80	F_2 = 0.85	F_5 = 0.95	1.00	1.05	1.15	1.20

Step 8: Obtain the rainfall intensity multiplier 'R_Y' from Table 4.4.

Table 4.4 – Rainfall intensity multiplier (R_Y)

State / Territory	Rainfall intensity multiplier (R_Y)						
	R_1	R_2	R_5	R_{10}	R_{20}	R_{50}	R_{100}
Queensland east coast [1]	0.55	0.70	0.89	1.00	1.15	1.33	1.47
NT, Qld-west, ACT, NSW-west	0.55	0.70	0.89	1.00	1.15	1.36	1.52
NSW east coast [1]	0.51	0.66	0.87	1.00	1.16	1.38	1.55
Tasmania	0.53	0.67	0.87	1.00	1.17	1.43	1.63
Victoria & WA (south) [2]	0.48	0.64	0.85	1.00	1.20	1.49	1.74
Western Australia (north) [2]	0.41	0.56	0.82	1.00	1.22	1.53	1.78
South Australia	0.41	0.56	0.82	1.00	1.26	1.66	2.00

[1] 'East coast' means east of the Great Dividing Range. 'West' means west of the Great Dividing Range.

[2] Western Australia (north) refers to the northern half of the state, WA (south) the southern half.

Step 9: Calculate the design discharge for the chosen storm frequency (Q1, Q2, Q5, Q20, Q50 or Q100).

$$QY = F_Y \cdot R_Y \cdot Q10 \qquad (4.2)$$

Alternatively:

$$QY = ((F_Y \cdot C_{10}) \cdot (R_Y \cdot I_{10}) \cdot A)/360 \qquad (4.3)$$

where:

A = Surface area of the up-slope drainage catchment (hectares); but note, 'A' is also used as the symbol for the cross-sectional area of a channel.

C_{10} = Discharge coefficient (dimensionless).

F_Y = Discharge coefficient multiplier for the 1 in Y year storm (dimensionless).

F_{20} = Discharge coefficient multiplier for the 1 in 20 year storm (dimensionless), etc.

Group = Each town has been placed in a specific rainfall group (1 to 7) based on the town's 1-hour, 1 in 10 year rainfall intensity (**Group 1:** $^1I_{10}$ < 44 mm/hr; **Group 2:** 45–49 mm/hr; **Group 3:** 50–54 mm/hr; **Group 4:** 55–59 mm/hr; **Group 5:** 60–64 mm/hr; **Group 6:** 65–69 mm/hr; **Group 7:** $^1I_{10}$ > 70 mm/hr).

I_{10} = Average rainfall intensity for the 1 in 10 year storm (mm/hr), which varies depending on the nominated storm duration.

QY = Peak discharge for the 1 in Y year storm (m^3/s).

Q10 = Peak discharge for the 1 in 10 year storm (m^3/s), etc.

R_Y = Rainfall intensity multiplier for the 1 in Y year storm (dimensionless).

R_{20} = Rainfall intensity multiplier for the 1 in 20 year storm (dimensionless), etc.

Soil = Three soil groups have been identified (Soil 1, Soil 2, Soil 3) based on the expected permeability of the soil for use in determining the C_{10} value.

T_C = Critical storm duration for a given location (minutes, refer to Table 4.1).

Table 4.5 – Average rainfall intensity (I_{10}) for a 10 yr storm, Queensland east coast

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Blunder Creek	144	122	108	89	76	62	Group 5
Boonah	145	121	106	86	73	59	Group 4
Bowen	173	147	129	107	91	75	Group 7
Brisbane	168	142	124	102	87	71	Group 7
Bundaberg	160	134	117	95	80	65	Group 6
Caboolture	163	137	120	98	83	68	Group 6
Cairns	183	157	139	117	101	84	Group 7
Caloundra	169	143	125	102	87	71	Group 7
Dayboro	159	134	117	96	81	66	Group 6
Gladstone	162	136	119	97	82	66	Group 6
Gold Coast	170	144	126	104	88	72	Group 7
Gympie	152	127	111	90	76	61	Group 5
Ingham	184	158	141	118	102	85	Group 7
Innisfail	180	154	136	113	97	81	Group 7
Ipswich	162	137	120	98	83	68	Group 6
Mackay	183	155	137	114	97	80	Group 7
Maroochydore	171	144	127	104	88	72	Group 7
Maryborough	159	133	116	95	80	65	Group 6
Mooloolah River	168	142	124	101	86	70	Group 7
Nambour	168	141	124	101	86	70	Group 7
Nitchaga Creek	158	134	118	98	84	69	Group 6
Rockhampton	156	131	115	94	79	64	Group 5
Samford	163	138	121	99	84	69	Group 6
Toowoomba	125	103	90	72	61	49	Group 2
Townsville	177	152	135	113	97	81	Group 7
Yeppoon	168	142	124	102	87	71	Group 7

Table 4.6 – Average rainfall intensity (I_{10}) for a 10 yr storm, Queensland western region

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Biloela	145	122	106	86	73	59	Group 4
Blackwater	149	125	110	90	76	62	Group 5
Charleville	110	92	81	66	56	45	Group 2
Charters Towers	149	126	111	92	78	64	Group 5
Chinchilla	128	107	93	75	63	51	Group 3
Dalby	122	101	87	70	59	48	Group 2
Emerald	148	125	110	90	77	63	Group 5
Gayndah	144	120	105	85	72	58	Group 4
Goondiwindi	119	99	86	70	59	48	Group 2
Inglewood	119	99	86	69	58	47	Group 2
Kingaroy	136	114	99	80	67	54	Group 3
Longreach	127	108	95	79	67	55	Group 4
Mareeba	152	128	113	93	79	65	Group 6
Moura	144	121	106	86	73	59	Group 4
Mt Isa	115	99	87	73	63	52	Group 3
Roma	127	106	93	75	63	51	Group 3
St George	117	98	85	69	58	47	Group 2
Stanthorpe	116	96	83	66	56	45	Group 2
Warwick	120	99	86	69	58	46	Group 2
Weipa	212	183	163	138	119	100	Group 7
Winton	116	99	87	72	62	51	Group 3

Table 4.7 – Average rainfall intensity (I10) for a 10 yr storm, New South Wales east coast

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Casino	133	111	97	78	66	53	Group 3
Coffs Harbour	159	135	119	98	83	68	Group 6
Grafton	135	113	99	80	68	55	Group 4
Lismore	149	125	109	89	75	61	Group 5
Murwillumbah	170	143	126	104	88	72	Group 7
Newcastle	122	102	89	72	61	50	Group 3
Nowra	148	126	112	93	80	66	Group 6
Port Macquarie	151	128	112	93	79	65	Group 6
Sydney	145	123	109	90	77	63	Group 5
Taree	126	105	92	75	63	51	Group 3
Wollongong	159	136	120	100	86	71	Group 7

Table 4.8 – Average rainfall intensity (I10) for ACT and New South Wales western region

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Armidale	97	80	69	55	46	37	Group 1
Bathurst	91	75	65	52	44	35	Group 1
Bourke	103	86	75	61	52	42	Group 1
Broken Hill	82	68	59	48	40	32	Group 1
Canberra	86	71	61	49	41	33	Group 1
Dubbo	102	84	73	59	50	40	Group 1
Goulburn	90	74	64	51	43	34	Group 1
Griffith	86	71	62	50	42	33	Group 1
Lithgow	93	76	66	53	44	35	Group 1
Moree	114	95	82	67	56	45	Group 2
Orange	97	80	69	56	47	38	Group 1
Tamworth	99	81	70	56	47	37	Group 1
Wagga Wagga	85	70	60	49	41	32	Group 1

Table 4.9 – Average rainfall intensity (I10) for a 10 yr storm, Victoria

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Bairnsdale	79	65	55	45	37	29	Group 1
Ballarat	79	65	56	45	38	30	Group 1
Bendigo	79	65	56	45	38	30	Group 1
Horsham	74	61	52	42	35	27	Group 1
Melbourne	77	63	55	44	37	29	Group 1
Mildura	78	64	55	44	37	29	Group 1
Morwell	79	65	56	45	38	30	Group 1
Portland	64	52	45	36	30	23	Group 1
Sale	77	63	54	43	36	29	Group 1
Shepparton	79	65	56	45	38	30	Group 1
Wangaratta	81	66	57	46	38	30	Group 1
Warrnambool	65	53	46	36	30	23	Group 1
Wodonga	84	69	60	48	40	32	Group 1

Table 4.10 – Average rainfall intensity (I10) for a 10 yr storm, Northern Territory

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Alice Springs	91	77	69	57	49	41	Group 1
Darwin	194	163	143	117	99	81	Group 7
Katherine	156	132	116	96	82	67	Group 6
Tennant Creek	108	92	82	69	60	50	Group 3

Table 4.11 – Average rainfall intensity (I10) for a 10 yr storm, South Australia

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Adelaide	72	59	50	40	33	26	Group 1
Ceduna	73	60	52	41	34	27	Group 1
Coober Pedy	76	63	55	44	37	30	Group 1
Mount Gambier	65	53	45	36	30	23	Group 1
Murray Bridge	70	57	49	39	32	25	Group 1
Port Augusta	75	61	53	42	35	28	Group 1
Port Lincoln	68	55	47	37	31	24	Group 1
Port Pirie	74	61	52	42	35	28	Group 1
Streaky Bay	70	57	49	39	32	25	Group 1
Whyalla	72	59	50	40	33	26	Group 1
Woomera	80	66	57	46	39	31	Group 1

Table 4.12 – Average rainfall intensity (I10) for a 10 yr storm, Western Australia

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Albany	82	65	54	42	34	26	Group 1
Bunbury	90	71	60	46	38	29	Group 1
Derby	169	142	125	103	87	71	Group 7
Esperance	70	56	47	36	29	22	Group 1
Geraldton	85	70	60	48	40	31	Group 1
Kalgoorlie	68	55	47	37	31	24	Group 1
Northam	72	58	49	38	31	24	Group 1
Perth	87	70	59	46	38	29	Group 1
Port Headland	153	130	114	95	81	67	Group 6

Table 4.13 – Average rainfall intensity (I10) for a 10 yr storm, Tasmania

Location	Critical storm duration (T_C, minutes)						Group
	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	
Burnie	71	58	50	40	33	26	Group 1
Devonport	70	58	50	40	33	26	Group 1
Hobart	58	48	41	32	26	20	Group 1
Kingston	59	48	41	32	27	21	Group 1
Launceston	65	52	45	36	30	23	Group 1
Queenstown	67	55	47	38	32	25	Group 1

Worked examples using the modified Rational Method



Bargara, Queensland

Bargara, Queensland

- Nearest town: Bundaberg, Qld east coast
- Length of up-slope flow path = 1000 m
- Area = 25 ha, Land slope = 1 in 100
- From Table 4.1: T_C = 30 minutes
- From Table 4.5: I_{10} = 95 mm/hr, and the town is in a Group 6 location
- Sugarcane farm, and the ground has medium permeability, thus Soil 2
- From Table 4.2: C_{10} = 0.66
- **Q10 = (0.66 x 95 x 25)/360 = 4.35 m^3/s.**



Bathurst, New South Wales

Bathurst, NSW

- Length of up-slope flow path = 700 m
- Area = 15 ha, Land slope = 1 in 100
- Table 4.1: choose T_C = 20 minutes
- Table 4.8: I_{10} = 65 mm/hr, and Group 1
- Short grass & medium permeability: Soil 2
- Table 4.2: C_{10} = 0.40
- Q10 = (0.40 x 65 x 15)/360 = 1.08 m^3/s
- Table 4.3: F_{20} = 1.05
- Table 4.4: R_{20} = 1.15
- **Q20 = 1.05 x 1.15 x 1.08 = 1.31 m^3/s.**



Port Lincoln, South Australia

Port Lincoln, South Australia

- Length of up-slope flow path = 300 m
- Area = 2.5 ha, Land slope = 1 in 1000
- Table 4.1: T_C = 45 minutes
- Table 4.11: I_{10} = 31 mm/hr, and Group 1
- Minimal grass & low permeability: Soil 3
- Table 4.2: C_{10} = 0.48
- Q10 = (0.48 x 31 x 2.5)/360 = 0.103 m^3/s
- Table 4.3: F_{50} = 1.15
- Table 7.4: R_{50} = 1.66
- **Q50 = 1.15 x 1.66 x 0.103 = 0.20 m^3/s.**



Yulara, Northern Territory

Yulara, Northern Territory

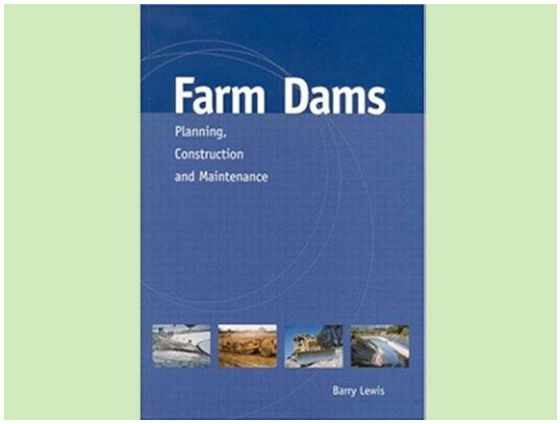
- Nearest town: Alice Springs
- Length of up-slope flow path = 400 m
- Area = 6 ha, Land slope = 1 in 700
- Table 4.1: choose T_C = 30 minutes
- Table 4.10: I_{10} = 57 mm/hr, and the town is in a Group 1 location
- Vegetation is sparse, and the ground has medium permeability, thus Soil 2
- From Table 4.2: C_{10} = 0.40
- **Q10 = (0.40 x 57 x 6)/360 = 0.38 m^3/s.**

5. Storage Basin Design

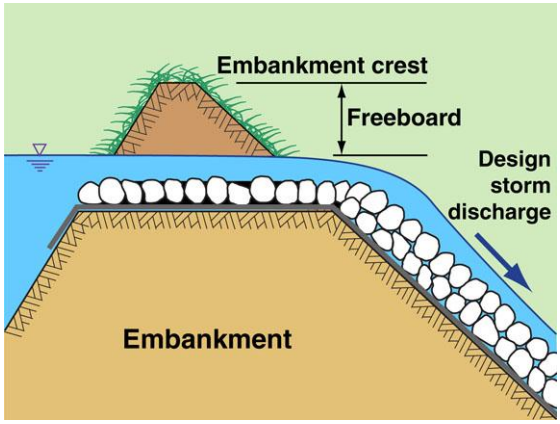
Introduction



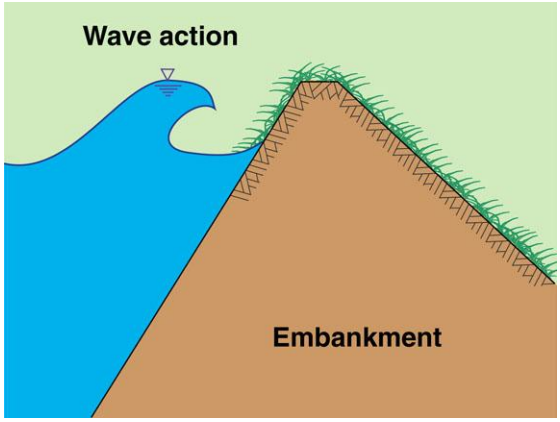
Earth embankment (Qld)



Barry Lewis, 2002



Freeboard



Wave action

Introduction

- Design issues for storage basins are likely to include:
  - location and design of any inflow channels, including batter chutes
  - sizing of the storage volume
  - surface treatment of the embankment and any cut batters
  - design of a low-flow outlet system (if any)
  - property and basin fencing (if any)
  - the use of wildlife islands.

Sizing the storage volume

- Barry Lewis (2002) suggests designers allow 40% of the storage volume for evaporation and seepage, which means:

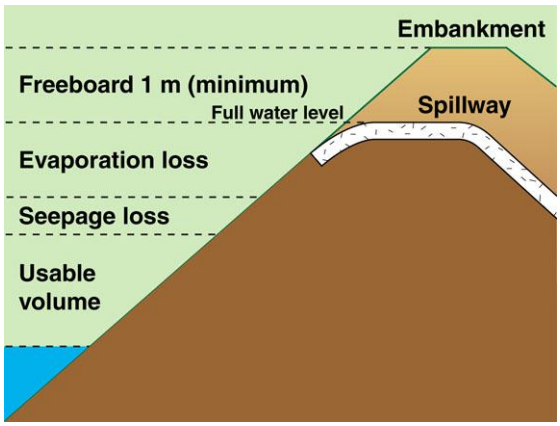
  The required storage volume = 1.67 x estimated water usage volume

- Barry Lewis (2002) also provides a guide to estimating water usage on a rural property (not discussed within this field guide).

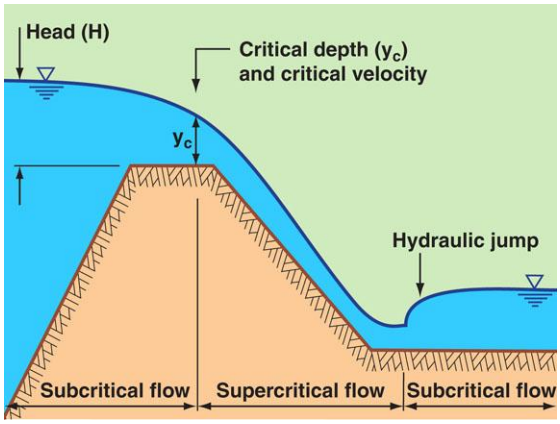
Maximum water level

- The maximum storage level is usually based on the crest elevation of the bywash or spillway.
- The maximum allowable water level is the embankment crest level (not the spillway crest) minus the required freeboard.
- The bywash and/or spillway must be designed such that the basin's water level does not exceed the 'maximum allowable water level' while discharging the design storm.
- The maximum allowable water level should be based on:
  - the lowest crest elevation of any fill embankment minus freeboard
  - the expected long-term 'settlement' (slumping or compaction) of the fill embankments
  - the design flow conditions over the spillway
  - the expected height of wind-generated waves on the storage basin
  - any required freeboard or other safety factors.

Freeboard



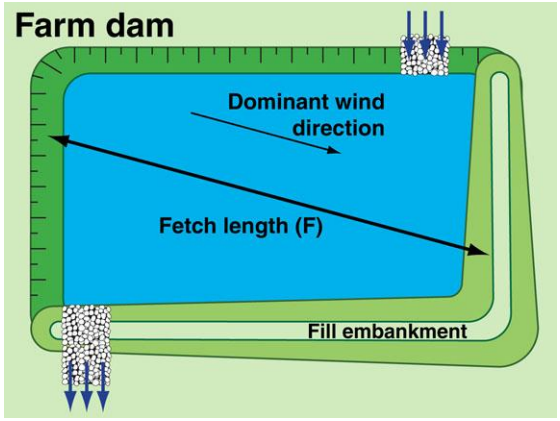
Barry Lewis (Figure 1.7 modified)



Hydraulic head



Long-term soil compaction



Fetch length on a storage basin

Freeboard

- Reader may observe that the term 'freeboard' is very poorly defined.
- Sometimes the term is measured from the water surface, sometimes it is measured from the spillway crest; also, sometimes it includes all variables, and sometimes it is added to the estimated wave height.
- Barry Lewis (2002) suggests a total freeboard of 1.0 metres.
- Alternatively adopt 0.3 m **plus** hydraulic head, **plus** embankment settlement, **plus** a wave height allowance.

Maximum hydraulic head

- The maximum hydraulic head is the maximum elevation of the storage water level above the spillway crest while the spillway is discharging the maximum design flow.
- The maximum hydraulic head (H) can be determined from a weir flow analysis (refer to Chapter 6).

Long-term embankment settlement

- All embankments formed from fill material will continue to compact over time, which will cause minor settlement of the top elevation of the embankment.
- As a first preference, landowners should obtain advice on the likely settlement from a geotechnical (soils) expert.
- Barry Lewis (2002) suggests:
  - 5% for roller compacted soil
  - 8% for scraper placement
  - 10% for dozer compaction.

Estimating wave height

- The wave height above the mean water level can be assumed to be:

$$H_{wave} = 0.02\ (F)^{0.5}\ \text{[metres]}$$

H_{wave} = wave height above mean water level [m]

F = fetch length [m]

- The maximum fetch length (F) must take account of the dominant wind direction.
- A 50% reduction in wave height can be assumed if the dam is protected from the dominant winds by a wind break.

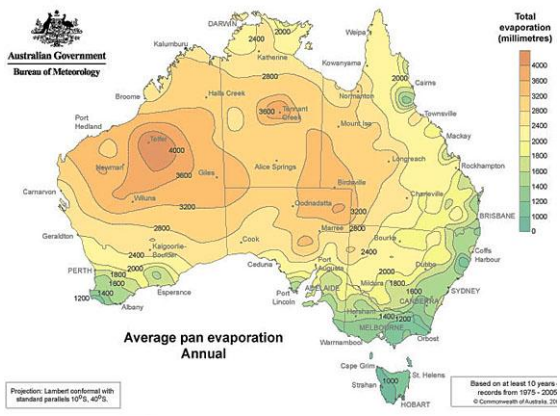
Maximum allowable water level



Grass bywash (Qld)



High risk



Bureau of Meteorology website



Dry soil on the base of a new basin

Low or medium risk sites

- If the dam is considered to be a low-risk structure (refer to Chapter 2), then the maximum allowable water level may be based on:
  - the bywash or spillway crest elevation, plus 1.0 m freeboard, or
  - the bywash crest, plus hydraulic head, plus wave height, plus 10% of the embankment height, plus 150 mm, or
  - the spillway crest, plus hydraulic head, plus wave height, plus 150 mm.

High risk dam sites

- If the dam is considered to be a high-risk structure (refer to Chapter 2), then the maximum allowable water level must be based on:
  - the relevant State or Territory legislation, or
  - the recommendations from the Australian National Committee on Large Dams (ANCOLD), and
  - a detailed hydraulic analysis.

Evaporation losses

- The expected evaporation from a storage volume is likely to be less than the official evaporation depth because the official values are based on a standardised test that represents evaporation off land.
- An estimation of the evaporation loss may be based on 67% of the official evaporation depth (Barry Lewis, 2002):

Annual evaporation depth (mm) = 0.67 (locally reported annual evaporation, mm)

- Refer to Bureau of Meteorology website.

Seepage losses

- If, at the time of construction, the excavated bed of the storage basin exposes a ‘dry’ soil surface, then this suggests that the soil allows the infiltration of water (i.e. rainwater had fully drained through the soil prior to the excavation).
- This suggests that the basin will initially leak water.
- You may choose to line the basin with an impervious clay or synthetic mat, or choose to allow silts to slowly seal your storage basin (refer to Chapter 9).

Fill embankments

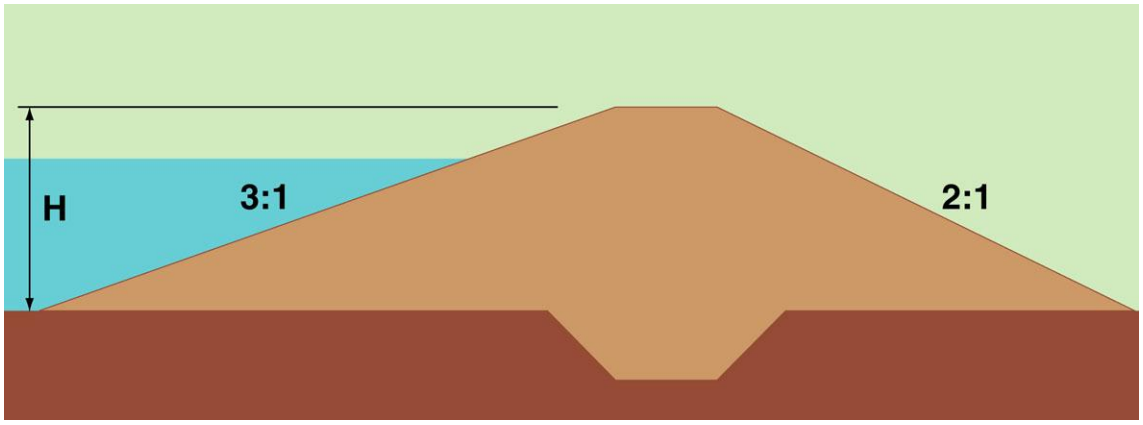


Department of Water Resources

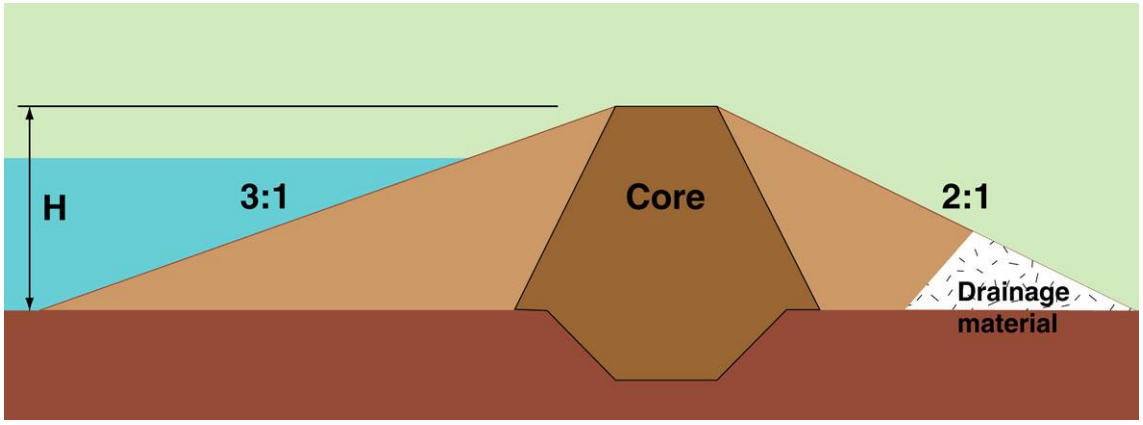
Embankment cross-section

- The following embankment cross-sections were presented in Barry Lewis (2002), which was a modification of CDWR (1986).
- On all diagrams, the water storage is on the left-hand side.

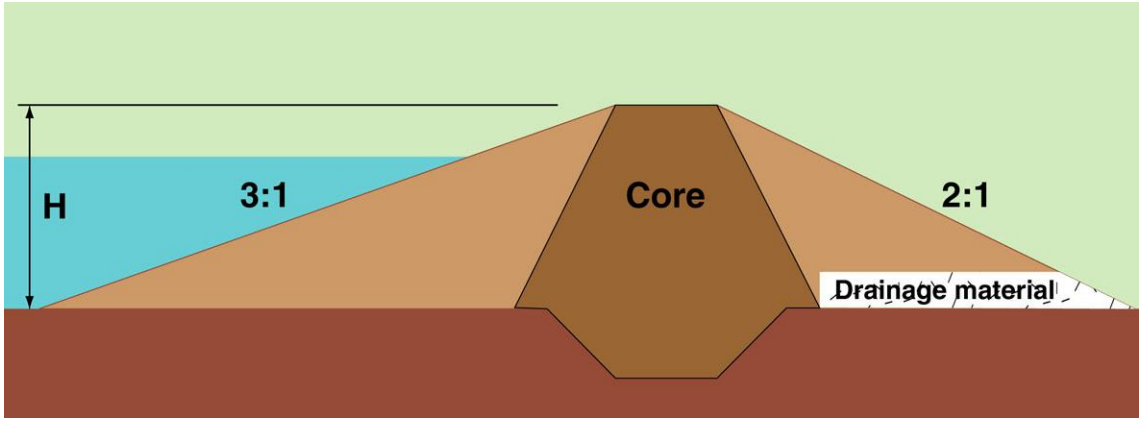
CDWR, 1986, *Guidelines for the Design and Construction of Small Embankment Dams*. California Department of Water Resources, Sacramento, Ca, USA.



Option A: Maximum embankment height (H) less than 5.5 metres

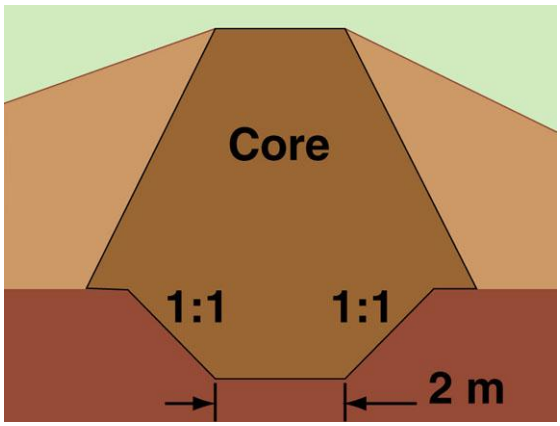


Option B: Maximum embankment height (H) less than 8.5 metres



Option C: Maximum embankment height (H) less than 16 metres

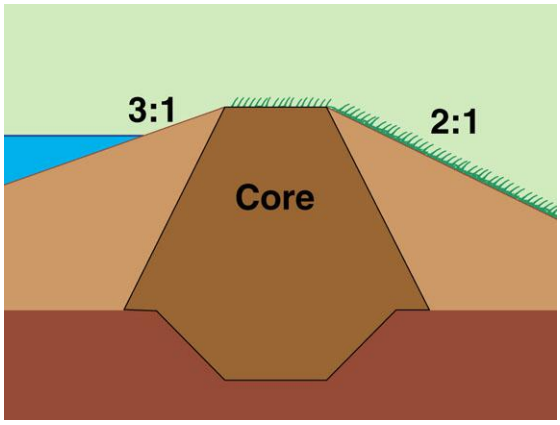
Fill embankments



Embankment core

Core trench (embankment key)

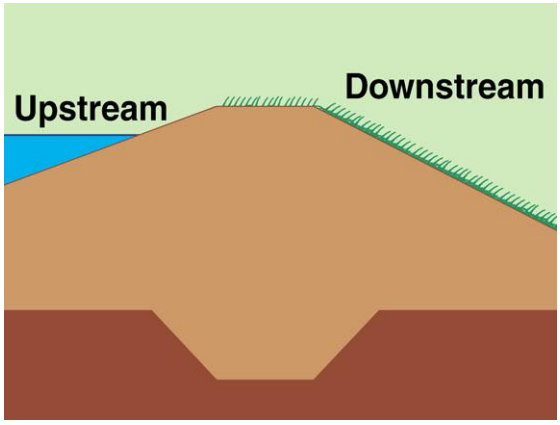
- Side slope of 1:1 for depths up to 3 m.
- Side slope of 1.5:1 for depths exceeding 3 metres.
- The base width of the core trench is usually based on the width of the dozer, or excavator bucket; however, Barry Lewis (2002) recommends a minimum width of 2 metres.
- Ideally the trench should extend to the depth of bedrock, or a suitable foundation material.



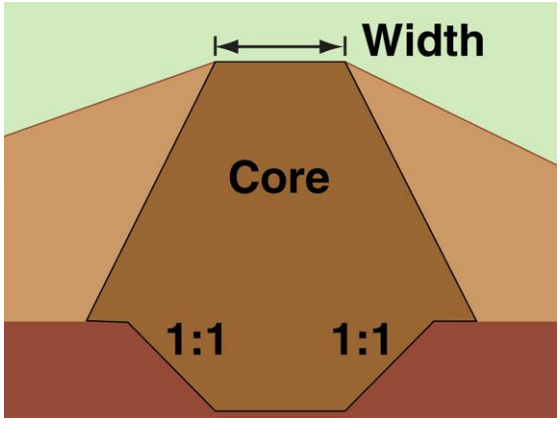
Embankment bank slopes

Embankment side slopes

- The following information refers to the Unified Soil Classification Groups.
- **GC, GM, SC & SM:**
  - H < 3 m, upstream 3:1, downstream 2:1
  - H = 3–7 m, upstream 3.5:1, d/s 2.5:1
  - H = 7–10 m, upstream 3.5:1, d/s 3:1
- **CL & ML:**
  - H < 3 m, upstream 3.5:1, d/s 2.5:1
  - H = 3–7 m, upstream 4:1, d/s 3:1
  - H = 7–10 m, upstream 4:1, d/s 3.5:1
- **CH & MH:**
  - H < 3 m, upstream 4:1, d/s 2.5:1
  - H = 3–7 m, upstream 4:1, d/s 3:1
  - H = 7–10 m, upstream 4:1, d/s 3.5:1



Defining: upstream & downstream



Embankment crest width

Crest width

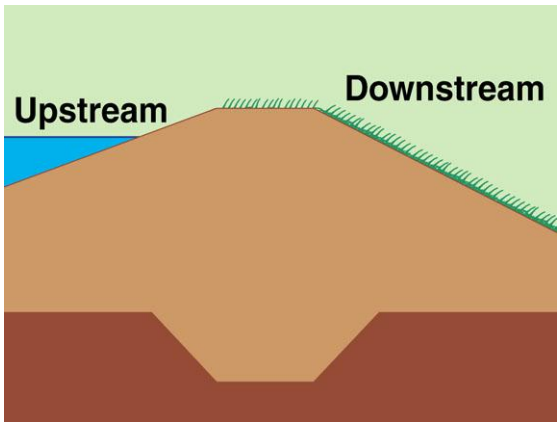
- Barry Lewis (2002) recommends a minimum crest width based on the following formula:

$$\text{Crest width} > (H)^{0.5} + 1 \text{ metre}$$

where:

  - H = height of the fill embankment [m]
- The minimum crest width is 2.5 m.
  - H = 3 m, width = 2.75 m
  - H = 6 m, width = 3.50 m
  - H = 9 m, width = 4.00 m

Batter protection



Defining: upstream & downstream

Introduction

- The exposed surfaces of a fill embankment need to be appropriately protected from erosion and scour.
- **Terminology**: Within various documents, and in this field guide, the surface of a fill embankment may be referred to as:
  - batter, or fill batter
  - inside batter, or upstream slope
  - outside batter, or downstream slope.



Unprotected earth batter (Qld)

The need for erosion and scour protection

- Erosion and/or scour protection is required to manage the adverse effects of:
  - wave action
  - overtopping flows
  - storm runoff
  - trampling by stock animals
  - burrowing by wildlife.
- If the embankment earth is slightly dispersive, then rainfall landing on the batter can cause rilling (fluting erosion) as shown in this image (left).



Stiff grasses (Qld)

Using surface materials to allow ease of egress from the basin

- If there is the risk of a child or adult entering the water storage, then consideration must be given to how a person can exit the basin when the soil is wet and slippery condition, for example:
  - a 2 metre wide strip of turf that extends from the embankment crest to the water's edge
  - a safety rope, rope ladder, or 2 metre wide rope mesh
  - full vegetation cover.



Fully vegetated earth batter (Qld)

Types of vegetation on the upstream batter (inside batter)

- Surface protection on the upstream batter may consist of:
  - full grass cover (including topsoil)
  - full vegetation cover with clumping plants that can aid the egress of a person
  - vegetated rock beaching.

Types of vegetation on the downstream batter



Grassed embankment (Qld)



Grassed embankment (Qld)



Tunnel erosion (Qld)



Hoof marks in the mud (Qld)

Introduction

- The type of vegetation that can be planted on the downstream (outside) batter of an earth embankment depends on a number of factors, including:
  - will wave action cause water to spill over the embankment from time to time
  - is the embankment of sufficient height that only rainfall will land on the batter
  - is the embankment susceptible to tunnel erosion
  - will livestock have access to the embankment?

If water could spill over the embankment from time to time

- If water could spill over the embankment from time to time, then the vegetation should not consist of:
  - stiff grasses
  - clumping plants
  - shrubs, or
  - trees.

If the embankment soil is susceptible to tunnel erosion

- If the embankment soil is susceptible to tunnel erosion, then deep-rooted plants, such as trees and shrubs, should NOT be planted on the embankment.
- **The reason:** When the plant dies, its old root system can form small tunnels in the soil as the root material rots away. These small tunnels can carry groundwater, which can expand the small tunnels into damaging tunnel erosion.

If livestock has access to the embankment

- If the embankment contains slightly dispersive soil, or soil that is susceptible to tunnel erosion, and
  - the soil is protected with a thin layer of topsoil, and
  - livestock has access to the embankment, then
  - the choice of plants should not encourage livestock to feed off the embankment.

Inflow chutes



Unlined batter chute (Qld)

Introduction

- Soil erosion must be controlled at the point where inflows spill into the dam.
- Some soils are strong enough to withstand regular surface flow without eroding, but these soils are rare.
- If necessary, a temporary chute lining can be provided by the placement of a sheet of 'filter cloth' (a 'grey', non-woven, building fabric, which is usually available from hardware stores or produce stores).



Grass chute

Grass-lined inflow chute

- Even though an inflow chute is often very steep, grass can be used in many cases because the inflow rate is usually small, which causes minimal stress on the grass.
- A common problem, however, is that the grass can spend too much time in the 'shade' (depending on the alignment of the dam).
- The strength of grass can be increased by placing a sheet of plastic mesh (not shade cloth) on the soil before planting the grass.



Rock-lined chute

Rock-lined inflow chute

- Rock-lined inflow chutes are more stable if appropriate vegetation (i.e. flexible grasses or ground covers) is integrated into the rocks.
- The sizing of the rocks can be determined from Chapter 6: *Bywash and Spillway Design.*



Concrete chute

Concrete inflow chute

- Concrete lining is the obvious solution if inflows are regular and of high discharge.
- Do NOT place concrete directly on a dispersive soil—always cover a dispersive soil with a non-dispersive soil (e.g. topsoil) before placing the concrete (otherwise, tunnel erosion will occur under the concrete).
- On steep slopes, form some 'steps' or cut-off trenches into the soil foundations before pouring the concrete chute.

Wildlife islands



Wildlife island (Qld)

Introduction

- The primary question that I wish to address here is whether or not you should include a wildlife island within your water storage.
- It is, of course, your choice.



Farm dam with wildlife island (Qld)

Nutrient-rich water

- Animals will introduce nutrients into the water, which will encourage algae blooms.



Wildlife island (Qld)

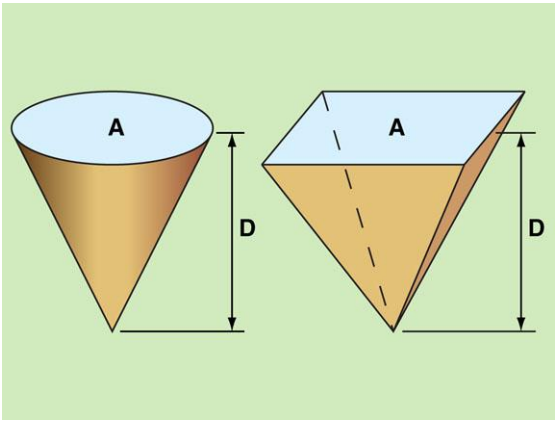
Good algae vs bad algae

- **Caution:** I am not trained in algae identification or it's toxins, so readers should seek expert advice.
- In general, blue-green algae is the one you should avoid, and blue-green algae requires both aerobic and anaerobic (low oxygen) zones in the water, which means they generally appear in deep water ponds, which includes most farm dams.
- Aerating the water can remove the bottom anaerobic zone.



Waterbird habitat (Qld)

Volume calculations (geometry)



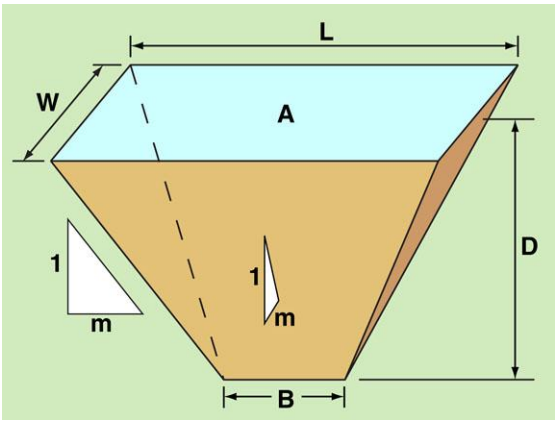
Cone and rectangular pyramid

Cone and pyramid shapes

$$V = (1/3).A.D$$

where:

V = pond volume [m^3]
A = top surface area [m^2]
D = depth of volume [m]



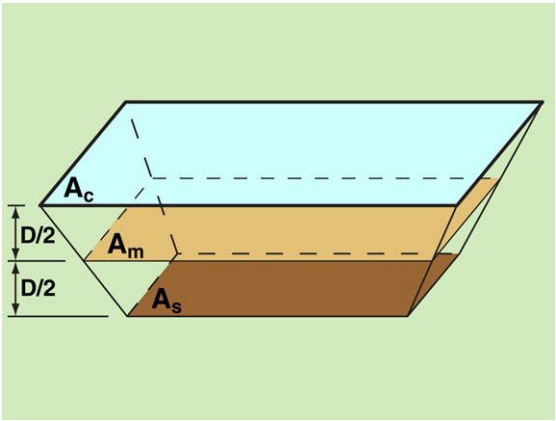
Rectangular prism

Rectangular prism

$$V = (1/3).W.(L - B).D + (1/2).W.B.D$$

where:

V = pond volume [m^3]
W = width of top surface [m]
L = length of top surface [m]
B = width of bottom edge [m]
D = depth of volume [m]



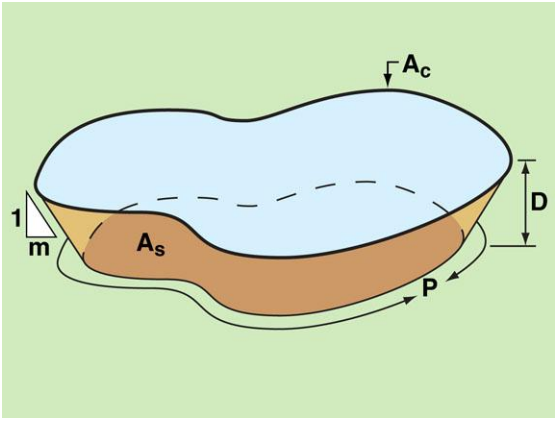
Truncated pyramid (Frustum)

Simpson's Rule

$$V = (D/6).(A_C + 4.A_M + A_S)$$

where:

V = pond volume [m^3]
D = depth of volume [m]
A_C = surface area at top of volume [m^2]
A_M = surface area at mid depth [m^2]
A_S = surface area at base of volume [m_2]



Curved three-dimensional shape

Estimation of required basin depth given the pond surface area and bank slope

$$D \approx \frac{-A_s + \sqrt{(A_s^2 + 2.P.m.V)}}{P.m}$$

where:

D = pond depth [m]
A_S = pond surface area at base [m^2]
P = circumference of the base of the volume [m]
V = required basin volume [m^3]
m = constant bank slope around the volume

6. Bywash and Spillway Design

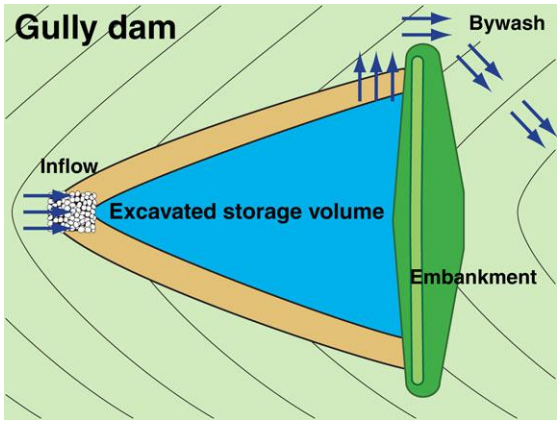
Introduction



Rock-lined spillway

Terminology

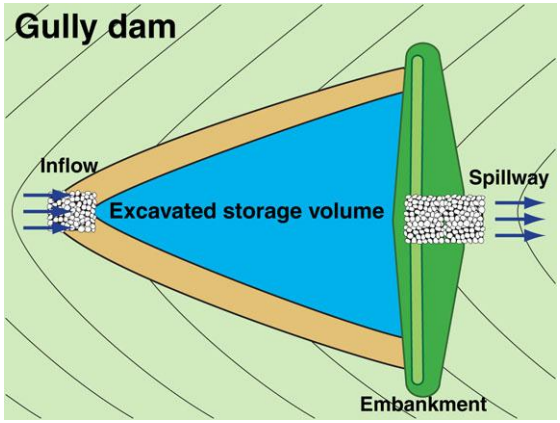
- A variety of terms have been used to describe the spillways attached to farm dams, including:
  - bywash
  - spillway
  - emergency spillway
  - formal spillway
  - stabilised spillway
  - plus; grass-lined, rock-lined, rock mattress, and concrete spillway.



Gully dam with bywash spillway

Bywash

- A bywash is typically a well-grassed overland flow path, which is used on low risk dam sites.
- The risk category can be determined from the information presented in Chapter 2.
- A bywash **cannot** be used if the water storage is located on a watercourse.
- A bywash **cannot** be formed over fill material (i.e. only suitable for excavated or natural land surfaces).



Gully dam with formal spillway

Spillways

- A spillway is a purpose-built drainage structure that has been designed to be stable when subjected to a specific flow condition (i.e. the design discharge).
- Spillways are typically lined with rock, rock mattresses, or concrete.
- Spillways are typically engineered structures that need to be designed by trained experts.



Engineering design

Design storm (author's opinion)

- For low risk sites, a minimum 1 in 10 year design storm.
- For hillside dams, a minimum 1 in 20 year design storm.
- For medium risk sites, a minimum 1 in 50 year, possibly 1 in 100, design storm.
- For high risk sites, refer to ANCOLD guidelines.
- Always investigate if design standards have been specified by the regulating authority.

The need for ring tank spillways



Ring tank (NSW)

Ring tank spillways

- Based on the author's very limited experience, it would appear that most ring tanks are constructed without a formal spillway.
- The 'reasoning' would appear to be that ring tanks are only filled through the actions of controlled pumping, so overtopping of the embankment is unlikely to occur.



Embankment failure (2011)

The 2011 Queensland floods

- However, allow me to remind you of what happened in 2011.
- During December 2010, Queensland experienced several wet days, which allowed landowners to bring their ring tanks up to maximum water level.
- Unfortunately, during January 2011, Queensland experienced a large storm that dropped around 500 mm of rainfall.
- This rainfall caused some ring tanks to overtop.



Embankment failure (2011)

The hydraulics of an overtopped embankment

- Having just 1, 2 or 3 cm of water overtopping an earth, or even a grassed embankment, is usually not a problem if the flow only occurs for a few hours.
- However, if this overtopping extends over several hours, or several days, then erosion problems should be expected.
- The worst form of erosion is 'tunnel erosion', which can occur in dispersive soils.
- Other problems include the 'rilling' of the outer slope of earth embankments.
- Rills are minor cuts in the soil that are less than 30 cm deep (deeper cuts are called gullies).
- If a very minor 3 cm deep rill is cut through the crest of a 'full' ring tank, then this means that the water level in the ring tank will attempt to fall by 3 cm.
- If you multiply the surface area of the ring tank by 3 cm, then you will calculate the **volume** of water that is trying to spill over the eroding embankment—all within a few hours—**Problem, Big Problem!**



Rill erosion (Qld)

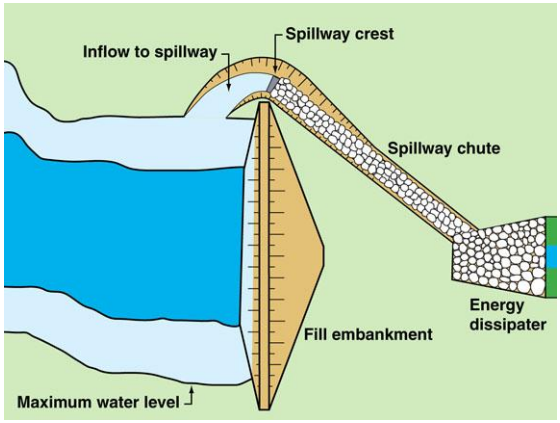
Bywash usage



Spillway (Qld)



Bywash (Qld)



Dam spillway



Combined grass and rock surface (NSW)

Introduction

- I am sure many people have heard the expression that all poodles are dogs, but not all dogs are poodles.
- Well, we can also say that all bywashes are spillways, but not all spillways can be called a bywash.
- A bywash is a spillway that is formed on a natural ground surface, or a surface cut into natural ground, but not a surface formed from new or old fill material.

Usage of a bywash

- As previously stated, a bywash can only be used when the dam is not located on a watercourse.
- If the dam is located on a watercourse, and if the spillway was located on natural ground (i.e. formed around the end of the fill embankment), then:
  - it should still be referred to as a 'spillway', and
  - it should be lined with concrete or rock, but not grass.

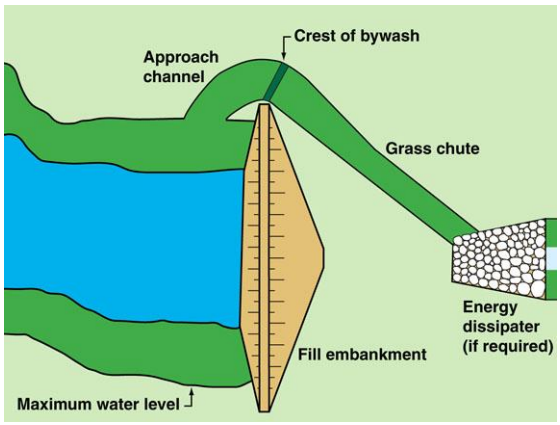
Bywash design rules

- Design requirements include:
  - formed on natural soil (not fill)
  - the inflow channel may be curved up to the 'crest' of the bywash, which is the location of highest elevation on the bywash
  - the 'chute', which exists from the crest to the energy dissipation basin, must form a straight flow path
  - the surface protection must be sufficient to prevent scour.

Scour protection

- The width and gradient of a bywash is typically chosen such that:
  - a healthy cover of grass can be maintained over the bywash
  - flow velocities are sufficiently low to prevent damage to the grass.
- Where necessary, parts of the bywash can be protected with concrete or rock, especially within a region of energy dissipation.

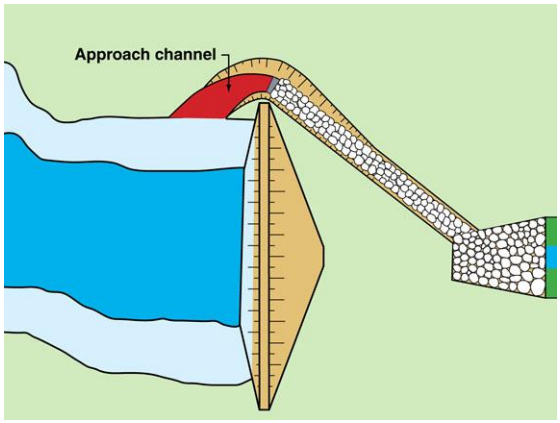
Critical design components



Grass bywash

Introduction

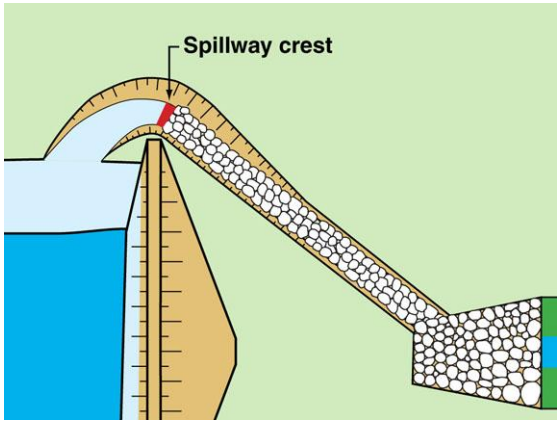
- A bywash must pass around the fill embankment, while a formal spillway may either pass around (preferred), or over a fill embankment.
- The main outflow channel is called a 'chute', and this channel must be straight from the crest of the bywash to the energy dissipation zone.
- The chute must be straight because the flows passing down the chute will be supercritical (i.e. very fast!).



Approach channel

The approach channel

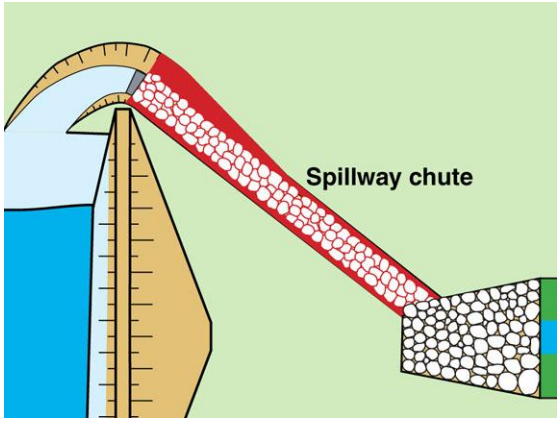
- Parts of the approach channel can be curved, but only if the bed of this portion of the channel has a negative gradient (i.e. it is sloping backwards away from the crest, meaning it is constantly rising in elevation until it reaches the crest).
- Over this region of the bywash, the flow conditions will be 'subcritical', which is a flow condition that:
  - is generally slow
  - allows the flow to pass smoothly along a curved trajectory.



Spillway crest

The spillway crest

- The crest of a bywash is the location of maximum elevation.
- Flows will only spill over the spillway when the basin water level exceeds the elevation of this crest.
- The flow width and depth at the crest will be defined by a critical velocity analysis.
- If the flow is confined within a channel, then the dimensions of the weir crest will be defined by an appropriate weir equation.



Spillway chute

The spillway chute

- Flow conditions down the outlet chute will usually be supercritical.
- The average flow velocity can be determined from a Manning's equation analysis.
- If the chute is lined with rock, then this velocity analysis becomes complicated because of the fact that the effective roughness of rocks increases as the flow depth reduces (i.e. as the flow depth reduces, the water turbulence increases).

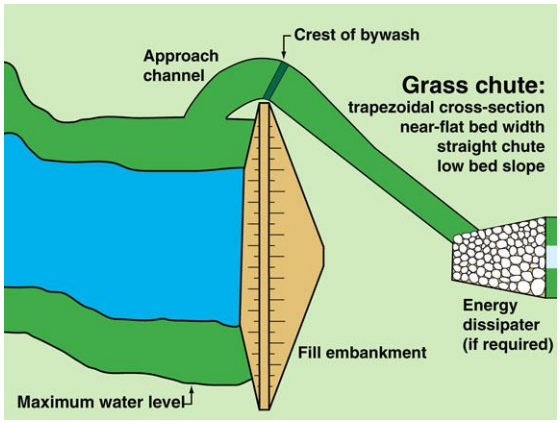
Design options



Design process

Introduction

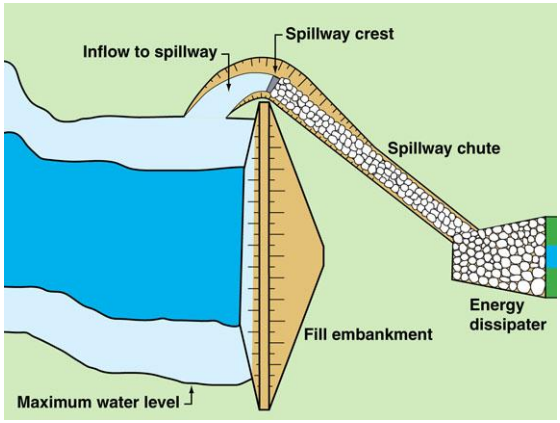
- A landowner could spend $5,000 to $20,000 in investigations and engineering to design a simple farm dam.
- If a risk assessment suggests that the proposed dam site is a high risk site, then the landowner will have no option but to seek costly expert advice.
- However, this chapter provides a simplified design procedure, which may be considered suitable for low or medium risk sites (refer to Chapter 2 for risk analysis).



Low risk dam site

Designing low risk structures

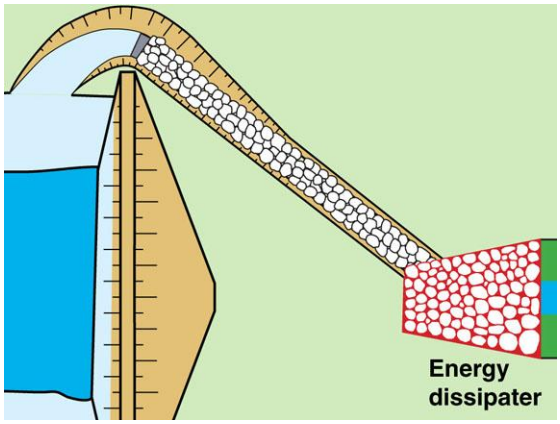
- The first part of this chapter provides a design procedure for a bywash.
- This design process is only suitable for low risk structures.
- The design process is less reliable than the more detailed hydraulic analysis presented for medium risk structures later in this chapter.
- The risk category can be determined from the information presented in Chapter 2.



Medium risk dam site

Designing medium risk structures

- A separate discussion has been provided later in this chapter for the hydraulic analysis and design of medium risk structures.
- A medium risk structure is defined as:
  - a dam expected to have a slight risk of structural failure, and
  - a dam where such a failure may cause unrepairable damage, or environmental harm.

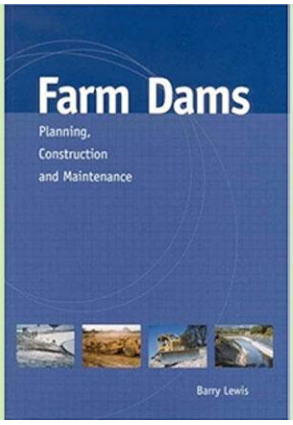


Energy dissipation zone

Designing the energy dissipation zone

- Both low risk and medium risk structures will require consideration of the design and construction of an energy dissipation zone at the base of the outflow chute (spillway chute).
- On medium risk structures, the energy dissipation zone should be designed by a suitably qualified engineer.
- On high risk structures, the spillway and energy dissipation zone must be designed by a suitably qualified engineer.

Designing a Low Risk Bywash or Spillway



Farm Dams, 2002

Introduction

- The risk rating is discussed in Chapter 2.
- Several publications, including Barry Lewis (2002), provide design charts and tables that can be used to size spillways.
- As an alternative, this chapter provides a design procedure that is based on a series of 'simple' mathematical steps.
- A more detailed design procedure is provided in the following section titled *'Designing a Medium Risk Spillway'.*



Design rules

Design of low risk spillways

- The critical aspects of a bywash or spillway include:
  - sizing the width and slope of the chute based on an 'allowable velocity'
  - giving the crest the same bed width as the outlet chute
  - designing the approach channel as a gradually-contracting channel (starting as a wide width at the water's edge, then contracting to the crest width).



Flow over grass

The allowable flow velocity

- The first step in this design procedure is to determine the surface conditions of the bywash or spillway chute.
- The second step is to determine an allowable flow velocity for this surface conditions (see over page).
- The third step involves designing the spillway chute based on a maximum water depth (this means we do not treat the chute as a complex two-dimensional channel, which would be required in the design of a medium risk site).

Selecting the allowable flow velocity



Poor grass cover

Poor grass cover

- Allowable flow velocity is:
  - **0.30 m/s** for an extremely erodible soil
  - **0.45 m/s** for a sand soil
  - **0.50 m/s** for a sandy loam soil
  - **0.60 m/s** for a silty loam soil
  - **0.70 m/s** for a firm loam soil
  - **1.10 m/s** for a stiff clay.



Dead or dormant grass cover

Dead or dormant grass cover

- Consider the likely grass cover at the time of a major storm event—it is noted that major storms often occur at the end of a drought when grass cover is poor.
- Allowable flow velocity is:
  - **1.20 m/s** for an easily eroded soil
  - **1.60 m/s** for an erosion-resistant soil.
- If the vegetation cover is not close to 90%, then adopt the allowable flow velocity from the above *'Poor grass cover'*.



Healthy grass cover

Healthy grass cover

- Long grass is considered better than short grass; **however**, 'stiff' or 'clumping' grasses should **never** be grown on a bywash.
- Allowable flow velocity for healthy grass is:
  - **1.60 m/s** for an easily eroded soil
  - **2.10 m/s** for an erosion-resistant soil.

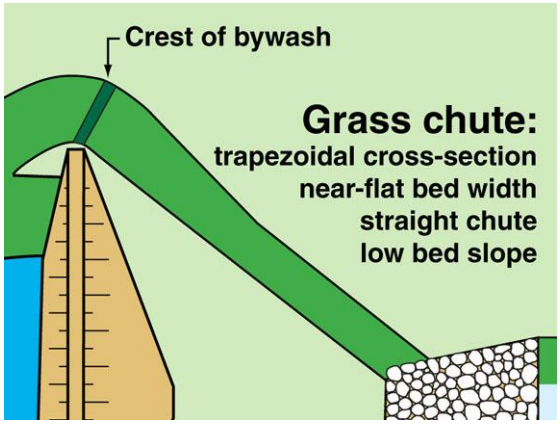


Rock

Rock-lined spillway chutes

- Below is the suggested rock size based on the chute slope (H:V) and the design flow per unit width ('q' = flow per metre width).
- **Chute slope of 3:1 (H:V)**
  - 300 mm rock for q = 0.3 $m^3/s/m$
  - 500 mm rock for q = 0.6 $m^3/s/m$
  - 800 mm rock for q = 1.2 $m^3/s/m$
- **Chute slope of 4:1 (H:V)**
  - 300 mm rock for q = 0.3 $m^3/s/m$
  - 400 mm rock for q = 0.6 $m^3/s/m$
  - 700 mm rock for q = 1.2 $m^3/s/m$
- **Chute slope of 6:1 (H:V)**
  - 300 mm rock for q = 0.3 $m^3/s/m$
  - 400 mm rock for q = 0.6 $m^3/s/m$
  - 600 mm rock for q = 1.2 $m^3/s/m$
  - 700 mm rock for q = 1.8 $m^3/s/m$

Design of the spillway chute



Grass bywash chute

Introduction

- Ideally the bywash or spillway chute should have the following design features:
  - trapezoidal cross-section
  - flat bed producing a near-uniform flow depth across the width of the chute
  - a straight channel, unless the bywash slope is very flat (less than 10%).
- The following design procedure is based on the flow velocity at the centre of the chute, not the average flow velocity.

Step 1

Determine the chute slope

- In most cases, the chute will need to be re-profiled (i.e. partially excavated to form a uniform slope and width), and then re-grassed, or lined with concrete or rocks.
- The first step is to select the surface conditions of the bywash or spillway chute.
- The second step is to determine an allowable flow velocity for this surface condition.
- The third step involves selecting a chute slope, and determining the required width of the chute for that slope.
  - Given the allowable flow velocity and the bed slope for the bywash chute, determine the allowable flow per unit width (q) from Table 6.3.
  - Calculate the minimum bed width of the chute (b) from:

$$b = Q/q \qquad (6.1)$$

- If the calculated chute width (b) is too large, then try an alternative bed slope, or consider a stronger surface lining such as concrete, or rocks.

Step 2

Mathematical analysis

- Tables 6.1 to 6.3 are based on:

$$V = (1/n)\,(y)^{2/3}\,(S)^{0.5} \qquad (6.2)$$

$$q = Q/b \qquad (6.3)$$

where:

- V = maximum flow velocity [m/s]
- n = Manning's roughness of grass
- y = maximum flow depth [m]
- S = bed slope of chute [m/m]
- q = unit flow rate [m3/s/m]
- Q = maximum flow over crest [m^3/s]
- b = bed width of the chute [m]

Step 3

Table 6.1 – Adopted Manning's roughness values for the grass chute analysis

Allowable velocity (m/s)	Bed slope (%)							
	1	2	3	4	5	6	8	10
0.3	0.09	0.10	0.11	0.12	0.13	0.13	0.14	0.15
0.4	0.07	0.08	0.09	0.10	0.10	0.10	0.11	0.12
0.5	0.06	0.07	0.08	0.08	0.09	0.09	0.09	0.10
0.6	0.05	0.06	0.07	0.07	0.07	0.08	0.08	0.09
0.7	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.08
1.1	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.06
1.2	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
1.6	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.05
2.1	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04

Table 6.2 – Calculated maximum flow depth, y (m) for the grass chute analysis

Allowable velocity (m/s)	Bed slope (%)							
	1	2	3	4	5	6	8	10
0.3	0.13	0.10	0.08	0.08	0.07	0.06	0.06	0.05
0.4	0.15	0.11	0.09	0.08	0.08	0.07	0.06	0.06
0.5	0.17	0.12	0.10	0.09	0.08	0.08	0.07	0.06
0.6	0.19	0.14	0.11	0.10	0.09	0.08	0.07	0.07
0.7	0.21	0.15	0.12	0.11	0.10	0.09	0.08	0.07
1.1	0.29	0.20	0.16	0.14	0.12	0.11	0.10	0.09
1.2	0.31	0.21	0.17	0.15	0.13	0.12	0.10	0.09
1.6	0.41	0.27	0.22	0.18	0.16	0.15	0.13	0.11
2.1	0.56	0.36	0.28	0.23	0.21	0.18	0.16	0.14

Table 6.3 – Maximum allowable flow per unit width, q ($m^3/s/m$) = Q/bed width

Allowable velocity (m/s)	Bed slope (%)							
	1	2	3	4	5	6	8	10
0.3	0.040	0.030	0.025	0.023	0.021	0.019	0.017	0.016
0.4	0.060	0.045	0.038	0.033	0.030	0.028	0.025	0.023
0.5	0.084	0.062	0.052	0.046	0.042	0.038	0.034	0.031
0.6	0.112	0.081	0.068	0.059	0.054	0.050	0.044	0.040
0.7	0.144	0.103	0.085	0.075	0.068	0.062	0.055	0.050
1.1	0.318	0.218	0.177	0.153	0.137	0.125	0.109	0.098
1.2	0.374	0.255	0.205	0.177	0.158	0.144	0.125	0.113
1.6	0.660	0.435	0.345	0.294	0.260	0.236	0.203	0.181
2.1	1.171	0.748	0.583	0.491	0.431	0.388	0.330	0.292

Vegetation coverage of a bywash chute



Long grass

Introduction

- The best form of vegetation on a bywash is a uniform coverage of long grass; 100 to 200 mm blade length.
- Grass longer than 200 mm is still acceptable so long as the grass can readily fold flat when water passes down the bywash.



Native grass

No clumping grasses

- Clumping grasses should **not** be used on a bywash, which includes most native grasses.



Lomandra

No Lomandra

- *Lomandra* should **not** be used on a bywash.

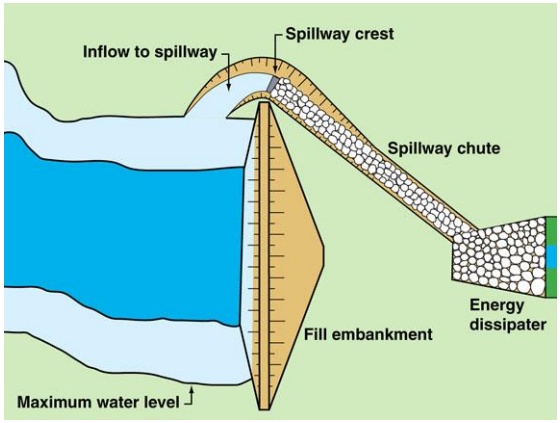


Vetiver grass

No vetiver grass

- The sterile, but very tall, *Vetiveria zizanioides* grass should **not** be used on bywash or spillways.

Rock stabilisation of a spillway chute



Rock-lined spillway chute



- **Chute slope of 3:1 (H:V)**
  - 300 mm rock for q = 0.3 $m^3/s/m$
  - 500 mm rock for q = 0.6 $m^3/s/m$
  - 800 mm rock for q = 1.2 $m^3/s/m$
- **Chute slope of 4:1 (H:V)**
  - 300 mm rock for q = 0.3 $m^3/s/m$
  - 400 mm rock for q = 0.6 $m^3/s/m$
  - 700 mm rock for q = 1.2 $m^3/s/m$
- **Chute slope of 6:1 (H:V)**
  - 300 mm rock for q = 0.3 $m^3/s/m$
  - 400 mm rock for q = 0.6 $m^3/s/m$
  - 600 mm rock for q = 1.2 $m^3/s/m$
  - 700 mm rock for q = 1.8 $m^3/s/m$

Rock sizing for low risk spillways

Table 6.6(10) – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4				Size distribution, d_{50}/d_{90} = 0.5	
Unit flow rate ($m^3/s/m$)	Bed slope = 1:1		Bed slope = 1:3		Bed slope = 1:4		Bed slope = 1:6	
	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}
0.1	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.10
0.2	0.15	0.30	0.15	0.30	0.16	0.20	0.16	0.20
0.3	0.20	0.40	0.20	0.30	0.21	0.30	0.21	0.30
0.4	0.24	0.50	0.25	0.40	0.25	0.40	0.26	0.30
0.5	0.28	0.50	0.28	0.50	0.29	0.40	0.30	0.30
0.6	0.31	0.60	0.32	0.50	0.33	0.40	0.34	0.40
0.8	0.38	0.70	0.39	0.60	0.40	0.50	0.41	0.40
1.0	0.44	0.80	0.45	0.70	0.46	0.60	0.47	0.50
1.2	0.50	0.90	0.51	0.80	0.52	0.70	0.53	0.60
1.4	0.55	1.00	0.57	0.90	0.58	0.80	0.59	0.60
1.6	0.60	1.10	0.62	0.90	0.63	0.80	0.64	0.70
1.8	0.65	1.20	0.67	1.00	0.68	0.90	0.70	0.70
2.0	0.70	1.30	0.72	1.10	0.73	0.90	0.75	0.80
3.0	0.92	1.70	0.94	1.40	0.96	1.20	0.98	1.00
4.0	1.11	2.00	1.14	1.70	1.16	1.50	1.19	1.20
5.0	1.29	2.30	1.32	1.90	1.34	1.70	1.38	1.40

Rock sizing table (later in this chapter)



Grass integrated into the rocks

Introduction

- All parts of a bywash should have a low gradient.
- The slope of the grass should be so minor that a person in a wheel chair could ascend the slope unaided.
- If the slope exceeds, say 5-degrees, then consider:
  - reinforced grass
  - a combined rock and grass mixture
  - rock lining.

Rock sizing for low risk spillways

- If the design storm analysis suggests that the flow velocities down the spillway chute will be excessive for a grassed surface, then a stronger surface lining will be required.
- Suggested rock sizes have already been presented (on previous page) for various bed slopes (3:1, 4:1 & 6:1) and unit flow rates from 0.3 to 1.7 $m^3/s/m$.

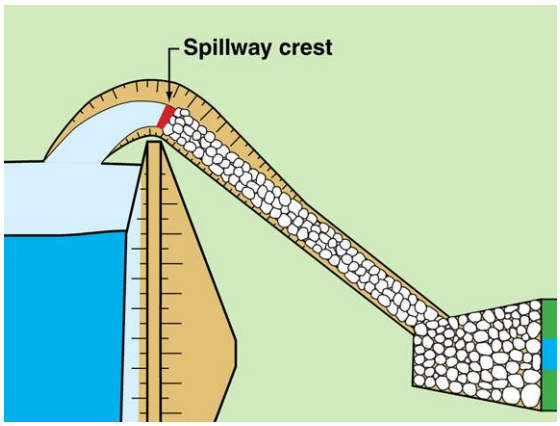
Rock sizing

- In the section titled *'Designing a medium risk spillway'*, there are tables that provide the required rock size based on the slope of the spillway, and the unit flow rate (i.e. the discharge across a 1-metre width).

The benefit of integrating grass

- A rock-lined spillway chute can be made much more stable by integrating soft grasses into the rocks.
- Ideally, topsoil is mixed with the rocks as the rocks are being placed—add only sufficient soil to fill the voids.
- After placement of the rocks, the chute is grass seeded, and the grass can be allowed to grow 'long', but the grass each side of the rock chute must be allowed to grow as long and rough as the chute.

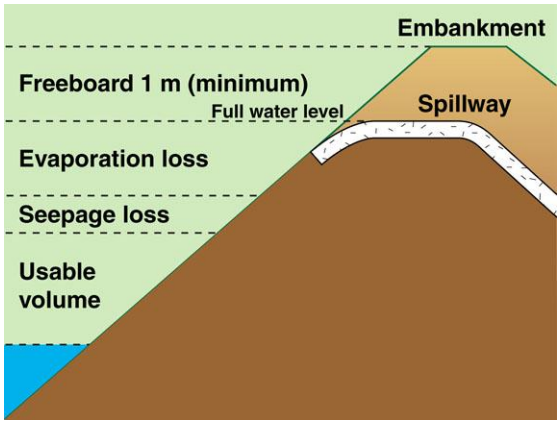
Design of the bywash/spillway crest



Spillway crest

Introduction

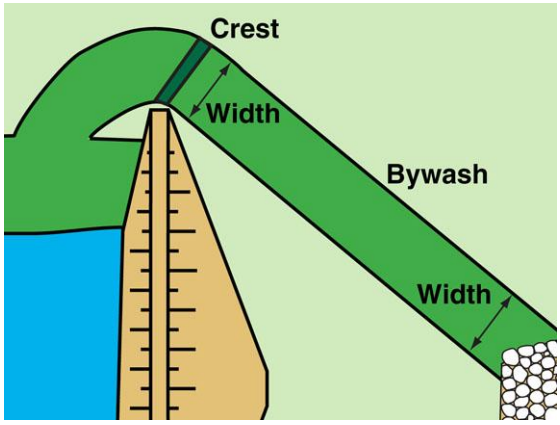
- The spillway crest plays an important role in determining:
  - the maximum water level, and
  - the flow conditions down the spillway chute.



Potential freeboard

Elevation of the bywash/spillway crest

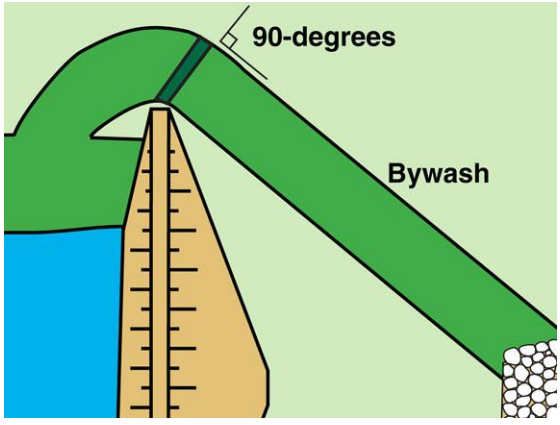
- The crest elevation of a grassed bywash is usually determined by the maximum natural ground elevation along the proposed pathway of the bywash.
- However, for an embankment spillway, the crest elevation could be based on:
  - the crest elevation of the fill embankment, minus the freeboard (including wave action and embankment settlement)
  - maximum allowable water level.



Crest width

Minimum width of the bywash/spillway crest

- It is standard practice for the width of the bywash/spillway crest to be equal to the width of the outflow chute.
- Also, the alignment of the crest should be 90-degrees to the alignment of the outlet chute.

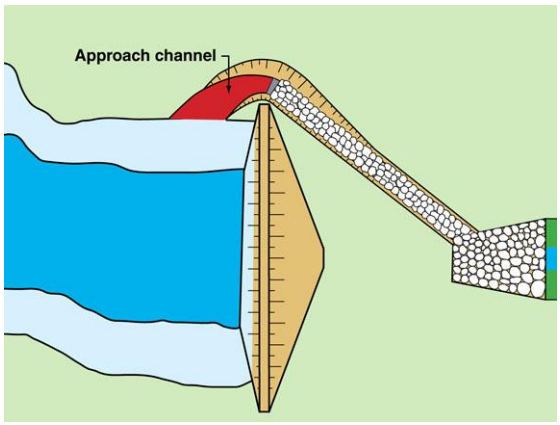


Alignment of the crest

Stabilisation of the bywash/spillway crest

- For a grassed bywash, the only stabilisation that is normally required is a healthy grass cover.
- If gully erosion is migrating up towards the crest, then a deep cut-off wall could be installed.
- If the spillway of rock lined, then the rocks should extend over the crest, and into the approach channel.

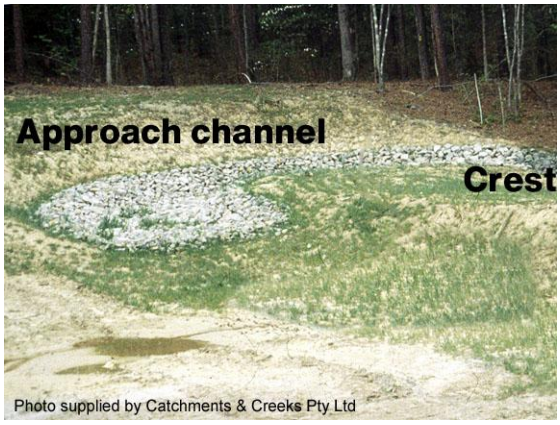
Design of the approach channel



Approach channel

Introduction

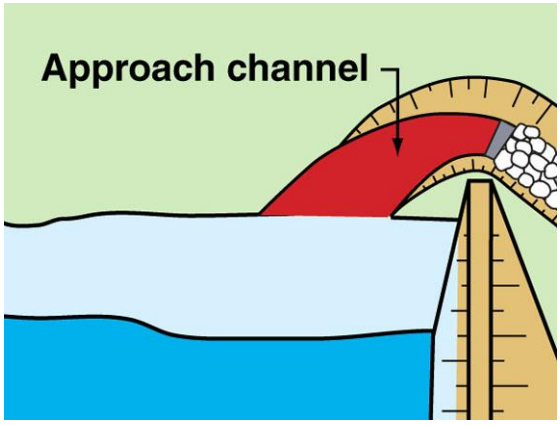
- In most cases, the flow of water is governed by the slope of the land, but there is an exception to the rule.
- When a channel is considered to be 'drowned', then water flow is controlled by the slope of the water surface.
- This is the case for the approach channel, which has an adverse bed slope (i.e. the channel bed climbs in elevation as it approaches the crest of the bywash).



Curved approach channel

Use of a curved channel

- Because the approach channel operates as a drowned channel, it:
  - experiences low flow velocities
  - the flow condition is said to be 'subcritical'
  - flow conditions within the approach channel are controlled by the hydraulic choke that exists at the 'crest'
  - (most importantly) the channel can be 'curved' without causing hydraulic problems.



Gradual contraction in channel width

Gradual contraction of the channel width

- It is typical (but not compulsory), that the approach channel:
  - starts at the water's edge with a width of around twice the width of the crest
  - has a bed that rising in elevation at a slope of 2 to 5 percent.

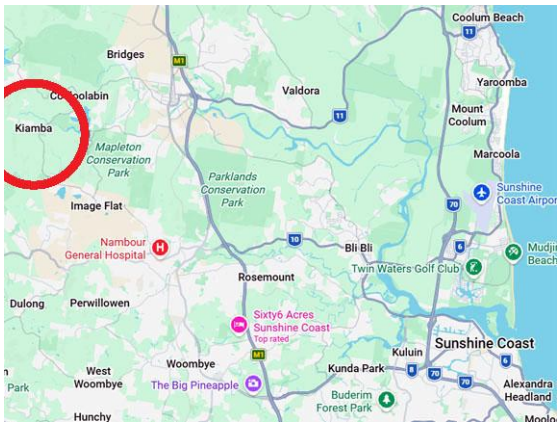


Grassed approach channel (Qld)

Stabilisation of the approach channel

- Typically, the approach channel can be stabilised with grass, but **not** stiff grasses, native grasses, Lomandra, or Vetiver grass.

Example design #1 – Grassed bywash for a low risk site



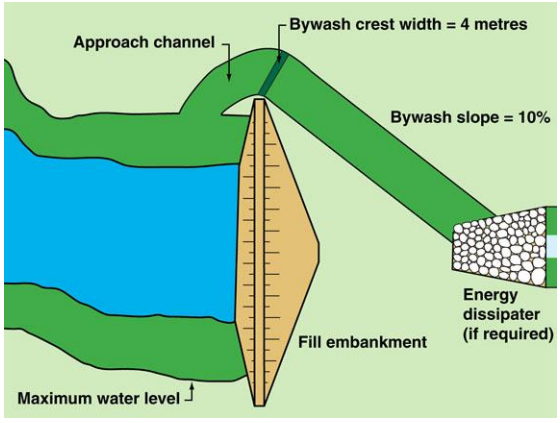
Location map



Up-slope conditions



Down-slope conditions



Grassed bywash

Site conditions

- The following example is for a grassed bywash located on a low risk dam site.
- Site conditions summarised as:
  - located at Kiamba, near Nambour, Qld
  - catchment condition is rural-residential
  - catchment area = 3 hectares
  - up-slope land = 1 in 20 at 300 m length
  - assessed as a low risk site
  - even though the site is assessed as low risk, I have nominated a 1 in 50 year design storm just to show the analysis.

Estimation of the design discharge

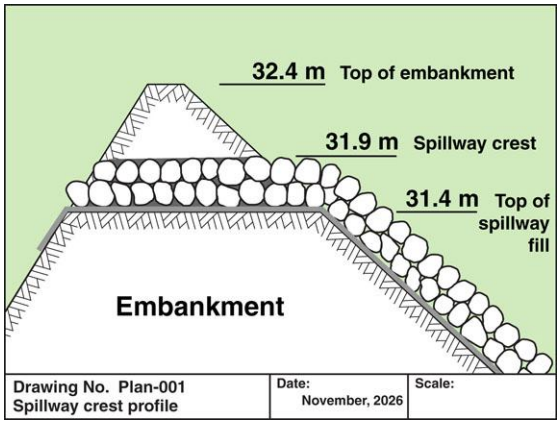
- Length of up-slope flow path = 1000 m
- Area = **3 ha**, and land slope = 1 in 20
- From Table 4.1: T_C = 10 minutes
- From Table 4.5: I_{10} = **168 mm/hr**, and the town is in a Group 7 location
- Adopt Soil 2 conditions
- From Table 4.2: C_{10} = 0.70
- From Table 4.3: F_{50} = 1.15
- Therefore: C_{50} = 1.15 x 0.70 = **0.805**
- **Q50 = (0.805 x 168 x 3)/360 = 1.13 m^3/s**

Design of the bywash

- Step 1: is to select the surface conditions of the bywash or spillway chute.
  - nominate healthy grass cover.
- Step 2: is to determine an allowable flow velocity for this surface condition.
  - nominate 2.1 m/s allowable velocity
- Step 3: involves selecting a chute slope, and determining the required width of the chute for that slope.
  - land slope of the proposed bywash is 1 in 10 (i.e. 10%), which is 'steep' for a grassed bywash.
- From Table 6.3 we can determine an allowable unit flow rate of 0.292 $m^3/s/m$, given the allowable velocity of 2.1 m/s and the bywash slope of 10%.
- Therefore, from Equation 6.1 we can determine the minimum required width of the bywash is:

  b= Q/q = 1.13/0.292 = 3.9 m, say 4 m
- A bywash width of 4 metre is wide for a grassed surface, but it reflects the high design standard that is required given the site's safety risk.

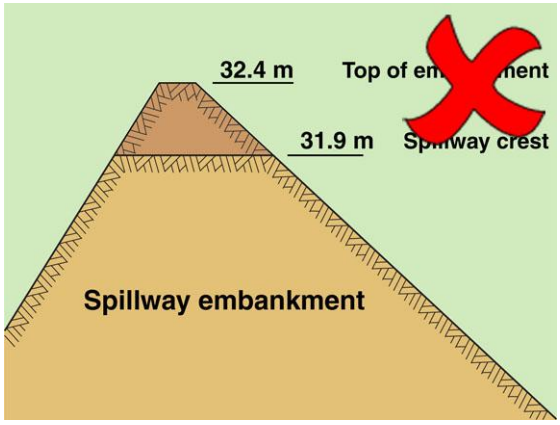
Common Design Problems



Construction plans of the spillway crest

Problem #1

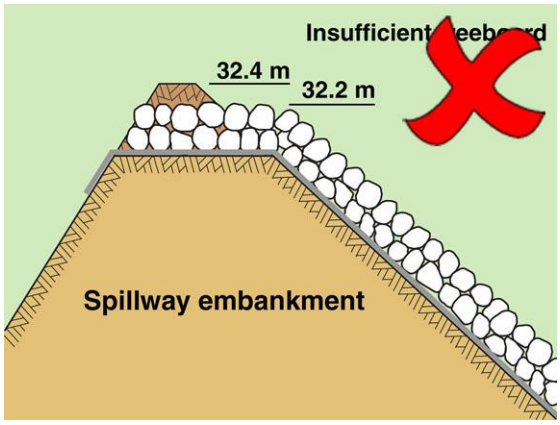
- Construction plans should specify, numerically, the elevation of the top of the embankment, the spillway crest, and the compacted earth below the rock.
- This will require designers to know the thickness of the specified scour protection placed over the spillway crest.
- It is noted (over the page) that the scour protection of the spillway crest may be different from that used down the face of the spillway.



Incorrect earthworks

What we are trying to avoid!

- The problem that we are trying to avoid is the case where the earthworks at the location of the spillway is formed to the specified elevation of the *finished spillway crest*, and no space has been allowed for the placement of the scour protection.
- If this error is not corrected, then once the scour protection has been added to the compacted earth, the final crest elevation will be well-above the desired value.



Incorrect outcome

What the spillway looked like after placement of the rocks

- This diagram (left) displays what the finished spillway would look like if this error had been made.
- The following page shows real life examples of this problem actually occurring—note the height of the rocks on the spillway crest relative to the top of the adjacent embankment.

Common design and construction problems



Insufficient freeboard

Example of spillway construction problems

- It is important to ensure that the spillway crest has sufficient depth and width to fully contain the design discharge.
- A poorly defined spillway crest profile (e.g. a crest with insufficient cross-sectional width or depth) can result in flows bypassing the spillway.
- In such cases (left, and below) damage to the earth embankment is likely to occur.



Insufficient freeboard



Insufficient freeboard



Insufficient freeboard



Insufficient freeboard

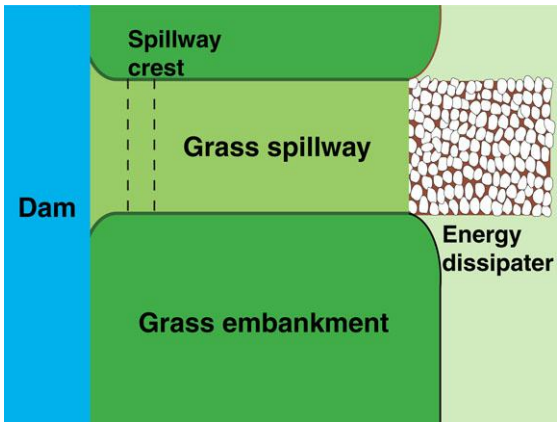


Insufficient freeboard

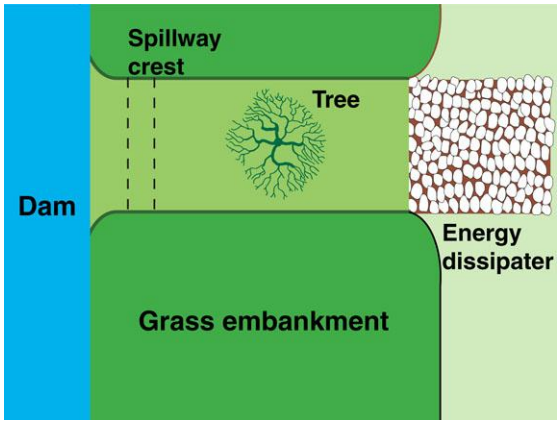


Insufficient freeboard

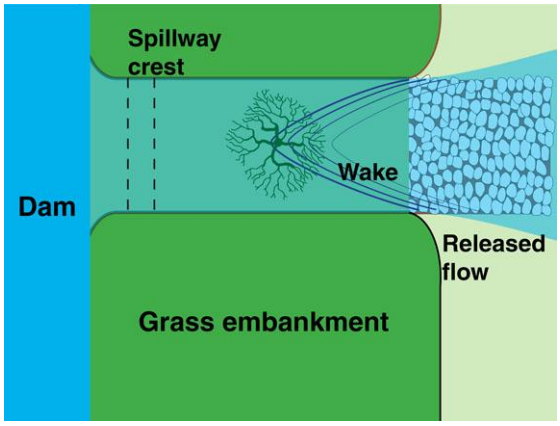
The reason why trees are NOT planted on spillways



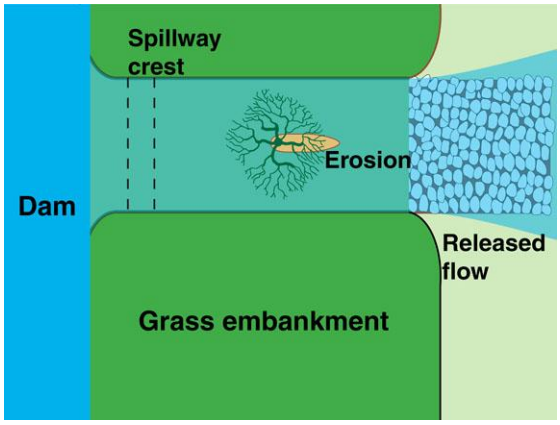
Plan view of a grass spillway



(a) Tree planted on a grass spillway



(b) Turbulent flow generated by the tree



(c) Scour hole formed at base of tree

Problem #2 – Planting trees or shrubs on a spillway

- A spillway can be lined with concrete, loose rock, or rock integrated with flexible grasses.
- In some cases, a spillway can be lined only with grass (i.e. a bywash).
- However, a spillway **must** never incorporate trees, shrubs, or stiff grasses, because these plants can induce turbulence in the high-velocity water, which can cause soil scour, and trigger gully erosion.



Trees planted on a grass spillway

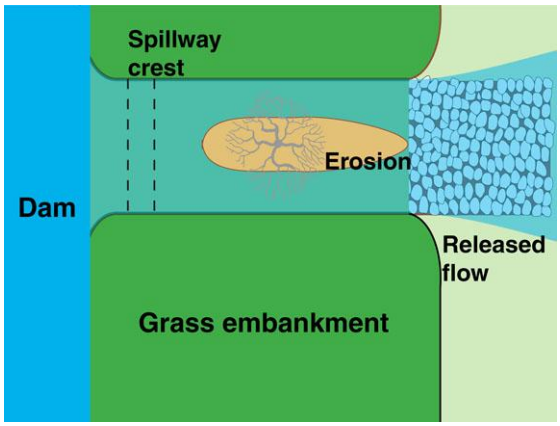
The cause of turbulence and erosion

- The type of objects that can cause flow problems and erosion issues on a grass spillway include:
  - trees
  - shrubs
  - fence posts
  - randomly-placed rocks (often placed on a bywash to help dissipate energy, but in some cases can cause more 'harm' than 'good'), or
  - park furniture, such as a bench seat.



Scour hole at base of tree

The reason why trees are NOT planted on spillways



(d) Expansion of scour hole

Formation of gully erosion

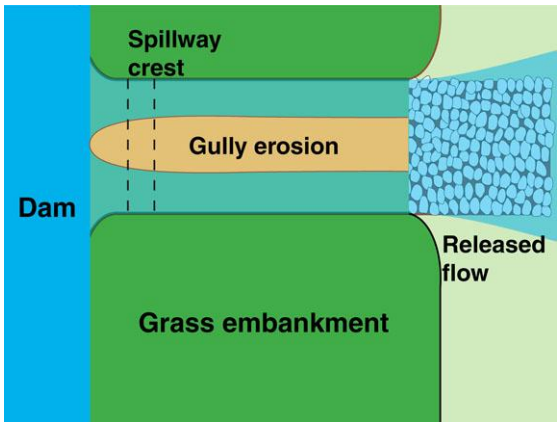
- Once a scour hole is formed in the grass, the spillway flows can quickly (i.e. during one storm event) turn such minor erosion into major gully erosion.
- If the soil that was used to form the earth spillway is slightly dispersive, then this gully erosion can cut a deep scar through the spillway.



Scour hole downstream of tree



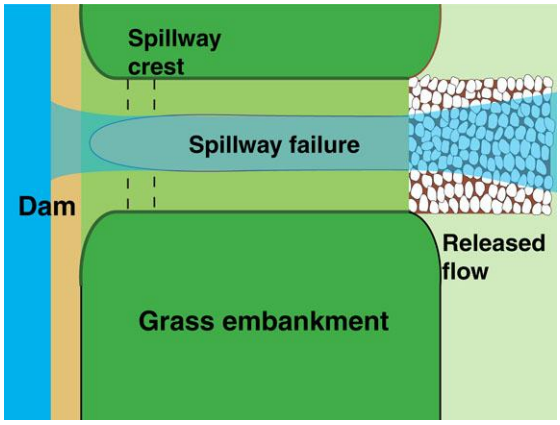
Scour hole



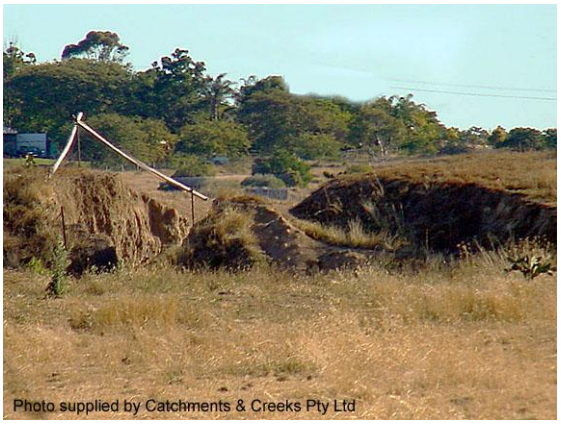
(e) Formation of gully erosion

Dam failure

- A worst-case outcome would involve the collapse of the whole spillway, which will cause the dam to quickly drain its contents.
- It is this sudden release of water than can result in the loss of life downstream because the wave of water can arrive without warning.

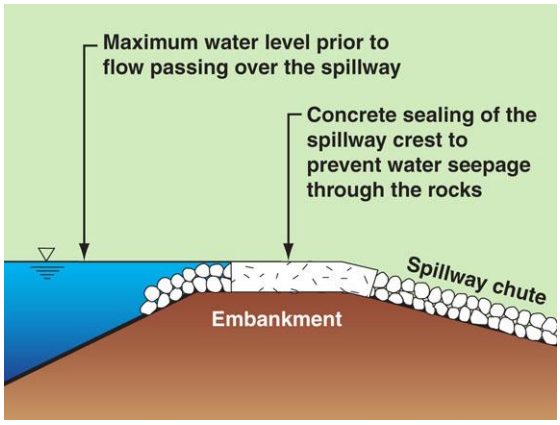


(f) Gully erosion reaches the water basin

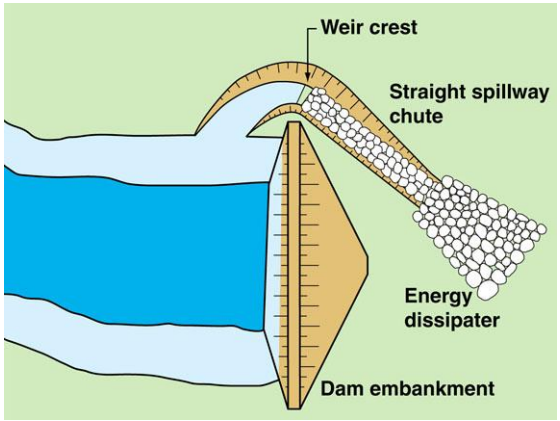


Failed spillway

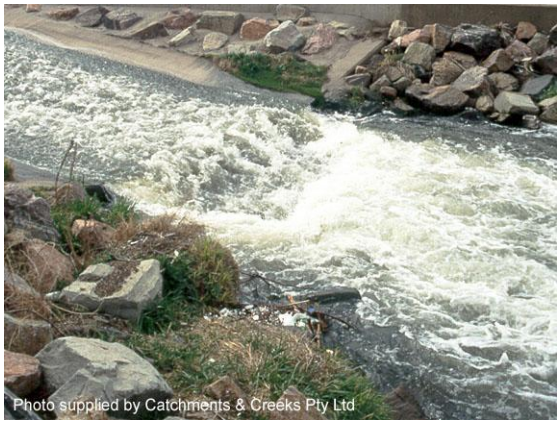
Designing a Medium Risk Spillway



Sealing the spillway crest



Spillway cut into virgin soil



Spillway with energy dissipation zone

The spillway crest

- The risk rating is discussed in Chapter 2.
- Flow conditions at the spillway crest may be analysed using an appropriate weir equation.
- It is important to ensure that the maximum potential water level within the dam, at peak discharge, will be fully contained by the basin's embankment.
- The concrete sealing of the spillway crest is necessary to prevent water flowing through the voids in the rock protection.

The spillway chute

- The determination of an appropriate rock size is based on either the maximum unit flow rate (q), or the maximum flow velocity (V) down the spillway.
- The 'unit flow rate' (q) is determined as the design discharge (Q) divided by the width of the chute (W):

$$q = Q/W \quad [m^3/s/m] \qquad (6.4)$$

- The spillway chute **must** be straight.

The energy dissipation zone

- An appropriate energy dissipater is usually required at the base of the spillway.
- It is possible that a medium risk bywash may not require a formal energy dissipation zone, but this is unlikely.
- The design of the energy dissipater must be assessed on a case-by-case basis; however, a generic design procedure is presented at the end of this chapter.

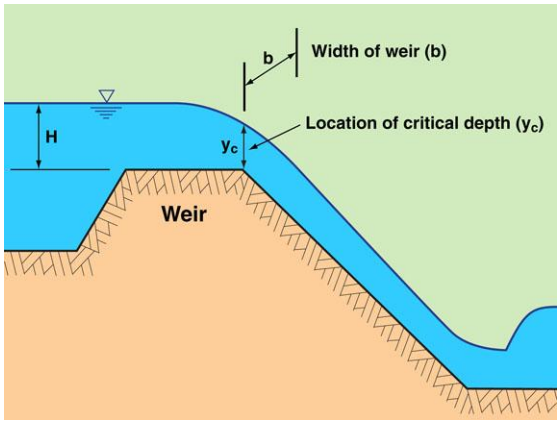
Weir flow equations



Crest of a rock-lined spillway

Introduction

- The spillway chute should have a constant cross-section from the crest of the chute to the base of the chute.
- Flow conditions at the crest of a chute can be determined from a weir equation.
- The weir equation defines the relationship between the flow rate (**Q**), the width of the weir crest (**b**), and the **upstream** water depth relative to the weir crest (**H**).



Weir flow head (H) and width (b)

Weir equation for a wide flat weir crest

- For wide chutes (say, b > 5H), it can be acceptable to adopt a simple rectangular weir equation, such as:

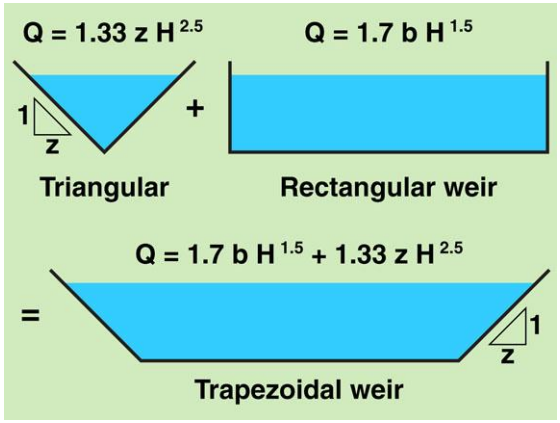
$$Q = 1.7\ b\ H^{1.5} \qquad (6.5)$$

where:

Q = total flow rate [m^3/s]

b = width of the weir crest [m]

H = upstream hydraulic head (water level) relative to the weir crest [m]



Components of a trapezoidal weir

Weir equation for a trapezoidal weir crest

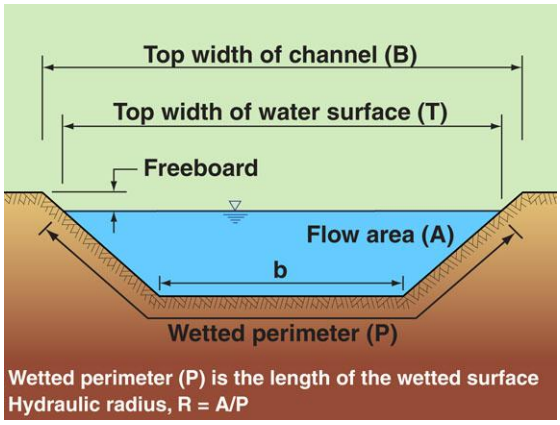
- For trapezoidal weirs, either use a numerical model, or analyse by combining rectangular weir equation (above) plus a triangular weir equation (below).
- The equation for a triangular weir is:

$$Q = 1.33\ z\ H^{2.5} \qquad (6.6)$$

where: z = the side slope (1 in z) of the trapezoidal weir.

- Thus, the trapezoidal weir equation is:

$$Q = 1.7\ b\ H^{1.5} + 1.33\ z\ H^{2.5} \qquad (6.7)$$



Chute cross-section

Manning's equation

The flow velocity down a chute may be estimated using Manning's equation:

$$V = (1/n)\ R^{0.67}\ .\ S^{0.5} \qquad (6.8)$$

where:

V = average flow velocity [m/s] = Q/A

n = Manning's roughness coefficient

A = cross-sectional area of flow [m^2]

R = hydraulic radius [m] = A/P

P = wetted perimeter of flow [m]

S = channel slope [m/m]

Scour protection for the spillway crest and chute



Rock-lined spillway (Qld)

Rock

- Rock is a common scour protection material.
- If the rock protection were to fail, the most common cause is likely to be:
  - the rock size is too small
  - on the spillway chute, the earth is compacted into a smooth surface, then filter cloth placed over this smooth surface, which turns the spillway into a slippery dip causing the rocks to slide—the earth should be rough and irregular before filter cloth is added.



Rock mattress spillway (NSW)

Rock mattress

- Rock mattresses can be expensive and time-consuming to assemble, but they can be reliable in the short-term.
- Long-term reliability requires appropriate integration with grasses (when used on a spillway chute)
- The rocks used to fill the mattresses are smaller than the size required for loose rock, so a rock-filled mattress can be 'thinner' than two layers of loose rock.
- Rock mattresses are possibly the best option if you have access to small rocks.



Stepped stone block spillway (NSW)

Placed stone and stepped spillways

- Placed or stacked stone can be used to form a steeper spillway when space is limited.
- These structures generally need a stable cut-off wall at their base to prevent undermining.
- A stepped spillway does not remove the need for appropriate energy dissipation at the base.
- Money and lateral thinking can turn these structures into garden features.



Concrete spillway crest (Qld)

Concrete or grouted rock

- Reinforced concrete can be used as:
  - a solid spillway crest
  - a strong spillway chute.
- If the spillway crest is lined with loose rock, then consider using concrete to fill the voids across the spillway crest to prevent water passing through these rocks—this will raise the 'full' water level to the top of the concrete, rather than the top of the underlining earth fill embankment.

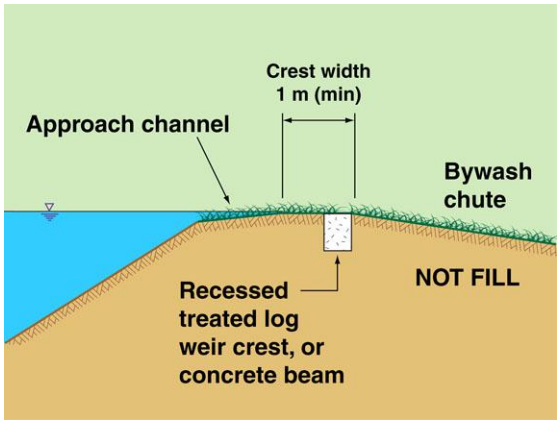
Stabilisation of the bywash crest



Gully erosion within a bywash chute

Introduction

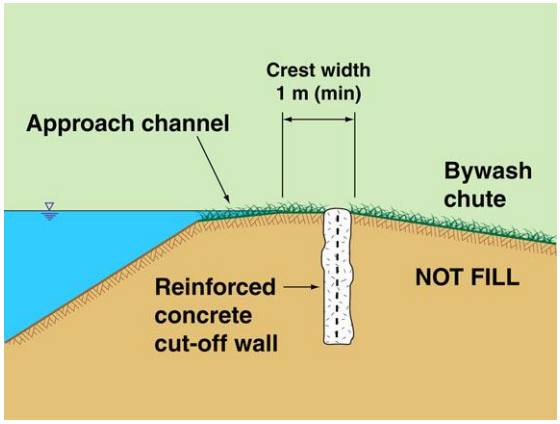
- The most common cause of the structural failure of a dam is severe erosion within the dam's spillway.
- Gully erosion can occur within a spillway either because of:
  - high flow velocities spilling down the spillway, or
  - gully erosion migrating up to the dam from a downstream source.



Precast concrete beam/post

Recessed log or concrete beam

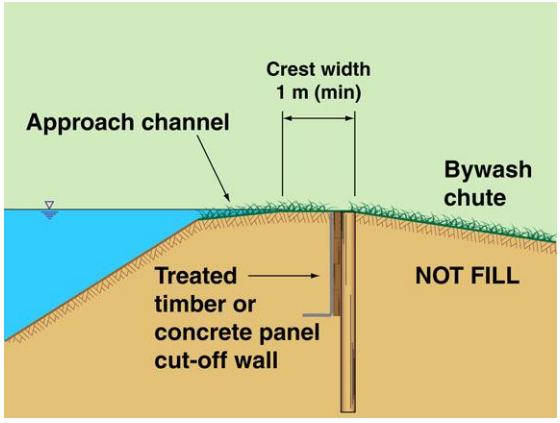
- If livestock is allowed to walk over the spillway crest while the soil is wet, which can trigger gully erosion, then it may be necessary to further stabilise the crest with:
  - a treated timber log recessed into the earth
  - a series of precast concrete fence posts recessed (horizontal) into the earth
  - an in-situ reinforced concrete trench.



Reinforced concrete cut-off trench

Concrete cut-off trench

- If there is the risk of gully erosion occurring on the spillway chute, or migrating up to the spillway from a downstream source, then consider installing a cut-off wall at the spillway crest and/or at the based of the spillway.
- The following page provides discussion on the installation of a deep concrete cut-off wall.



Treated timber cut-off wall

Treated timber or concrete panel cut-off wall

- A cut-off wall can also be formed from treated timber logs, or precast concrete posts.
- Further discussion is provided over the page on the installation of deep timber or concrete post cut-off walls.

Stabilisation of a bywash crest – Concrete cut-off wall



Excavation of trench

Excavation of trench

- Depending on the design of the cut-off wall, topsoil from the site may be stripped and stockpiled.
- The trench can be excavated with a variety of tools, including a cable trencher (narrow trench), or a backhoe.
- A wider trench increases the potential structural integrity of the cut-off wall, but also its cost.
- Ideally, the trench should be deeper than the approaching gully erosion.



Installed reinforcing mesh

Install steel reinforcing mesh

- Steel reinforcing mesh should be installed in the trench to increase the structural integrity of the cut-off wall.
- In a wide trench, the steel mesh should be placed 100 mm from each side of the trench (unless otherwise directed).
- In a wide trench, placing reinforcing mesh only in the centre of the trench will significantly reduce the potential strength of the wall once the gully erosion reaches the wall (reinforcing is best placed near the side of the wall that is in tension).



Filling the trench with concrete

Placement of concrete

- When backfilling the trench, ensure:
  - the concrete reaches all the way to the base of the trench
  - all air voids are removed from the concrete (use a concrete vibrator)
  - the steel reinforcing is not pushed up against either side of the trench—long timber strips can be used to hold the mesh in position, which can then be used to help remove air from the concrete while they are being removed.

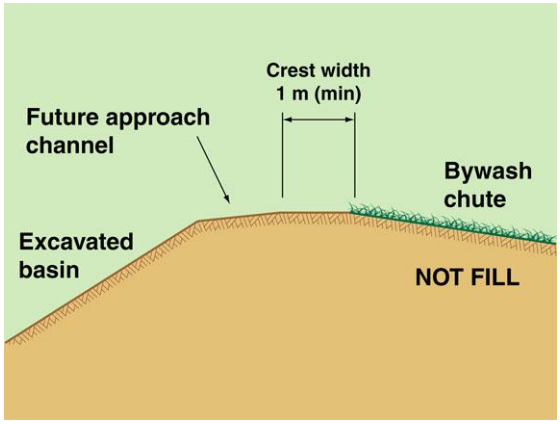


Finished concrete cut-off trench

Design of the upper concrete cap

- The upper surface of the cut-off wall can be designed to be:
  - flush with the surrounding land, which means flows will continue to spill down the chute, or
  - elevated above the normal weir elevation in order to divert flows down an alternative, newly-formed, replacement spillway chute.

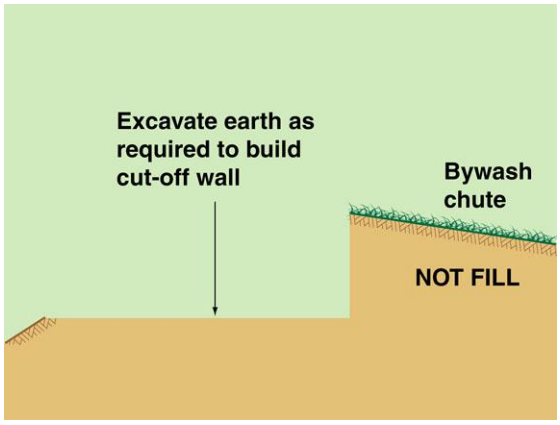
Stabilisation of a bywash crest – Concrete or timber post cut-off wall



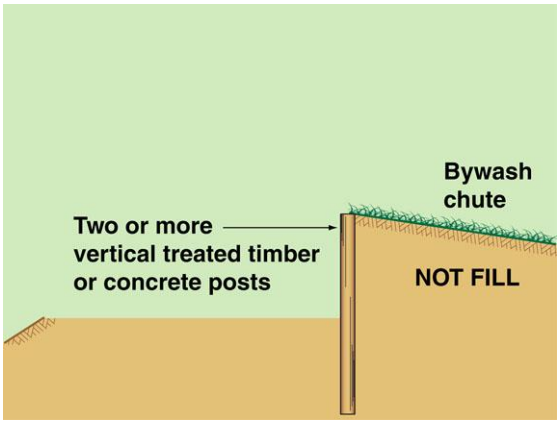
Existing spillway crest

Introduction

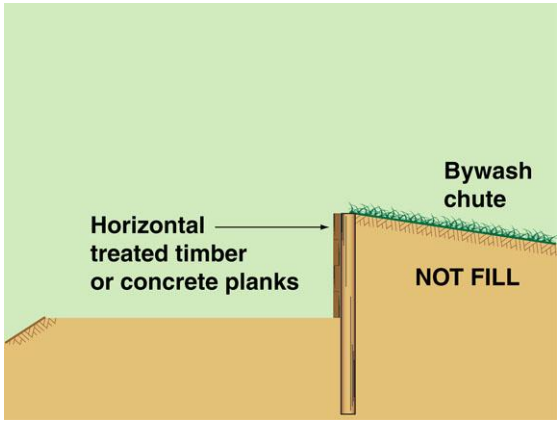
- **Step 1:** Excavate a trench upstream of the spillway crest.
- **Step 2:** Install vertical support posts.



Step 1: Excavated trench

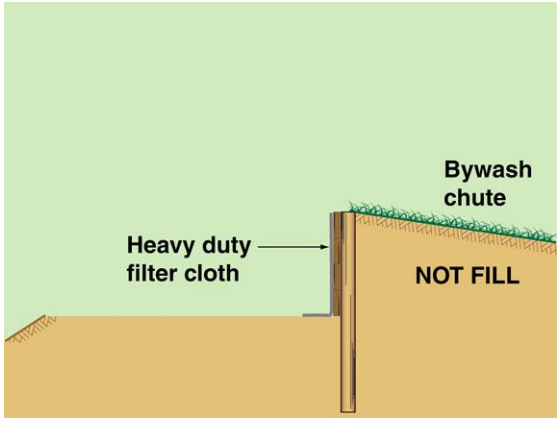


Step 2: Install vertical support posts

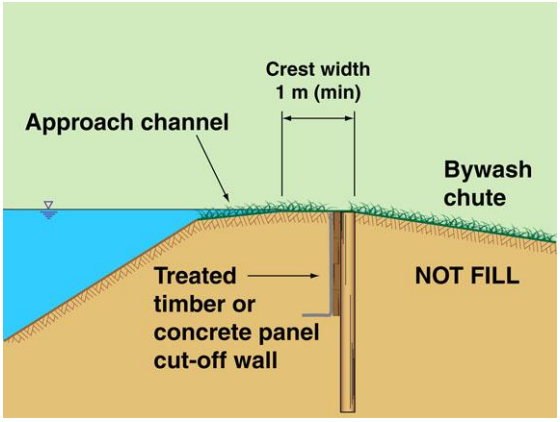


Step 3: Install horizontal panels

- **Step 3:** Install horizontal panels to form a solid wall.
- **Step 4:** Protected the timber with heavy duty filter cloth (if timber is used).
- **Step 5:** Backfill and compact the approach channel.
- **Step 6:** Re-grass the bywash.



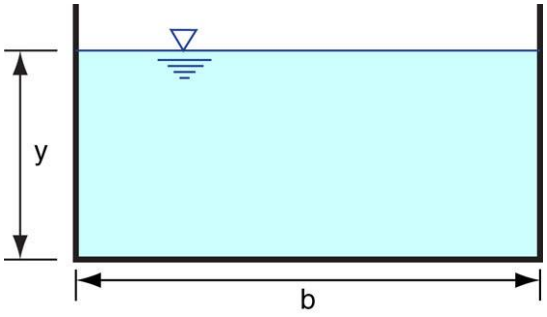
Step 4: Cover with filter cloth



Step 5: Reform the approach channel

Geometric properties of drainage channels

Rectangular:



Area (A):

$$A = by$$

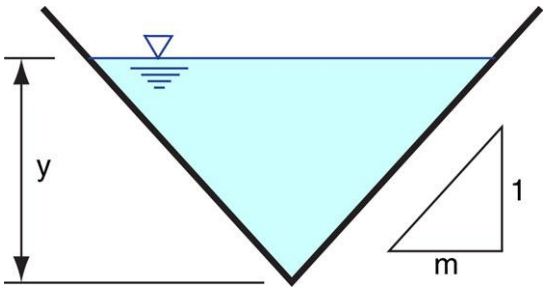
Wetted perimeter (P):

$$P = b + 2y$$

Critical depth (y_c):

$$y_c = (q^2/g)^{1/3} = 0.67(EL)$$

Triangular (V-drain):



Area (A):

$$A = my^2$$

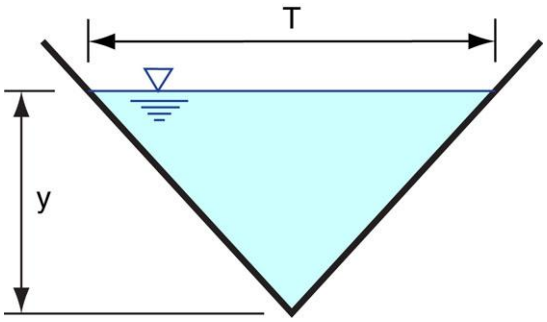
Wetted perimeter (P):

$$P = 2y\sqrt{(1+m^2)}$$

Hydraulic radius (R):

$$R = \frac{my}{2\sqrt{(1+m^2)}}$$

Triangular (V-drain):



Area (A):

$$A = 0.5\,T\,y$$

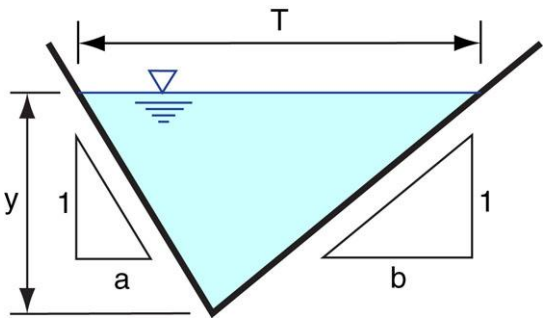
Wetted perimeter (P):

$$P = \sqrt{T^2 + 4y^2}$$

Hydraulic radius (R):

$$R = \frac{Ty}{2\sqrt{T^2 + 4y^2}}$$

Asymmetric Triangular (V-drain):



Area (A):

$$A = \left(\frac{a+b}{2}\right)y^2$$

Wetted perimeter (P):

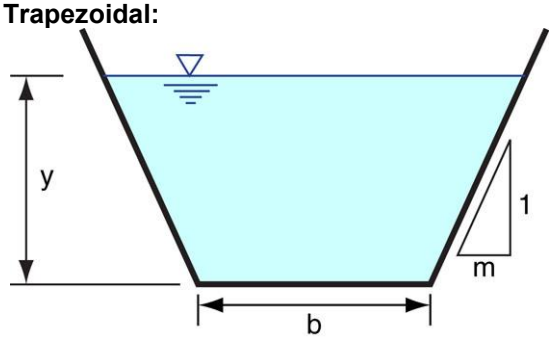
$$P = y\left[\sqrt{(1+a^2)} + \sqrt{(1+b^2)}\right]$$

Hydraulic radius (R):

$$R = \frac{0.5(a+b)y}{\sqrt{(1+a^2)} + \sqrt{(1+b^2)}}$$

Geometric properties of drainage channels

Trapezoidal:



Area (A):

$$A = y(b+my)$$

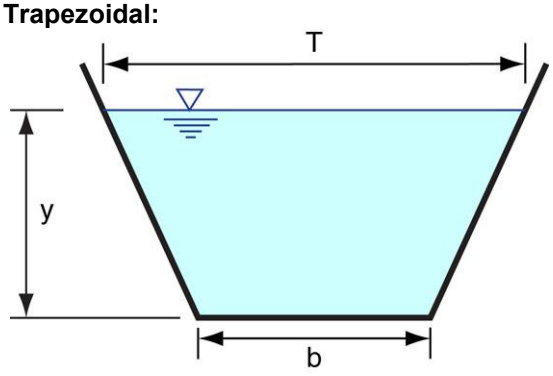
Wetted perimeter (P):

$$P = b+2y\sqrt{(1+m^2)}$$

Hydraulic radius (R):

$$R = \frac{y(b+my)}{b+2y\sqrt{(1+m^2)}}$$

Trapezoidal:



Area (A):

$$A = 0.5y(T+b)$$

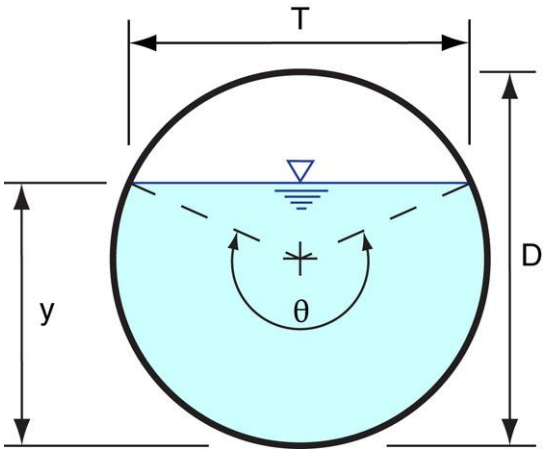
Wetted perimeter (P):

$$P = b+\sqrt{4y^2+(T-b)^2}$$

Critical depth (y_c):

$y = y_c$ when: $Q^2.T = g.A^3$

Circular:



Area (A):

$$A = \frac{D^2}{8}(\theta-\sin\theta)$$

Wetted perimeter (P):

$$P = 0.5(D.\theta)$$

Hydraulic radius (R):

$$R = \frac{D}{4}\left(1-\frac{\sin\theta}{\theta}\right)$$

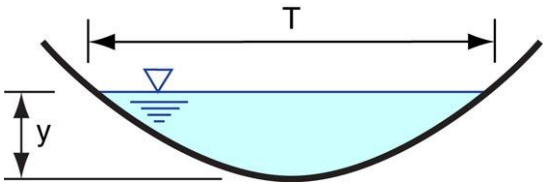
Top width (T):

$$T = 2\sqrt{y(D-y)} = D.\sin\left(\frac{\theta}{2}\right)$$

where:

$$\theta = 2\cos^{-1}\left(1-\frac{2y}{D}\right)$$

Parabolic:



Parabolic profile: $y = \text{constant}(T^2)$

Area (A):

$$A = 0.67(T.y)$$

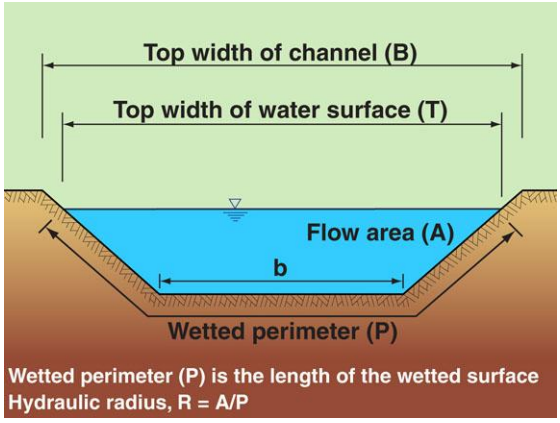
Wetted perimeter (P):

$$P = T+\frac{8y^2}{3T}$$

Hydraulic radius (R):

$$R = \frac{2T^2.y}{3T^2+8y^2}$$

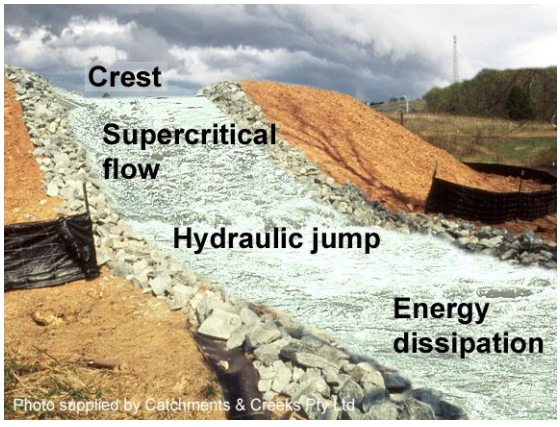
Sizing Rock Protection for Spillway Chutes



Channel geometry and flow conditions

Deep water flow conditions are unlikely to occur on a small dam spillway

Deep water flow conditions



Rock-lined spillway with energy dissipation

Manning's equation

- The **average** channel flow velocity may be calculated using Manning's equation:

$$V = (1/n)\, R^{2/3}\, S^{1/2} \qquad (6.9)$$

where:

V = average flow velocity (m/s)
n = Manning's roughness coefficient
R = hydraulic radius (m) = A/P
A = effective flow area of channel (m^2)
P = wetted perimeter of flow (m)
S = channel slope (m/m)

Manning's roughness in deep water

- The Strickler equation for deep water may be presented in the modified form:

$$n = ((d_{50})^{1/6})/21.1 \qquad (6.10)$$

- An alternative equation was developed by Meyer-Peter & Muller:

$$n = ((d_{90})^{1/6})/26.0 \qquad (6.11)$$

  - d_{50} = rock size for which 50% of rocks (by weight) are smaller [m]
  - d_{90} = rock size for which 90% of rocks (by weight) are smaller [m]

Manning's roughness in shallow water

- The Manning's roughness (n) of rock-lined surfaces in both shallow-water and deep-water flow conditions is provided below.

$$n = \frac{d_{90}^{1/6}}{26(1 - 0.3593^{m})} \qquad (6.12)$$

  - $m = [(R/d_{90})(d_{50}/d_{90})]^{0.7}$
  - R = hydraulic radius of flow [m]

- The relative roughness (d_{50}/d_{90}) of rock extracted from streambeds is typically in the range 0.2 to 0.5; while quarried rock is commonly in the range 0.5 to 0.8.

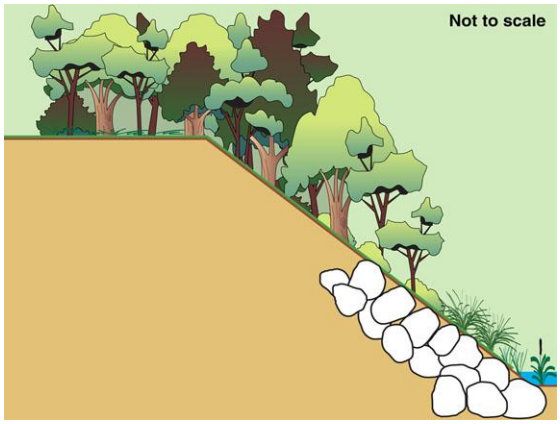
Placement of rock (extract from 'Creek Erosion Field Guide')



Example of 'placed rock' (Qld)

Introduction

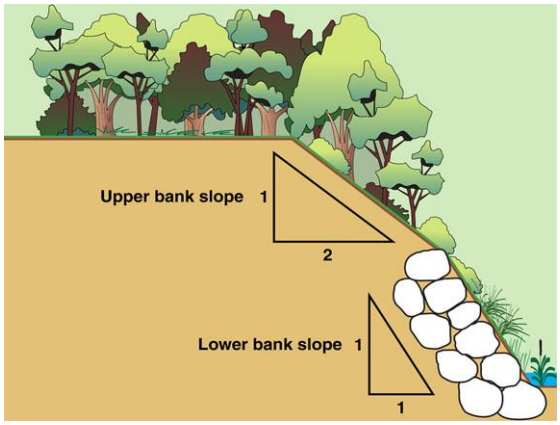
- The maximum gradient of rock-lined surfaces depends on:
  - how the rocks are placed (dumped from the back of a truck, individually placed by a rock grab, or stacked so as to minimise any individual movement)
  - the existing bank slopes upstream and downstream of the proposed rock work.



Dumped rock

Dumped rock

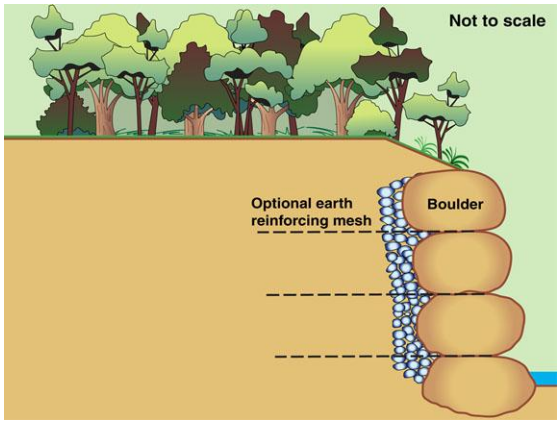
- Typical bank gradients for 'dumped' rock are:
  - 1 in 2 on the outside of channel bends
  - 1 in 3 on the inside of channel bends.
- Wherever practical, bank gradients should blend well with the existing upstream and downstream banks, i.e:
  - avoid sudden changes in bank slope
  - make sure your bank repair fits in with the rest of the creek.



Placed rock on outside of a channel bend

Placed rock

- 'Placed rock' means individual rocks are positioned on the creek bank in a manner that ensures good stability.
- Maximum bank gradient for 'placed' rock is:
  - 1 in 1 on the inside or outside of a channel bend.
- The desirable bank gradient on the inside of a channel bend is:
  - 1 in 2, but probably flatter.



Stacked rock retaining wall

Stacked rock

- Steeper banks can be achieved with the use of stacked rocks (boulders), but the rocks must sit on a stable bed.
- The stability of the boulder wall can be increased by integrating earth reinforcing mesh into the design.
- Warning; steep, high banks can represent a safety hazard to revegetation teams and the public.

Manning's roughness of rock-lined surfaces

The Manning's (n) roughness for rock-lined surfaces can be determined from Table 6.4 or Equation 6.12.

Table 6.4 – Manning's (n) roughness of rock-lined surfaces

	d_{50}/d_{90} = 0.5				d_{50}/d_{90} = 0.8			
d_{50} =	200mm	300mm	400mm	500mm	200mm	300mm	400mm	500mm
R (m)	Manning's roughness (n)				Manning's roughness (n)			
0.2	0.10	0.14	0.17	0.21	0.06	0.08	0.09	0.11
0.3	0.08	0.11	0.14	0.16	0.05	0.06	0.08	0.09
0.4	0.07	0.09	0.12	0.14	0.04	0.05	0.07	0.08
0.5	0.06	0.08	0.10	0.12	0.04	0.05	0.06	0.07
0.6	0.06	0.08	0.09	0.11	0.04	0.05	0.05	0.06
0.8	0.05	0.07	0.08	0.09	0.04	0.04	0.05	0.06
1.0	0.04	0.06	0.07	0.08	0.03	0.04	0.05	0.05

Equation 8 is considered to produce significantly better estimates of the Manning's roughness of rock-lined surfaces in shallow water flow compared to the use of traditional deep water equations such as the Strickler, Meyer-Peter & Muller or Limerinos equations.

Given the high variability of Manning's n and the wide range of variables that are believed to influence the hydraulic roughness of a rock-lined channel, Equation 6.12 is considered well within the limits of accuracy expected for Manning's n selection.

Data analysis during the development of Equation 6.12 indicated that the Meyer-Peter & Muller equation (Eqn 6.11) produced more reliable estimates of the deep water Manning's roughness values than the Strickler equation (Eqn 6.10). Possibly the choice between the two equations would come down to how reliable the determination of the d_{50} and d_{90} values were. If the estimate of d_{90} is not reliable, then it would be more appropriate to rely on the Strickler equation for the determination of the deep water Manning's n value, and vice versa.

Typical properties of rock

Crushed rock is generally more stable than natural rounded rock; however, rounded rock has a more 'natural' appearance. A 36% increase in rock size is recommended if rounded rock is used (i.e. K_1 = 1.36).

The rock should be durable and resistant to weathering, and should be proportioned so that neither the breadth nor the thickness of a single rock is less than one-third of its length.

Maximum rock size generally should not exceed twice the nominal (d_{50}) rock size, but in some cases a maximum rock size of 1.5 times the average rock size may be specified.

Typical rock densities (s_r) are presented in Table 6.5.

Table 6.5 – Relative density (specific gravity) of rock

Rock type	Relative density (s_r)
Sandstone	2.1 to 2.4
Granite	2.5 to 3.1 (commonly 2.6)
Limestone	2.6
Basalt	2.7 to 3.2

Thickness of rock placement

On basin spillways, the minimum height of the rock protection placed on the spillway banks should be equal to the critical flow depth (at the crest) plus 0.3 m.

The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size. The thickness of rock protection must also be sufficient to accommodate the largest rock size. It is noted that increasing the thickness of the rock placement will **not** compensate for the use of undersized rock.

In order to allow at least two layers of rock, the minimum thickness of rock protection (T) can be approximated by the values presented in Table 6.6.

Table 6.6 – Minimum thickness (T) of rock lining

Min. thickness (T)	Size distribution (d_{50}/d_{90})	Description
1.4 d_{50}	1.0	Highly uniform rock size
1.6 d_{50}	0.8	Typical upper limit of quarry rock
1.8 d_{50}	0.67	Recommended lower limit of distribution
2.1 d_{50}	0.5	Typical lower limit of quarry rock

Note: d_X = nominal rock size (diameter) of which X% (by weight) of the rocks are smaller.

Minimum dimensions, freeboard and safety factor

Recommended absolute minimum spillway depth is 300 mm plus freeboard.

A freeboard of 150 mm should exist. A greater freeboard may be required if it is necessary for the spillway to fully contain any splash.

The descending spillway chute must be straight from its crest to outlet (i.e. no bends or curves).

Vegetating rock-lined spillways can significantly increase the spillway's long-term stability. Flexible, mat-forming grasses (non-woody plants) must be used. Stiff grasses, such as *Lomandra* or *Vetiveria zizanioides,* are **not** recommended for basin spillways.

Table 6.7 – Recommended safety factor for use in determining rock size

Safety factor (SF)	Recommended usage	Example site conditions
1.2	• Low risk structures. • Failure of structure is most unlikely to cause loss of life or irreversible property damage. • Permanent rock chutes with all voids filled with soil and pocket planted.	• Dam spillways where failure of the structure is likely to result in easily repairable soil erosion. • Dam spillways that are likely to experience significant sedimentation and vegetation growth before experiencing high flows.
1.5	• Medium risk structures. • Failure of structure may cause loss of life or irreversible property damage. • Temporary structures that have a high risk of experiencing the design discharge while the voids remain open (i.e. prior to sediment settling within and stabilising the voids between individual rocks).	• Dam spillways where failure of the structure may cause severe gully erosion. • Dam spillways located up-slope of a residential area or busy roadway where an embankment failure could cause property flooding or loss of life. • Spillways designed for a storm frequency less than 1 in 20 years.

Sizing rock for small dam spillways

Application of equation	Primary rock sizing equation:
• This is the preferred design equation • Applicable for uniform flow conditions only, $S_e = S_o$ • Batter slopes (S_o) less than 50% (1 in 2)	$$d_{50} = \frac{1.27.SF.K_1.K_2.S_o^{0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)}$$ (Equation 6.13)

Tables 6.8 and 6.9 provide mean rock size (rounded up to the next 0.1 m unit) for angular rock, and a safety factor of both 1.2 and 1.5. These tables are based on Equation 6.13, and are best used in the design of long drainage chutes. Use of the 'unit flow rate' (q) as the primary design variable is preferred to the use of 'flow velocity' (V) because it avoids errors associated with the selection of Manning's roughness.

Alternatively, tables 6.10 and 6.11 provide mean rock size for angular rock and a safety factor of 1.2 and 1.5, based on Equation 6.13 with flow velocity presented as the primary variable. These tables are best used in the design of short drainage chutes where uniform flow conditions are unlikely to be achieved down the face of the chute.

Definition of equation symbols

d_X = nominal rock size (diameter) of which X% (by weight) of the rocks are smaller [m]

d_{15} = rock size of 'coarse' layer of which 15% of the rocks are smaller [m]

d_{85} = rock size of 'fine' underlay of which 85% of the rocks are smaller [m]

A & B = equation constants

K = equation constant based on flow conditions

= 1.1 for low-turbulent deep water flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent and/or supercritical flow

K_1 = correction factor for rock shape

= 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)

K_2 = correction factor for rock grading

= 0.95 for poorly graded rock ($C_u = d_{60}/d_{10} < 1.5$), 1.05 for well graded rock ($C_u > 2.5$), otherwise $K_2 = 1.0$ ($1.5 < C_u < 2.5$)

n_o = Manning's roughness value for deep water conditions [dimensionless]

q = flow per unit width down the embankment [$m^3/s/m$]

s_r = specific gravity of rock (e.g. sandstone 2.1–2.4; granite 2.5–3.1, typically 2.6; limestone 2.6; basalt 2.7–3.2)

S_e = slope of energy line [m/m]

S_o = bed slope = tan(θ) [m/m]

SF = safety factor

V = actual depth-average flow velocity at location of rock [m/s]

V_o = depth-average flow velocity based on **uniform** flow down a slope, S_o [m/s]

y = depth of flow at a given location [m]

θ = slope of channel bed [degrees]

Table 6.8 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Unit flow rate ($m^3/s/m$)	Bed slope = 1:2		Bed slope = 1:3		Bed slope = 1:4		Bed slope = 1:6	
	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}
0.1	0.09	**0.20**	0.09	**0.20**	0.09	**0.10**	0.09	**0.10**
0.2	0.14	**0.30**	0.14	**0.20**	0.14	**0.20**	0.15	**0.20**
0.3	0.18	**0.30**	0.19	**0.30**	0.19	**0.20**	0.20	**0.20**
0.4	0.22	**0.40**	0.23	**0.30**	0.23	**0.30**	0.24	**0.20**
0.5	0.26	**0.40**	0.26	**0.40**	0.27	**0.30**	0.27	**0.30**
0.6	0.29	**0.50**	0.30	**0.40**	0.30	**0.40**	0.31	**0.30**
0.8	0.35	**0.60**	0.36	**0.50**	0.37	**0.40**	0.37	**0.40**
1.0	0.41	**0.70**	0.42	**0.60**	0.42	**0.50**	0.44	**0.40**
1.2	0.46	**0.70**	0.47	**0.60**	0.48	**0.50**	0.49	**0.50**
1.4	0.51	**0.80**	0.52	**0.70**	0.53	**0.60**	0.54	**0.50**
1.6	0.56	**0.90**	0.57	**0.70**	0.58	**0.70**	0.60	**0.50**
1.8	0.60	**1.00**	0.62	**0.80**	0.63	**0.70**	0.64	**0.60**
2.0	0.65	**1.00**	0.66	**0.90**	0.67	**0.70**	0.69	**0.60**
3.0	0.85	**1.30**	0.87	**1.10**	0.88	**1.00**	0.90	**0.80**
4.0	1.02	**1.60**	1.05	**1.30**	1.07	**1.20**	1.10	**1.00**
5.0	1.19	**1.80**	1.22	**1.50**	1.24	**1.30**	1.27	**1.10**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 6.9 – Uniform flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.5

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Unit flow rate ($m^3/s/m$)	Bed slope = 1:1		Bed slope = 1:3		Bed slope = 1:4		Bed slope = 1:6	
	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}
0.1	0.10	**0.20**	0.10	**0.20**	0.10	**0.20**	0.10	**0.10**
0.2	0.15	**0.30**	0.15	**0.30**	0.16	**0.20**	0.16	**0.20**
0.3	0.20	**0.40**	0.20	**0.30**	0.21	**0.30**	0.21	**0.30**
0.4	0.24	**0.50**	0.25	**0.40**	0.25	**0.40**	0.26	**0.30**
0.5	0.28	**0.50**	0.28	**0.50**	0.29	**0.40**	0.30	**0.30**
0.6	0.31	**0.60**	0.32	**0.50**	0.33	**0.40**	0.34	**0.40**
0.8	0.38	**0.70**	0.39	**0.60**	0.40	**0.50**	0.41	**0.40**
1.0	0.44	**0.80**	0.45	**0.70**	0.46	**0.60**	0.47	**0.50**
1.2	0.50	**0.90**	0.51	**0.80**	0.52	**0.70**	0.53	**0.60**
1.4	0.55	**1.00**	0.57	**0.90**	0.58	**0.80**	0.59	**0.60**
1.6	0.60	**1.10**	0.62	**0.90**	0.63	**0.80**	0.64	**0.70**
1.8	0.65	**1.20**	0.67	**1.00**	0.68	**0.90**	0.70	**0.70**
2.0	0.70	**1.30**	0.72	**1.10**	0.73	**0.90**	0.75	**0.80**
3.0	0.92	**1.70**	0.94	**1.40**	0.96	**1.20**	0.98	**1.00**
4.0	1.11	**2.00**	1.14	**1.70**	1.16	**1.50**	1.19	**1.20**
5.0	1.29	**2.30**	1.32	**1.90**	1.34	**1.70**	1.38	**1.40**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 6.10 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.2 [1]

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Local velocity (m/s)	**Bed slope (V:H)**							
	1:2	**1:3**	**1:4**	**1:6**	**1:10**	**1:15**	**1:20**	**1:30**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05
1.0	0.20	0.10	0.10	0.10	0.10	0.10	0.05	0.05
1.3	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10
1.5	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.10
1.8	0.40	0.30	0.30	0.30	0.20	0.20	0.20	0.20
2.0	0.50	0.40	0.40	0.30	0.30	0.30	0.20	0.20
2.3	0.60	0.50	0.50	0.40	0.30	0.30	0.30	0.30
2.5	0.70	0.60	0.60	0.50	0.40	0.40	0.30	0.30
2.8	0.80	0.70	0.70	0.60	0.50	0.40	0.40	0.40
3.0	1.00	0.90	0.80	0.70	0.60	0.50	0.50	0.40
3.5	1.30	1.10	1.00	0.90	0.80	0.70	0.60	0.60
4.0	1.70	1.50	1.30	1.20	1.00	0.90	0.80	0.70
4.5	2.10	1.90	1.70	1.50	1.20	1.10	1.00	0.90
5.0				1.80	1.50	1.30	1.20	1.10
6.0						1.90	1.70	1.60

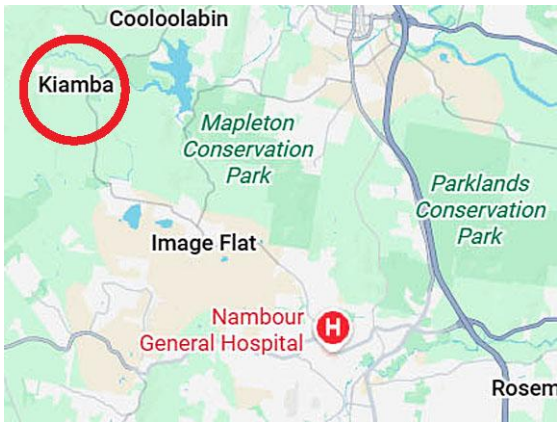
[1] Based on uniform flow conditions, **safety factor = 1.2**, rock specific gravity of 2.4, and a rock size distribution such that the largest rock is approximately twice the size of the mean rock size.

Table 6.11 – Velocity-based design table for mean rock size, d_{50} (m) for SF = 1.5 [1]

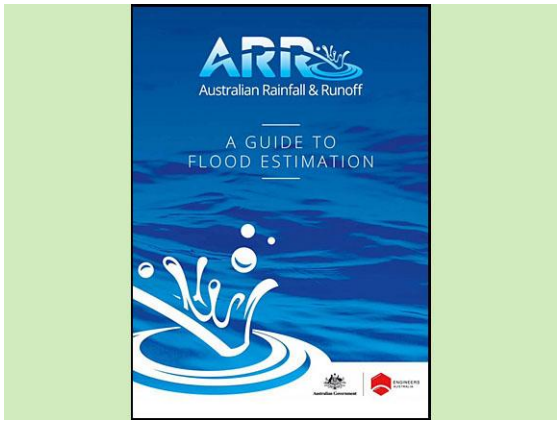
Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Local velocity (m/s)	**Bed slope (V:H)**							
	1:2	**1:3**	**1:4**	**1:6**	**1:10**	**1:15**	**1:20**	**1:30**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05
1.0	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10
1.3	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.10
1.5	0.40	0.30	0.30	0.30	0.20	0.20	0.20	0.20
1.8	0.50	0.50	0.40	0.40	0.30	0.30	0.30	0.20
2.0	0.70	0.60	0.50	0.50	0.40	0.40	0.30	0.30
2.3	0.80	0.70	0.60	0.60	0.50	0.40	0.40	0.40
2.5	1.00	0.90	0.80	0.70	0.60	0.50	0.50	0.40
2.8	1.20	1.00	0.90	0.80	0.70	0.60	0.60	0.50
3.0	1.40	1.20	1.10	1.00	0.80	0.70	0.70	0.60
3.5	1.90	1.70	1.50	1.30	1.10	1.00	0.90	0.80
4.0			1.90	1.70	1.40	1.30	1.10	1.00
4.5					1.80	1.60	1.40	1.30
5.0						1.90	1.80	1.60
6.0								2.20

[1] Based on uniform flow conditions, **safety factor = 1.5**, rock specific gravity of 2.4, and a rock size distribution such that the largest rock is approximately twice the size of the mean rock size.

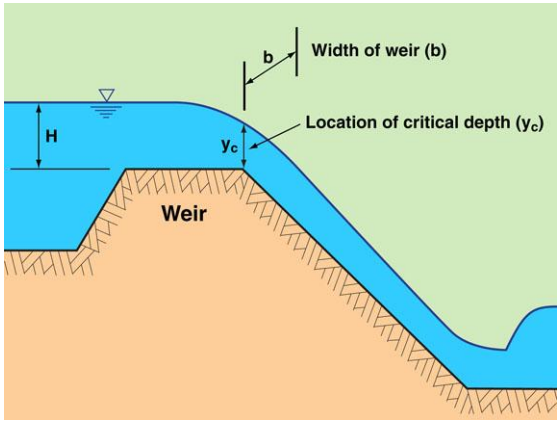
Example design #2 – Spillway for a medium risk site



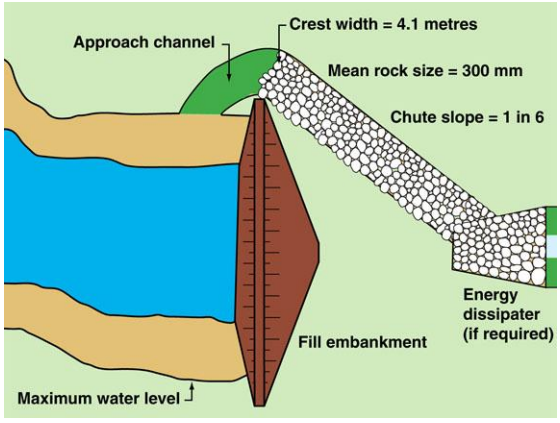
Location map



Australian Rainfall and Runoff (ARR)



Weir flow head (H) and width (b)



Rock-lined spillway

Site conditions

- Adopting the same site conditions as for Example 1.
- Site conditions:
  - located at Kiamba, near Nambour, Qld
  - catchment condition is rural-residential
  - catchment area = 3 hectares
  - up-slope land = 1 in 20 at 300 m length
  - assessed as a medium risk site due to close location of downstream road
  - nominated a 1 in 50 year design storm.

Estimation of the design discharge

- Being assessed as a medium risk site, the hydrologic analysis should be done using the latest information available for the Bureau of Meteorology (BoM), and the procedures presented in the latest Australian Rainfall and Runoff.
- Such analysis will not be shown here, instead I will adopt the same Q50 flow rate determined in Example 1.
- Let Q50 = 1.13 m^3/s.

Design the spillway crest

- At this site we know we have access to 300 mm rock, so the first attempt at a design will be based on this rock size.
  - d_{50} = 300 mm
  - Table 6.7, Safety factor = 1.5
  - Spillway slope is 1 in 6
  - Table 6.9, q = 0.5 $m^3/s/m$
  - Given that Q50 = 1.13 m^3/s, then the width of the spillway = 1.13/0.5 = 2.3 m
- We now need to look at the spillway crest.
  - Equation 6.5, $Q = 1.7\ b\ H^{1.5}$
  - Thus, $1.13 = 1.7 \times 2.3 \times H^{1.5}$
  - Therefore, H = 0.437 metres
- This means the maximum expected water level in the dam would be 0.44 m above the spillway crest, which I am going to pretend is too high.
- Let H_{Max} = 0.3 metres
  - Eqn 6.5, $1.13 = 1.7 \times b \times (0.3)^{1.5}$
  - Therefore, b = 4.05 metres, say 4.1 m
- Agree to a spillway width of 4.1 m, slope of 1 in 6, rock size of 300 mm, and a maximum allowable water level of 300 mm above the spillway crest.

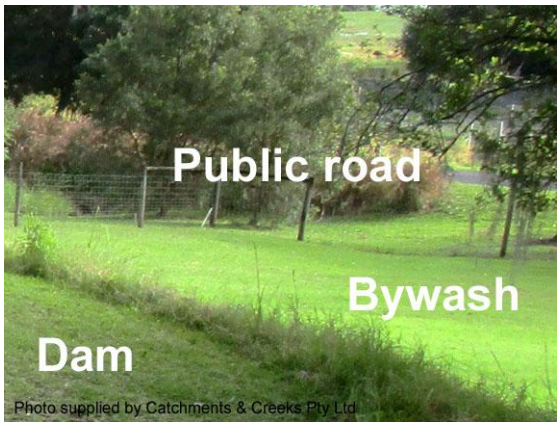
Designing the Energy Dissipation Zone



Design

Introduction

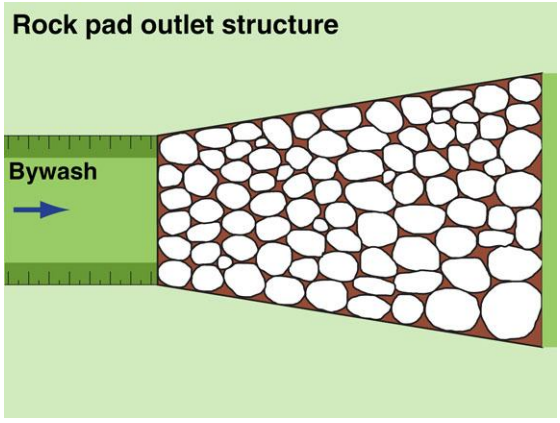
- The first step is to determine IF an energy dissipation zone is actually required.
- An energy dissipation zone is required if the flow at the base of the bywash or spillway is required to:
  - slow its velocity
  - suddenly change its direction of flow.
- An energy dissipation zone is **NOT** required if the flow at the base of the bywash continues to flow down a 'steep' slope at a supercritical velocity.



Discharge into a grass swale (Qld)

Example site conditions where an energy dissipation zone may not be required

- There is no point in slowing the flow velocity at the base of a spillway if the 'natural' flow conditions downstream of the spillway is a similar high velocity (i.e. supercritical flow condition).
- For example:
  - the water is released into a steep grass field or drainage swale
  - the dam is considered to be a hillside dam (Caution!).

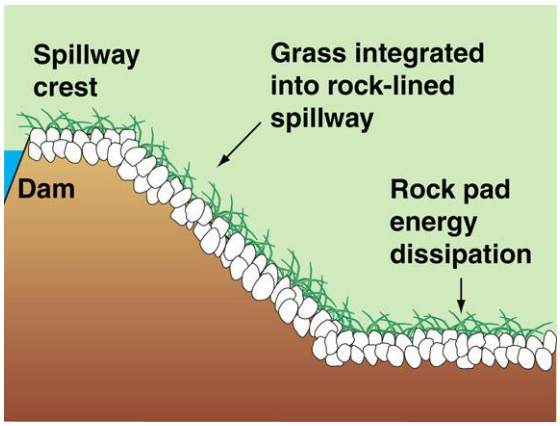


Rock pad outlet structure

Rock pad energy dissipaters

- The most common type of energy dissipation zone is a simple rock pad—the rocks are normally recessed into the ground, and covered with grass (i.e. the voids are filled with soil).
- The critical design parameters are the mean rock size (d_{50}) and length of the rock pad (**L**).
- The width of the rock pad depends on the width of the approaching flow (i.e. the spillway chute) and how much the flow is likely to 'spread' as its velocity slows.

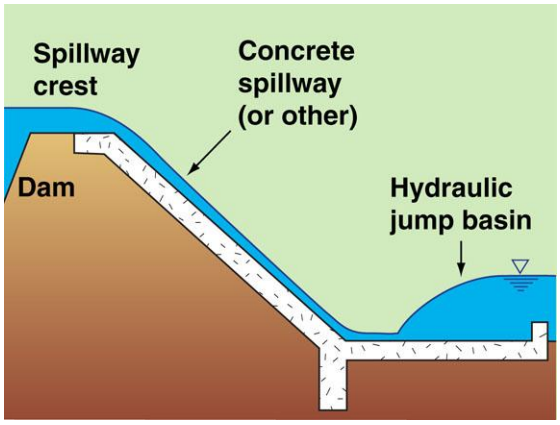
Types of energy dissipaters



Rock pad energy dissipater

Rock pads

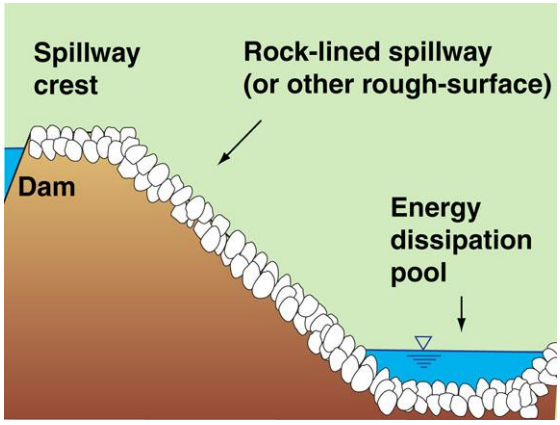
- As just discussed, a rock pad is the most common form of energy dissipation.
- The rocks should **not** simply be placed on the ground, as this will cause:
  - the flow to spill off, or around, the rocks
  - the rocks to be displaced by the flow.
- Ideally the rocks should be recessed into the ground and planted so the area could potentially be mown, or trimmed by livestock.



Hydraulic jump basin

Hydraulic jump basins

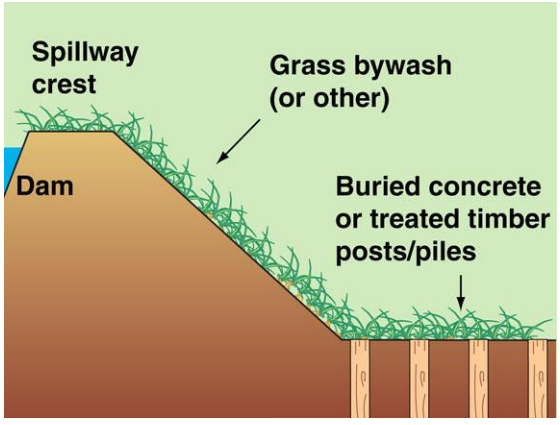
- Some of the larger, concrete spillways may incorporate a concrete stilling basin that provides energy dissipation by inducing flow turbulence in the form of a hydraulic jump.
- A hydraulic jump is a flow condition where supercritical flow is converted to subcritical flow, which means there is a rapid change in velocity and there is usually an increase in the depth of flow (causing a sudden rise in the water level).



Energy dissipation pond

Energy dissipation ponds

- Energy dissipation ponds are the most difficult to design because, if the pond is too small, then it will act like a 'ski jump', and water will stray everywhere.
- However, if a scour hole (erosion hole) has already formed at the base of your spillway due to past storm events, then 'nature' has shown you the size that the pond needs to be—you should now over-excavate this hole, then line the hole with rocks such that the finished pond has the same depth, width and length.



Buried pile field

Pile fields

- Pile fields are not a common solution to energy dissipation.
- The basic idea is that the piles will act like exposed tree roots—as the water begins to scour a hole at the base of the spillway, it will expose parts of the piles (posts), which will induce turbulence and energy dissipation.
- After the storm, the pile field can be re-buried and re-planted (i.e. hidden) until the next major storm event.

Sizing rock for a small dam rock pad energy dissipater

Recommended mean (d_{50}) rock sizes and length (L) of rock protection for small dam spillway energy dissipation are presented in tables 6.12 and 6.13. These rock sizes are based on information presented within ASCE (1992) rounded up to the next 100 mm increment, with a minimum size set as 100 mm.

Table 6.12 – Mean rock size, d_{50} (mm) for batter chute outlet protection [1]

Depth of approach flow (mm) [2]	Flow velocity at base of spillway chute (m/s)						
	2.0	3.0	4.0	5.0	6.0	7.0	8.0
50	100	100	100	200	200	200	300
100	100	100	200	200	300	300	400
200	100	200	300	300	400	[3]	[3]
300	200	200	300	400	[3]	[3]	[3]

[1] For velocities at the base of the chute not exceeding 1.5 m/s, and where growing conditions allow, loose 100 mm rock may be replaced with 75 mm rock stabilised with a good cover of grass.

[2] This is the flow depth at the base of the chute as it approaches the energy dissipater. The flow depth is based on the maximum depth, not the average flow depth.

[3] Consider using 400 mm grouted rock pad, or a rock-filled mattress outlet.

The energy dissipater lengths presented in Table 6.13 will not necessarily fully contain all energy dissipation and flow turbulence; therefore, some degree of scour may still occur downstream of the structure. Extending the length of the rock pad will reduce the risk of this downstream soil erosion.

Table 6.13 – Recommended length, L (m) of rock pad for a small dam energy dissipater

Depth of approach flow (mm)	Flow velocity at base of spillway chute (m/s)						
	2.0	3.0	4.0	5.0	6.0	7.0	8.0
50	1.0	1.5	2.1	2.6	3.1	3.6	4.2
100	1.3	2.0	2.7	3.4	4.1	4.8	5.5
200	2.1	2.7	3.4	4.3	5.2	6.1	7.0
300	2.7	3.6	4.3	4.8	5.8	6.8	7.9

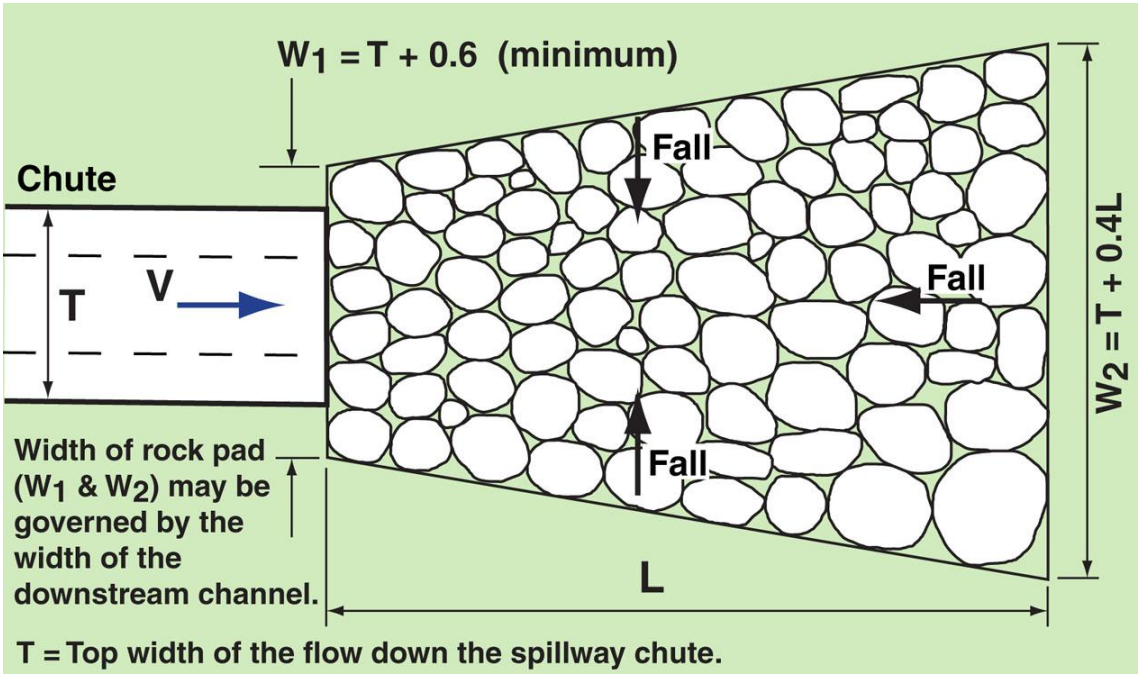


Figure 6.1 – Typical layout of a recessed rock pad energy dissipater (plan view)

As indicated in figures 6.1, 6.2 and 6.3, rock pad energy dissipaters for small dam spillways should ideally be recessed below the surrounding ground level to promote effective energy dissipation. Recessing the rock pad helps to ensure suitable tailwater conditions are achieved. The recommended recess depth (Z) can be determined from Table 6.14.

In circumstances where it is not practical to recess the rock pad (e.g. for safety or mosquito breeding reasons), appropriate steps should be taken to increase the depth of flow (i.e. tailwater conditions) at the base of the spillway chute.

Table 6.14 – Recommended recess depth, Z (m) of a rock pad energy dissipater

Depth of approach flow (mm)	Flow velocity at base of spillway chute (m/s)						
	2.0	3.0	4.0	5.0	6.0	7.0	8.0
50	0.13	0.20	0.28	0.36	0.43	0.50	0.60
100	0.14	0.23	0.32	0.42	0.50	0.60	0.70
200	0.12	0.21	0.31	0.42	0.50	0.60	0.70
300	0.07	0.16	0.25	0.35	0.44	0.55	0.65

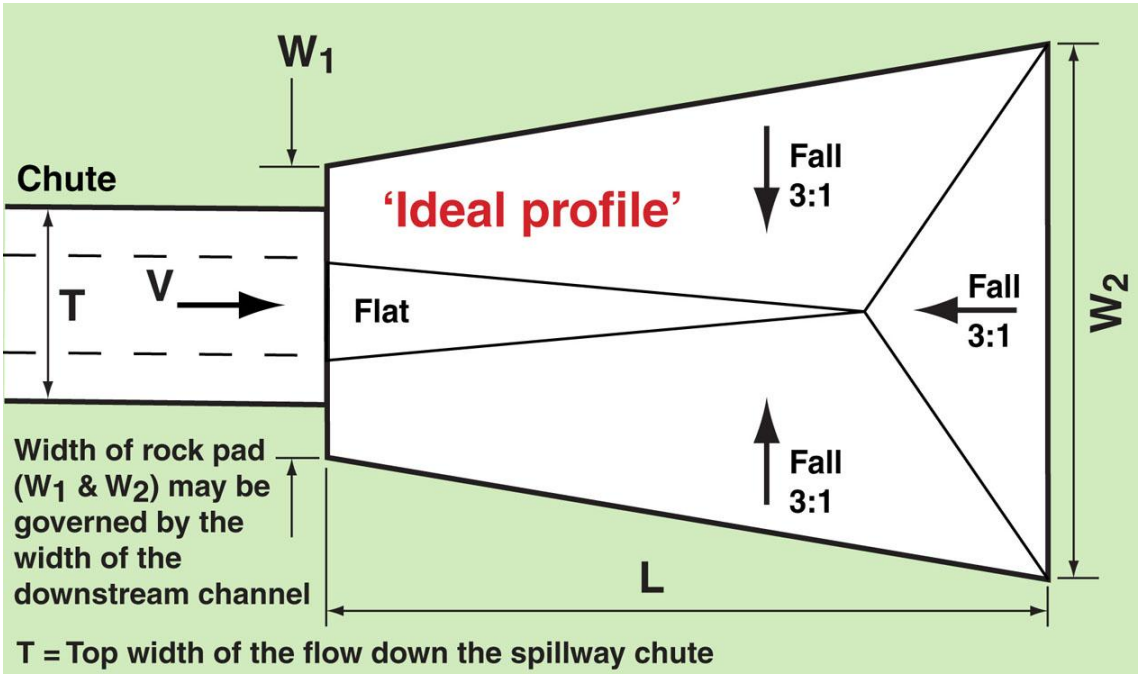


Figure 6.2 – Typical arrangement of a recessed rock pad energy dissipater (plan view)

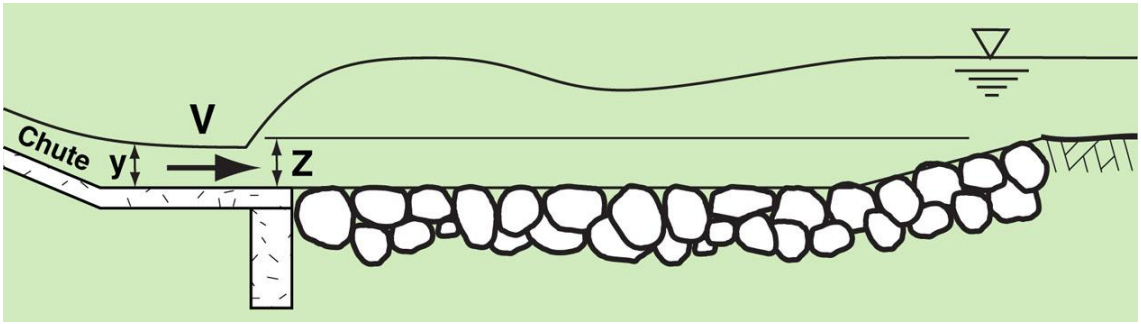
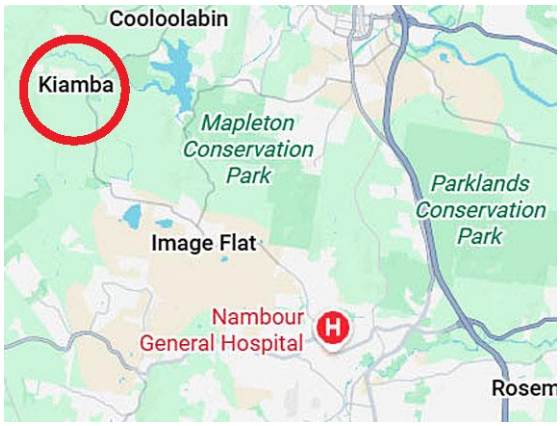


Figure 6.3 – Typical profile of a recessed rock pad energy dissipater (side view)

ASCE 1992, *Design and Construction of Urban Stormwater Management Systems*. ASCE Manuals and Reports of Engineering Practice No. 77, and Water Environment Federation Manual of Practice FD-20, American Society of Civil Engineers, New York.

Example design #3 – Rock pad energy dissipater



Location map

Site conditions

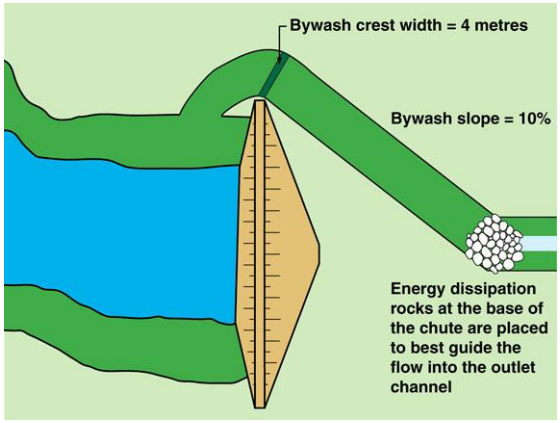
- Adopting the same site conditions as for Example 1.
- Site conditions:
  - located at Kiamba, near Nambour, Qld
  - catchment condition is rural-residential
  - catchment area = 3 hectares
  - up-slope land = 1 in 20 at 300 m length.



Hydrology

Estimation of the design discharge

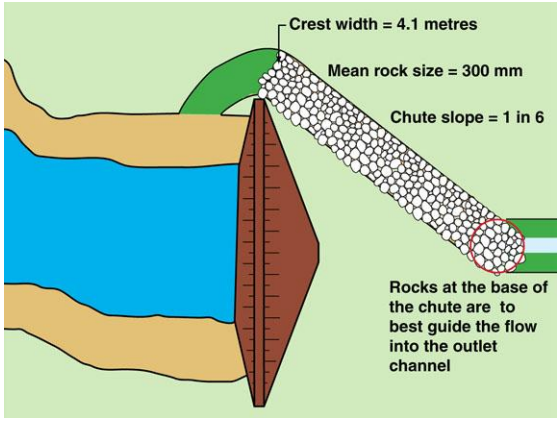
- For Example 1, which has been assessed as a low risk site, the design storm for the bywash could be as low as a 1 in 10 year event according to the recommendations in this field guide; however, the local authority (or State regulator) has specified a 1 in 50 year design storm.
- Therefore: C_{50} = 1.15 x 0.70 = 0.805, I_{50} = 169 mm/hr, and the catchment area is 3 hectares (as in Example 1).
- **Q50 = (0.805 x 168 x 3)/360 = 1.13 m^3/s.**



Possible rock pad design

Energy dissipater for Example 1

- Q = 1.13 m^3/s
- V = 2.1 m/s
- Flow area, A = Q/V = 1.13/2.1 = 0.538 m^2
- Flow depth, y = A/b = 0.538/4 = 0.135 m
- Table 6.12, d_{50} = 100 mm rock
- Table 6.13, L = 1.6 m (interpolation)
- Table 6.14, Z = 0.13 m (ideal)
- Given the relatively small rock size of 100 mm, I would suggest the use of gravel-grass as discussed in Chapter 9.



Flow released down the slope onto grass

Energy dissipater for Example 2

- Q = 1.13 m^3/s
- Table 6.9, flow depth, y = 0.3 m
- Flow area, A = b.y = 4.1x0.3 = 1.23 m^2
- Flow velocity, V = Q/A = 1.13/1.23 = 0.92
- Given an exit velocity of just 0.92 m/s, there does not appear to be any need for energy dissipation; instead, the flow can be released onto a grassed surface.

7. Hillside Dams

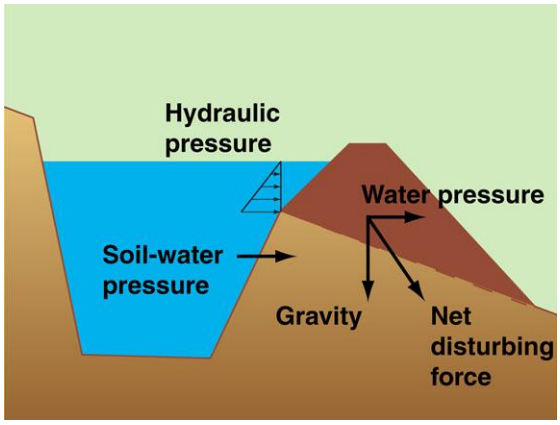
Introduction



Questionable information

Introduction

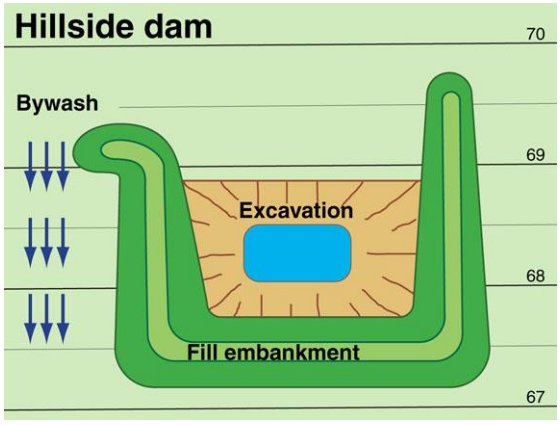
- The author has had very limited experience investigating hillside dams, and as such, the author recommends landowners seek expert advice from other sources, including a geotechnical engineer.
- In the author's opinion, building a hillside dam is not a situation where a person can rely solely on common sense—steep hillsides are places where hydraulic and geotechnical advice is essential.



Net 'disturbing' force on an embankment

Additional stress of earth embankments

- In a traditional earth embankment dam, the stresses on the earth embankment result solely from the hydraulic forces generated by the retained water.
- However, for a hillside dam, there is the additional stress generated by gravity and groundwater uplift.
- Therefore, for the same embankment height, a hillside dam can experience significantly higher stresses than a typical farm dam.



Hillside dam (Qld)

The concentration of flows down a hillside

- Depending on their design, hillside dams have the potential to release concentrated flows down a steep slope.
- Such flow conditions can trigger severe gully erosion and land slides.
- The safety of hillside dams can be greatly improved through the introduction of 'smart' hydraulics.

Note: The diagram (left) assumes that bed rock does not sit just below the surface.



Gully erosion down-slope of a hillside dam

The likely cause of a dam failure

- Hillside dams are at a greater risk of failure because the spillway, and/or bywash channel, are located on a steep slope, which means:
  - flow down the hill slope will be very fast
  - if these flows encounter trees or shrubs, then the turbulence can trigger gully erosion
  - if gully erosion occurs, then its migration up the hillside can be very fast, and it can easily undermine the dam's embankment.

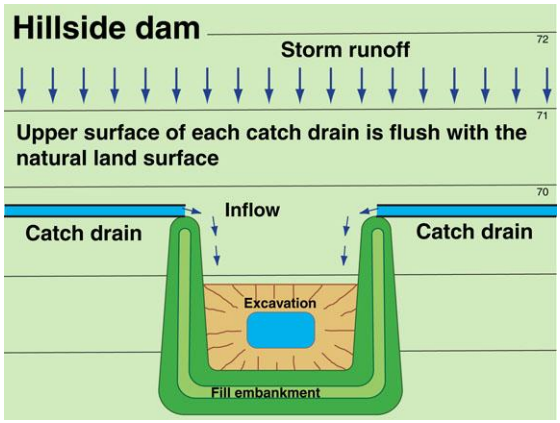
Designing the inflow system for hillside dams



Hillside dam (Qld)

The 'smart' design of water collection channels

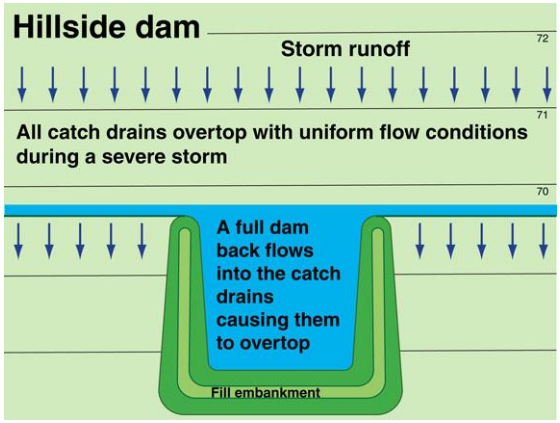
- Hillside dams often use lateral collection channels to direct stormwater runoff into the dam.
- On a poorly-design hillside dam, these collection channels will continue to direct water towards the dam during a severe storm (i.e. a storm > design storm).
- On a smart design, the collection channels are designed to overtop in a manner that releases the excess water as sheet flow.



Operation of catch drains

Use of collection channels (catch drains)

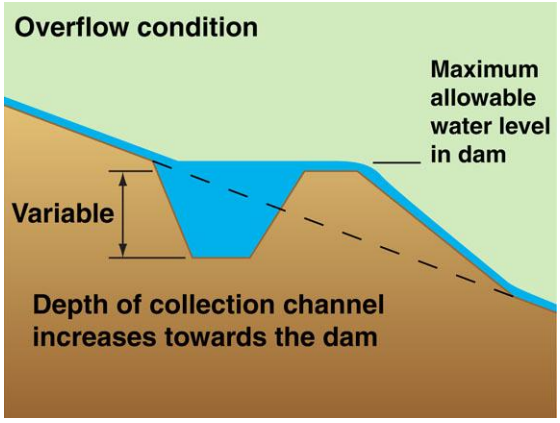
- Farm dams are typically located on an overland flow path, which allows the runoff from a wide catchment to feed into the dam.
- Hillside dam may not have the benefit of an up-slope swale or runoff depression; consequently, collection channels (also known as catch drains, contour drains, or contour banks), can be used to collect and transport stormwater runoff to the dam.



Severe storm flow condition

Hydraulics of a collection channel

- The cross-section profile (i.e. depth and width) and the gradient of these collection channels is CRITICAL for their optimum performance.
- The channels need to be designed such that:
  - when the dam is at its maximum allowable water level, the collection channels are about to overflow
  - flows overtop these channels uniformly along the full length of the channel.

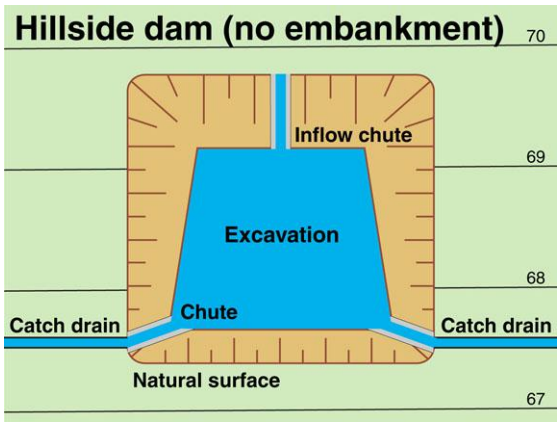


Cross-section of collection channel

Design of a collection channel

- In order to achieve this hydraulic performance, the design of the collection channels requires:
  - a longitudinal bed gradient as flat as possible (say, 1%) but still allows the channel to fully drain when rain has stopped
  - a uniform embankment crest along the length of the channel equal to the maximum allowable water level in the dam.

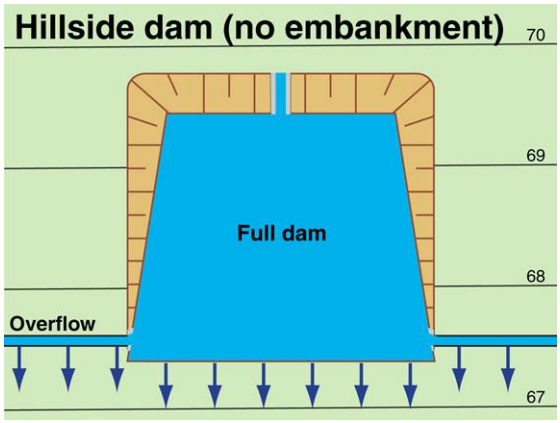
Alternative hillside dam design



Hillside dam without an embankment

Fully recessed hillside dam

- If the hillside dam can be fully recessed (i.e. no fill embankments), then the collection channels (catch drains) need to feed into the down-slope end of the dam.
- This is the 'safest' outcome for a hillside dam (from a hydraulic perspective).
- A geotechnical engineer would need to assess the risk of such a dam causing a major land slip due to the potential saturation of the hillside soil below the dam.



Severe storm flow condition

Sheet flow conditions maintained during surcharge conditions

- This arrangement means that when the dam begins to overtop, it will also cause the collection channels to overtop, which means the collection channels will no longer be feeding water into the dam.



Recently excavated hillside dam (Qld)

Example recessed hillside dam

- This is an example of the hillside dam that has the spillway set at natural land level (i.e. there is no fill embankment).
- During the initial stages of its operation, the spillway was covered with geofabric filter cloth (visible as 'white' material).
- The spillway will eventually be revegetated.



Hillside dam at max water level (Qld)

8. Water Quality Issues

Introduction



Drinking water

Introduction

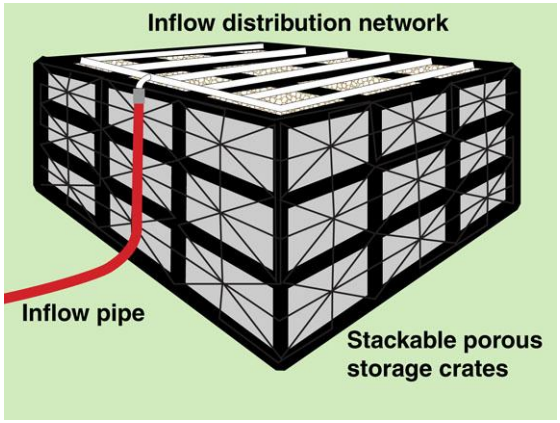
- There are as many different types of water as there are ways of storing the water.
- The two main categories are saltwater and freshwater.
- Freshwater can be further divided into stream flow, spring water, bore water, tank water, potable water and bottled water.
- In nature, farm dams are most closely associated with ponds and lakes, but not swimming pools.



Swimming pool

Farm dams are not swimming pools

- The management of water quality within ponds, lakes and farm dams has little to do with the management of water quality within a domestic swimming pool.
- In general, landowners should not seek advice from a pool supply shop, but rather a rural supply store (of course there are many exceptions).
- Dam water is normally not treated with chlorine, sand filters, or pool cleaners.



Lateral thinking

Alternative treatment options

- Three ‘unproven’ treatment options are presented at the end of this chapter.
- The science behind each of these treatment options is based on ‘proven’ water and wastewater treatment processes that the author is familiar with.
- These treatment options have been presented for the purpose of helping landowners to develop bespoke treatment solutions that satisfy their specific site conditions.



Fish tank

The fish tank analogy

- A discussion about ‘fish tanks’ and ‘concrete’ may not seem relevant to the topic of managing water quality in a farm dam, but I hope that by the end of this chapter you will see the connection.
- In simple terms, if you know how to manage the water quality in a domestic fish tank (aquarium), then you should know how to manage water quality in a farm dam.

The ‘fish tank’ analogy



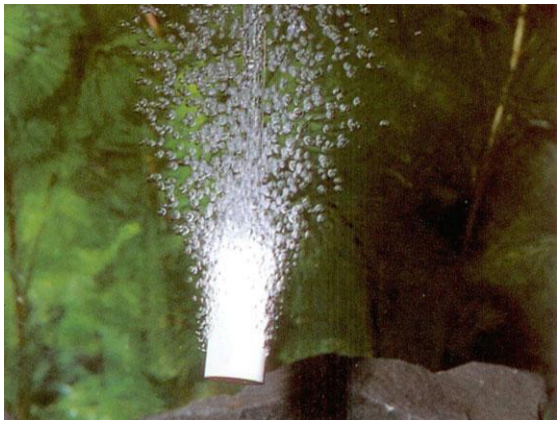
Control the food supply

Introduction

- The tasks for managing a fish tank include:
  - control the food supply
  - aerate the water
  - clean the water
  - clean the tank.

Control the food supply

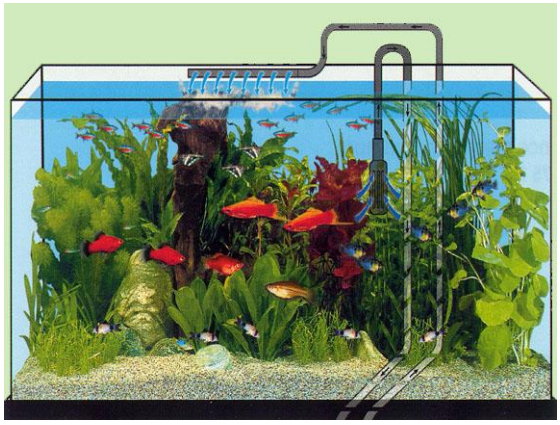
- Good water quality starts with controlling the supply of ‘food’ (nutrients) entering the water body.



Aerate the water

Aerate the water

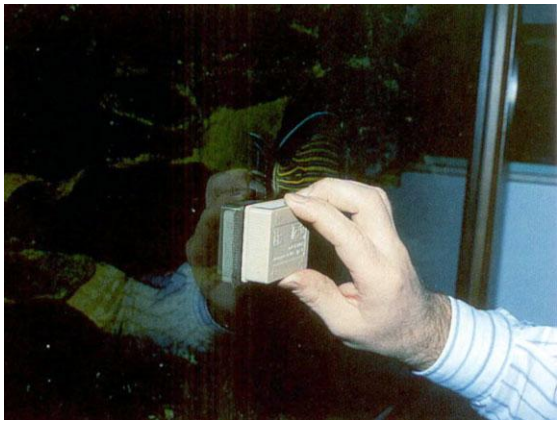
- In a fish tank, aeration adds oxygen to the water for the benefit of the fish, and it may also be used to carry a stream of water to a filter.
- In farm dams, introduced an aeration system can:
  - add oxygen to the water
  - prevent stratification within the dam
  - reduce the risk of odours
  - reduce the risk of blue-green algae.



Clean the water

Clean the water

- Cleaning the fish tank water can improve the tank’s visual appearance, and improve the health of the fish.
- In farm dams, cleaning the water can:
  - improve the dam’s appearance
  - improve the health of the aquatic life
  - reduce the risk of a toxic build-up within the settled sediment
  - reduce the risk of the dam needing to be de-silted.

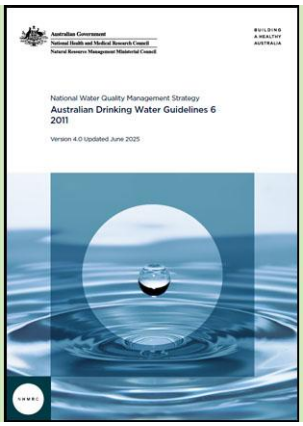


Clean the tank

Clean the tank

- Cleaning the fish tank improves its visual appearance, but can also reduce a potential source of food.
- Cleaning a farm dam can:
  - help to maintain the dam’s storage capacity
  - remove excessive sediment
  - remove a possible build-up of salt from the bottom sediment (rare)
  - remove undesirable plants from the bywash or spillway chute.

Drinking water quality



Australian Drinking Water Guidelines

Introduction

- A detailed discussion on water sampling and water quality standards is presented in:

'National Water Quality Management Strategy, Australian Drinking Water Guidelines 6, 2011' (Updated June 2025)

- Below is a summary of key elements as presented in Barry Lewis (2002).

Table 8.1 – Drinking water standard (sourced from Barry Lewis, 2002)

Common name	Maximum concentration limit (µg/L)
Biological	
Total coliforms	Not detected in two consecutive 100 mL samples.
Faecal coliforms	Not detected in a 100 mL sample.
Algae	Up to 5,000 cells/mL can be tolerated.
Toxic material – inorganic	
Arsenic	50
Barium	1,000
Cadmium	5
Cyanide	100
Nitrate–N	10,000
Nitrite–N	1,000
Selenium	10
Organic	
Benzene	10
Carbon tetrachloride	3
1.1–Dichloroethene	0.3
1.2–Dichloroethene	10
Pesticides	
Polychlorinated biphenyls	0.1
Tetrachloroethene	10
2,4,5–Trichlorophenol	1
Chemicals	
Aluminium	200
Ammonia (as N)	10
Chloride	400,000
Copper	1,000
Hardness (as CaCO3)	500,000
Iron	300
Manganese	100
pH	6.5–8.5
Sodium	300,000
Total dissolved solids	1,000,000

Water quality testing



Algae-rich water



Turbid dam water

Coliform and algae

- **Ask yourself:** What poo are you willing to drink?
  - kangaroos everywhere
  - cattle on pasture
  - ducks on your dam
  - possums on your roof.
- Algae problems are common, particularly during summer months.
- Local advice on water treatment methods can usually be obtained from a local consultant, or pump supplied.

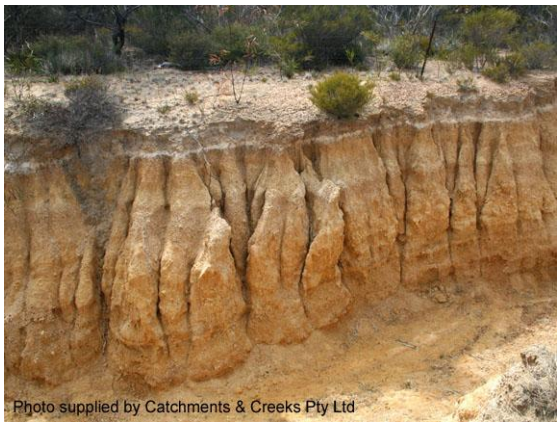
Turbidity (colour) and hardness

- Hardness can be a major issue for bore water, but should not be an issue for storm runoff.
- Turbidity is usually not a major issue for bore water, but it is a common issue for storm runoff in arid and semi-arid landscapes.
- It is clay particles that cause turbidity, which can take weeks, or even months to settle after a storm, or if some of the catchment soil is dispersive, then the turbidity may never settle unless the water is treated (typically with gypsum).

Table 8.2 – Impurities commonly found in dam water

Common name	Chemical name	Effect
Lime	Calcium carbonate	Hardness
Magnesium	Magnesium carbonate	Hardness
Gypsum	Calcium sulphate	Hardness
Epson salts	Magnesium sulphate	Hardness & purgative
Glauber's salt	Sodium sulphate	Taste & purgative
Common salt	Sodium chloride	Taste & purgative
Iron	Ferrous iron / Ferric iron	Rust stains
Manganese	Manganese / Manganese oxide	Black stains
Carbon dioxide	Carbon dioxide	Corrosive gas
Rotten egg gas	Hydrogen sulphide	Corrosive gas & bad odour
Marsh gas	Methane	Inflammable gas
Nitrogen	Nitrogen	Inert gas
Oxygen	Oxygen	Oxidising and corrosive

Typical water treatment requirements



A dispersive soil

Introduction

- Water typically comes in three colours.
- **Clear water**—usually means the catchment soil is non-dispersive.
- **Brown water**—long-term brown water usually means the drainage catchment, or the actual dam, contains dispersive soils.
- **Green water**—usually means algae exists in the water, which means a high nutrient inflow.



Screened intake

Stock water

- **Clear water**: On windy days the water can turn ‘brown’, so extract water from the top of the dam by attaching a float to the intake hose, and enclose the intake in a screen.
- **Brown water:** Extract water from the top of the dam, and as above.
- **Green water**: Make sure you do not have Blue-Green algae, which can be toxic, otherwise extract water from the top of the dam, and as above.



Sand filter

Laundry, toilet flushing and garden watering

- **Clear water**: On windy days the water can turn ‘brown’, so extract water from the top of the dam by attaching a float to the intake hose.
- **Brown water**: Extract water from the top of the dam, then pass the water through a pool-shop sand filter, and backwash the filter once a month.
- **Green water**: Extract water from the top of the dam, then pass the water through a pool-shop sand filter.



Filtration and UV disinfection system

Drinking water

- **Clear water**: On windy days the water can turn ‘brown’, so extract water from the top of the dam, then pass it through a two-stage filter, first a sand filter, then cartridge or diatomaceous earth filter (or similar).
- **Brown water**: Extract water from the top of the dam, then as above.
- **Green water**: Make sure you do not have Blue-Green algae—if so, then seek expert advice, and place an aerator in the deepest part of the dam.

Managing farm dam algae problems



Science

Introduction

- Algae problems include:
  - taste and odour issues
  - blockage of filters
  - corrosion of metal tanks
  - de-oxygenation of water
  - loss of aquatic livestock.
- The management of algae centres around the management of nutrients (food).
- Just like over-feeding your dog, the runoff from your land can over-feed your dam.



Cattle (Qld)

Control the food supply

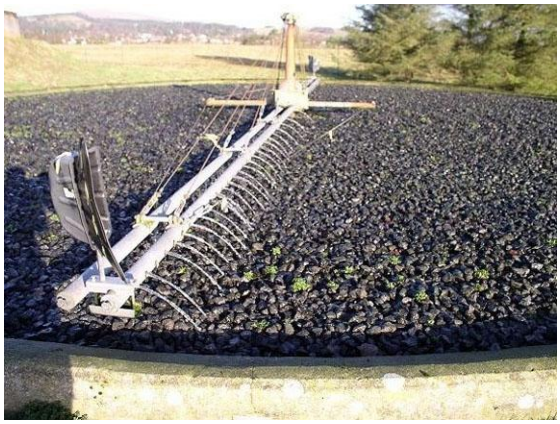
- Reducing the quantity of nutrients flowing into your dam will require you to consider what livestock and wildlife are able to access the dam's drainage catchment.
- However, controlling the food supply is not just about controlling the inflow of all 'nutrients', but more importantly it is about controlling one particular nutrient, that being 'phosphorus'.
- Phosphorus removal is usually the key to controlling algae growth.



Aeration system (NSW)

Aerate the water

- Aerating the water does not reduce the quantity of algae produced, but it can help prevent the growth of blue-green algae.
- The aim of the aeration cycle is to prevent temperature stratification within the dam (a situation where the water column settles in layers that have a different temperature, and water density).
- Preventing stratification helps to prevent anaerobic conditions forming at the base of the dam, which helps to prevent blue-green algae.



Trickling filter wastewater treatment

Clean the water

- The process of filtering the water helps to remove algae, and if correctly designed, helps to remove phosphorus from the water, which reduces the potential production of algae.

Nutrient management



Retired engineer

Introduction

- If you are not already aware, the author of this field guide is a retired civil engineer who specialised in water engineering.
- YOU, as an experienced farmer, may have no interest in reading what a retired civil engineer has to say about the feeding of plants; and if that were true, then maybe you should skip this page.
- I am sure that most readers will know more about this subject than me, but allow me to summarise what I have learnt.

Lesson 1

Lesson 1

Sometimes you need to feed the soil in order to feed the plant

- I once had a ‘sick’ hoop pine, so I poured a mixture of molasses and vegemite around the base of the tree, and it came to life—the tree didn’t need the molasses or the vitamin B, but this mixture got the soil bugs active, which as a consequence, made essential nutrients in the soil available to the tree.
- I fed the soil in order to feed the plant!

Lesson 2

Lesson 2

Sometimes it is not about the chemical composition of the fertiliser, but the structural make-up of that composition

- If a brickie asked you for sand, and you gave the brickie a block of sandstone, then you would have delivered ‘sand’, but not in a manner the brickie could use.
- If your soil test confirms that the soil has all the trace elements, but your plant is sick, then maybe those elements are locked away in compounds that your plant cannot use/access.

Lesson 3

Lesson 3 – Algae is just another plant

- If the water entering your dam has a high nutrient concentration, then the water will want to help grow a plant.
- The amount of plant matter (algae) that can be grown will be controlled by the ‘limiting nutrient’.
- The limiting nutrient is the first nutrient that will be depleted from the dam’s water while the water is growing algae, which could be either nitrogen or phosphorus.
- For more discussion, see over page.

Understanding the importance of the 'limiting nutrient'



Concrete mixing plant (NT)

The 'concrete-mix' analogy

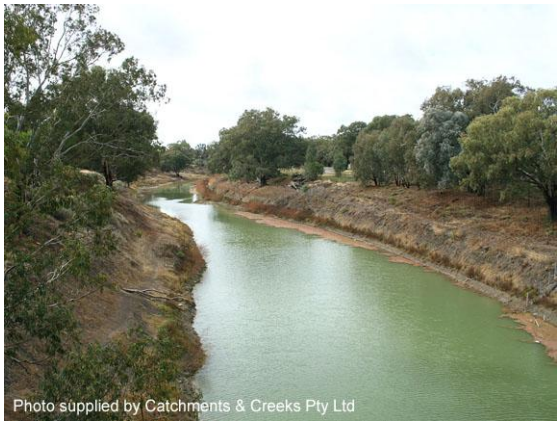
- When making concrete, the formula is basically:
  - 1 part cement
  - 2 parts sand
  - 4 parts aggregate.
- Now, if you had in your stores: 4 tons of cement, 4 tons of sand, and 4 tons of aggregate, then your mixing of concrete will be limited by your current supply of aggregate.
- In this case, 'aggregate' will be the limiting component (i.e. the limiting nutrient).



Townsville (Qld)

Coastal water

- In coastal waters, the limiting nutrient is usually nitrogen.
- The removal of nitrogen from water normally involves a cycle between aerobic and anaerobic conditions, which can be generated by the wetting and drying of a plant surface, such as generated in a wetland, especially if the water surface regularly rises and falls.
- Consequently, many stormwater treatment systems near the coast will use wetland processes.



Darling River (NSW)

Inland waterways

- For inland waterways, the limiting nutrient is usually phosphorus.
- The removal of phosphorus from water is best achieved by filtering the water through soil (earth).
- Consequently, stormwater treatment systems that release water to inland waterways will focus on stormwater filtration and infiltration processes.
- Also note, in rural areas, there is a focus on the use of low phosphorus detergents.



Farm dam (Qld)

Farm dams

- In a typical farm dam, it is the author's opinion that the focus should be on phosphorus removal in order to minimise the production of algae.
- This means the focus should be on filtration processes, not wetlands (just a personal opinion).
- However, wetland systems are 'easy' to set-up on a rural property, while filtration systems can be a lot harder.

Use of wetlands



Gully dam (Qld)

Introduction

- The first thing you should note is that a wetland is NOT a magical answer to your algae problems.
- Landowners should not expect to solve their water quality problems simply by converting part of their dam into a wetland.
- A wetland is good for the wildlife, and for improving the quality of water that leaves your property, especially in coastal regions.



Wetland plants (Qld)

Installing wetland plants in your dam

- Some technical guidelines recommend establishing wetland plants over a third of the water surface.
- Some technical guidelines recommend establishing wetland plants around the circumference of a dam.
- The author recommends you place wetland plants where you want them, and planting none in your dam if that is what you want!



Algae growth (SA)

Some wetland problems

- **Caution:** wetland plants can lessen the disturbance of the water surface by the wind, which can make the water surface more inviting for mosquito breading.
- Also, if you only place wetland plants around the circumference of the dam, then you may lose all of those plants when the water level fall below these plants.



Algae and slim growth (SA)

Maintenance of treatment wetlands

- Some guidelines have suggested that it is important to harvest the wetland plants on a regular basis in order to remove that plant matter from the dam.
- These days, that advice is not considered appropriate because the actual plant does not up-take much of the nutrients, rather the algae and slim growth on the outer surface of the plant does most of the nutrient up-take.

The ‘rapid’ settling of suspended sediments



Highly turbid dam water (Qld)

Introduction

- The water entering a farm dam can contain high concentrations of suspended solids, often making the water ‘brown’ in colour.
- If the suspended particles are not dispersive, then they will settle naturally, unless the water is being regularly circulated by strong winds.
- Otherwise, chemicals may need to be added to the water to assist the settlement process.



Polyelectrolyte

Coagulants

- Coagulants are used to neutralise or destabilise the charge on clay or colloidal particles.
- There is always the possibility of overdosing with coagulants.
- The dosage range of a coagulant will vary depending on water chemistry.
- Different coagulants have an optimum pH range over which they are effective, and pH buffering may be required depending on the coagulant and water chemistry.



Polyacrylamide

Flocculants

- Flocculation is a process of contact and adhesion whereby the particles of a dispersion form larger-size clusters.
- Putting things simply, flocculants cause the formation of ‘flocs’ in the water column, which are now big enough to be seen, and big enough to be ‘filtered’ from the water.
- Flocculation can occur through the use of a coagulant, flocculant, or both.



Aluminium sulfate

Ask your rural supplier about the use of these:

- Gypsum, calcium sulphate, at approximately 32 kg per 100m^3
- Polyelectrolytes, long chain natural and synthetic organic polymers, at 0.05 to 0.2 kg per 100 m^3
- Polyacrylamides (PAMS): seek advice.
- Alum, aluminium sulfate, 1.5 to 8 kg per 100 m^3 - likely toxic impacts.
- Ferric chloride, 1 to 3 kg per 100 m3, - is very corrosive, needs rubber or glass containment.

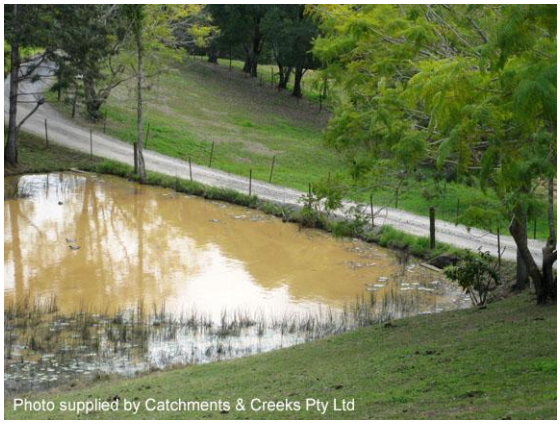
Is ‘brown’ water better than ‘clear’ water?



Algae (Qld)

Introduction

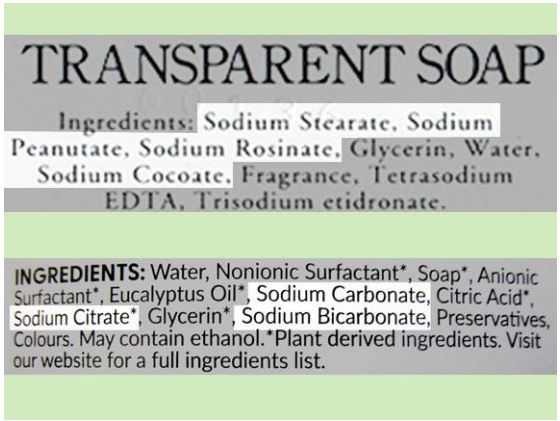
- As previously stated, algae is a plant.
- As a plant, algae need oxygen, water, nutrients, and sunlight.
- If one of these elements is removed, then algae will either die, or not grow in the first place.
- If the water is turbid, then light is prevented from entering the water, and thus algae grow is restricted to the surface water.



Brown water (Qld)

Turning clear water dam into brown water

- If you turn a clear water dam into a dirty water dam, then you will need to deal with the turbidity issues when you use the water.
- The methods for turning clear water into brown water include:
  - mixing a dispersive clay/soil into the water
  - removing windbreaks to encourage natural water circulation
  - add soap (don’t do this!).



Typical ingredients of soap

Why soap make water brown

- If you read the ingredients of soap, you will find that much of what is in soap, is a sodium-based compound, and sodium is a major cause of soil dispersion.
- When you apply soap to your hands, what you are effectively doing is turning the dirt on your hands to a dispersive (sodic) soil that wants to disperse and wash off your hands the moment you rinse them in water.
- Soap works by turning ‘good’ soil into a dispersive soil.



Black water (Qld)

What can happen if you use chemicals to turn a brown dam into a clear water dam

- If you use a flocculant or coagulant to settle the suspended sediment in your dam, then a possible outcome is:
  - the water settles clear for a week
  - the water then turns green as algae begins to grow in the water
  - the algae growth will consume all the oxygen from the water
  - if there is no wind, the algae will die and the water will eventually turn ‘black’.

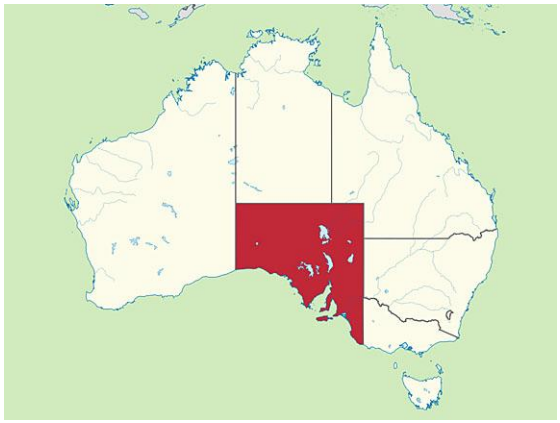
Managing water salinity



Accumulation of salt (NSW)

Introduction

- In South Australia, and much of southern Australia, there are well-known things that you should **not** do on a rural property because of the salinity risk.
- However, property owners in northern Australia constantly break all of those rules without causing a salinity problem.
- The reason why—it is because in the north, the high rainfall washes all the surface salinity away from the property.



South Australia

South Australia

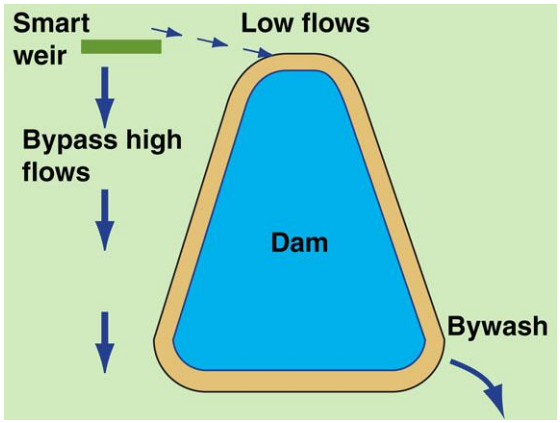
- I love South Australia.
- I love visiting and driving through South Australia.
- My favourite city in Australia is Adelaide.
- That said, I am no being mean when I say that building a ‘wetland’ in many parts of South Australia is equivalent to building a future ‘saltpan’.
- The evaporation rate is so high relative to the rainfall, that salinity levels in a wetland just keep rising.



Silt on a dry bed (SA)

Scrapping the floor when the dam is dry

- If your farm dam exists in a low rainfall and high evaporation region of Australia, then it can be a good idea to remove the top layer of silt from your dam each time the dam goes dry.
- The aim here is to remove salt from the dam.
- But don’t take all of the silt, otherwise you may restart your dam’s early-stage leakage problems.



Bypassing flows from major storms

Send all flows through the dam

- In northern Australia, it is a good idea to design your dam so that the runoff from major storms bypasses the dam and its spillway, thus reducing the risk of a spillway failure.
- In southern Australia, it may be beneficial to allow major storms to pass through, and flush-out your dam, but you need to design your embankment and spillway to a much higher standard to avoid a structural failure.
- Local advice is always valuable.

Water treatment options



Discussion

Introduction

- Problem solving techniques generally centre around the following outcomes:
  - remove yourself from the problem
  - remove the problem from yourself
  - change the outcome of the problem
  - change your response to the outcome.
- The following is just the author's suggested outcomes to an algae problem.
- Readers are, of course, free to choose their own solutions.



For Sale!

Author's suggestions

- Remove yourself from the problem.
  - Sell the farm!
- Remove the problem from yourself.
  - Decommission the dam.
  - Modify the drainage catchment to reduce the flow of nutrients into the dam.
- Change the outcome of the problem.
  - Allow the nutrients to grow plants other than algae.
  - Allow the algae to grow, but have the algae grow in another location.
  - Use an aeration system to modify the conditions within the dam such that only non-toxic algae will grow.
- Change your response to the outcome.
  - Allow the algae to grow, then filter-out the algae before you use the water.



Water treatment

- The remainder of this chapter will present two possible water treatment options which align with the outcome of allowing the algae to grow, but to have the algae grow in another location.



Wastewater trickling filter plant

Introducing the concept of an artificial wetland

- In many regional areas, wastewater is treated, in-part, by passing the water through a trickling filter tank.
- A trickling filter tank is effectively an artificial wetland that uses rocks as a media on-which algae grow, instead of wetland plants.
- The nutrient-rich water trickles past these rocks, and the attached moss and algae extracts nutrients from the water.

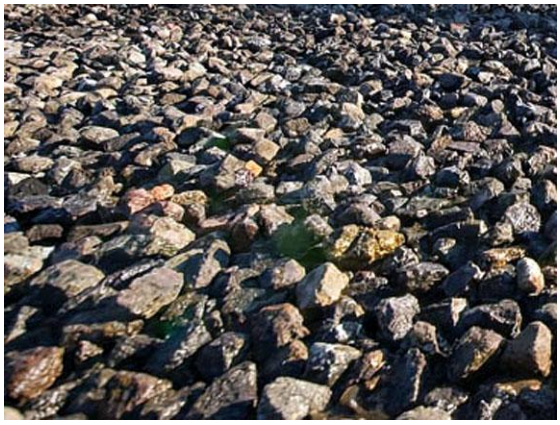
Artificial wetlands



Farm dam with wetland plants (Qld)

Introduction

- In the previous discussion about 'wetlands', it was mentioned that the wetland plants do not up-take much of the nutrients, rather the algae and slim that grows on the outer surface of the plants does most of the nutrient up-take.
- The reality is, you could fill part of your dam with 'plastic' plants, and it would still function as a wetland as far as its water quality benefits—of course, not its wildlife benefits.



Growth media

Artificial wetlands

- Artificial wetlands are used in many industrial water treatment processes.
- These wetland systems can be made from a wide variety of growth media, including:
  - rocks
  - ceramics
  - plastic grids.
- The main function is for the media to provide a surface on which algae can grow, but which can be backwashed in order to remove excess algae growth.



Backwashing

The benefits of artificial wetlands

- The maintenance problem facing natural wetlands is how to remove the attached slim from the plants, and the dam.
- The benefit of most commercial water treatment packages is the ability of these systems to be backwashed.
- Backwashing allows the system be flushed of any excess algae growth, thus helping to maintain the treatment system at its optimum performance.

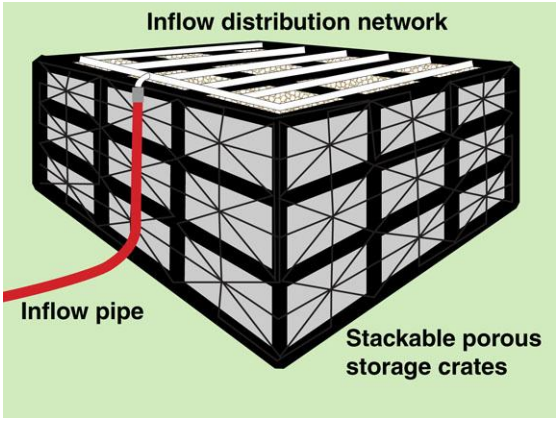


Just a thought

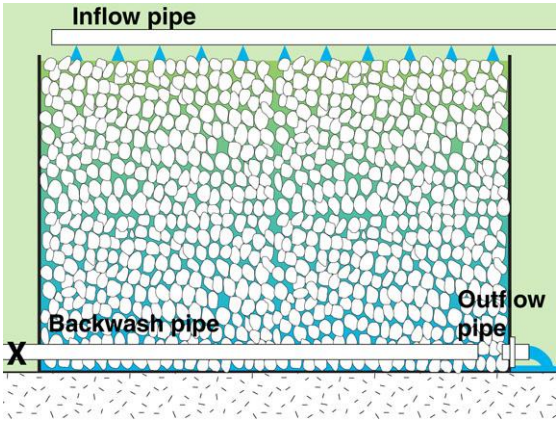
Lateral thinking

- As an engineer, most of my visits to rural properties involved the investigation into failed dam spillways.
- I have had some discussions about water quality issues and the algae problem, but I am unaware of any cases where the landowner has actually taken steps to implement some of my suggestions.
- So, the following ideas remain untested (to my knowledge), even though the ideas are based on the established technology of wastewater treatment systems.

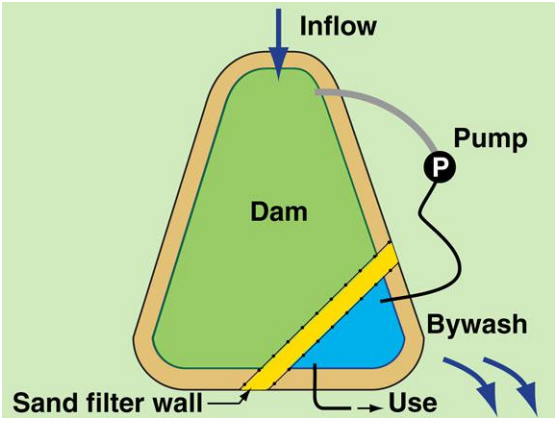
Alternative Treatment Options



Option 1



Option 2



Option 3

Introduction

- The following text describes three alternative treatment options that could potentially be formed on a typical rural property.
- Each of these treatment systems are based on current water and wastewater treatment processes.
- Hopefully someone will perfect each of these treatment options and then release detailed engineering plans of their final design.

Options 1 & 2 – Trickling filter tanks

- **Option 1** is a free-standing trickling filter system that is based on plastic storage crates filled with rocks.
- **Option 2** is the same concept as Option 1, but the growth media is installed in a free-standing tank, such as a commercial rainwater tank.
- These treatment options are based on the trickling filter plants commonly found in rural wastewater treatment plants.

Option 3 – Sand filter

- **Option 3** utilises sand filtration, which is a process commonly found at swimming pools and water treatment plants.
- In this option, the sand filter is formed from the same modular storage crates utilised in Option 1, except the crates are filled with sand instead of rocks.
- The sand filter is built as a free-standing wall, which divides part of the farm dam.
- Water is recirculated through the sand filter in order to remove algae.

Trickling filter system – Design option 1



Uniform rocks, say 50, 75 or 100 mm

Introduction

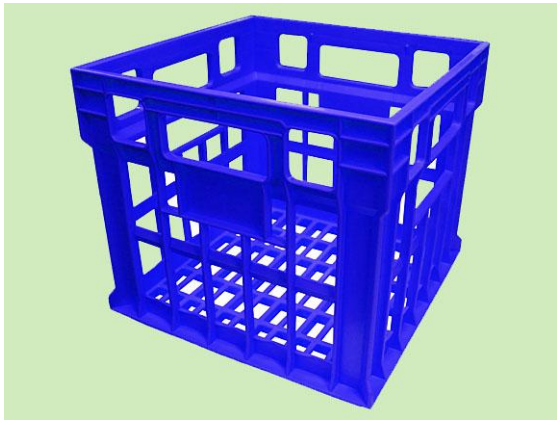
- At this point I am going to assume that many (most) landowners would prefer to trial a low cost version of a trickling filter system before moving onto Option 2.
- So, this first design is about as basic as I can make it, and it should be simple enough for anyone to assemble using nothing but regular farm tools.
- All of these trickling filter systems require some type of growth media—examples of growth media are shown in these images.



Synthetic rocks



Plastic growth media



Porous stackable storage crate

Temporary trickling filter tower

- Option 1 can vary in its length and width, but I suggest a maximum height of around 2 metres.
- Purchase a collection of ‘strong’, but porous stackable storage crates (I suggest a minimum number of 26).
- If you want increased filtration, then line the crate with filter cloth.
- Then fill the crate with as many rocks as you can lift comfortably—best results are achieved if the rocks are uniform in size.

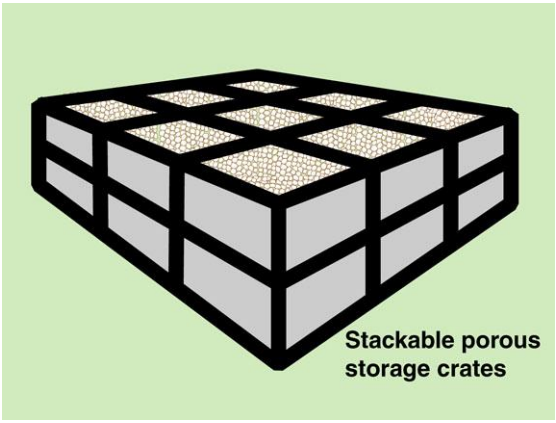


Filter cloth (say bidim A24 to A64)



Crates filled with rocks

Trickling filter system – Design option 1

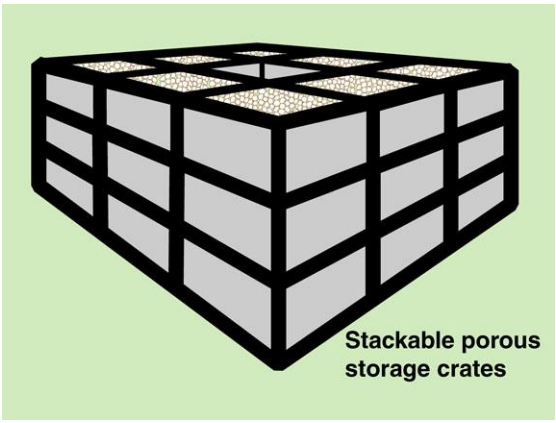


First two rows

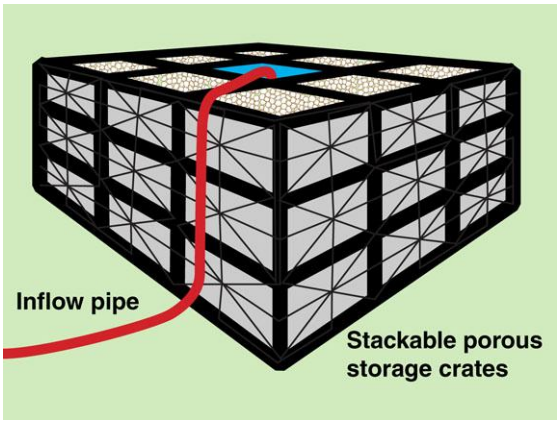
Build the filter tower

- Find a location where runoff from the trickling filter will drain back into the dam.
- If necessary (or desirable), pour a concrete base slab on which to assemble the tower.
- First and second rows (or more) consist of nine (9) crates in a square.
- The top row has just eight (8) crates, with the centre crate missing.

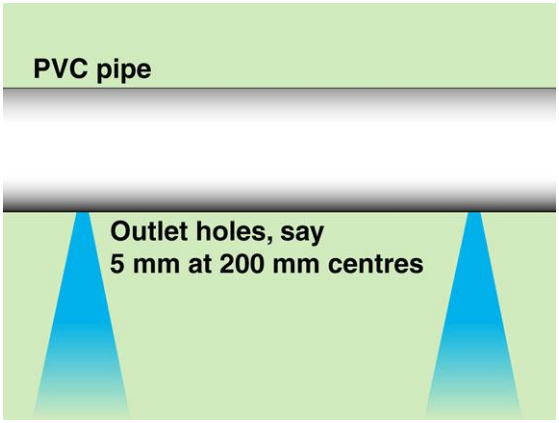
Note: The suggested height of these towers is around 2 m (the higher the better), so more than three rows may be required.



Top row with missing centre crate



Inflow via a single pipe

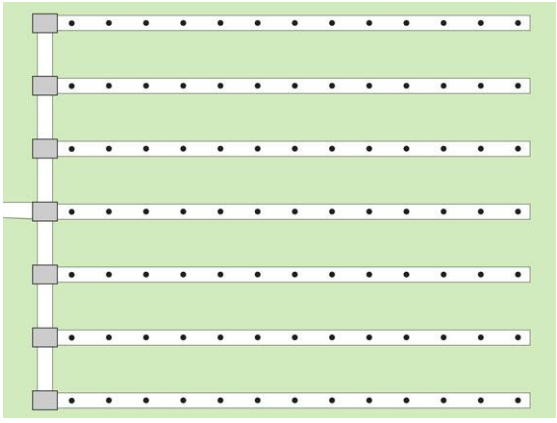


Inflow distribution pipe

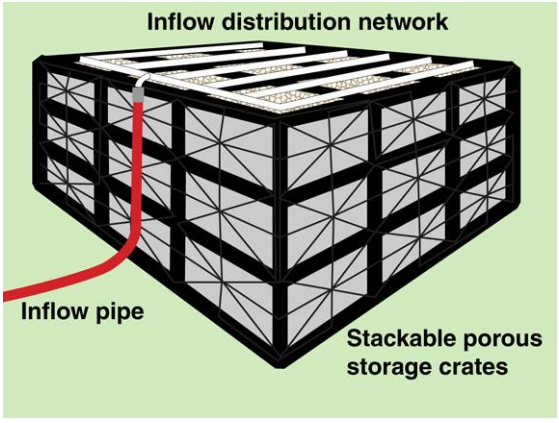
Water circulating system

- Using a relatively low volume pump, say one litre per second (1 L/s), possibly a solar-powered pump, direct dam water into the top of the trickling filter tower.
- Attach the pipe outlet to the centre of the tower, or make a distribution grid.
- An out-flow velocity of around 0.5 m/s would seem reasonable, so the total 'area' of the outlet holes can be determined from the flow rate of the pump.

Area = $Q_{Pump}/0.5$ (caution the equation's units)

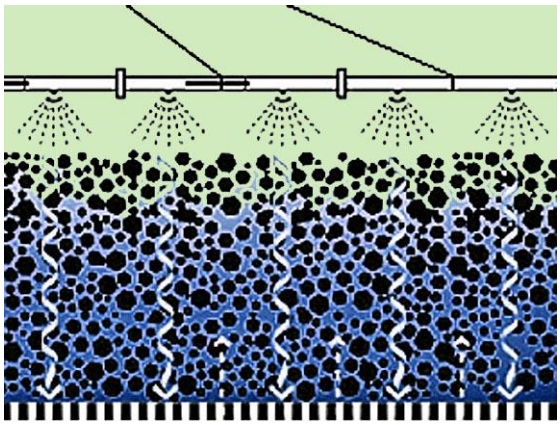


Inflow distribution pipe network



Inflow via distribution pipe

Trickling filter system – Design option 1



Cut-away view of trickling filter

Operation of a trickling filter system

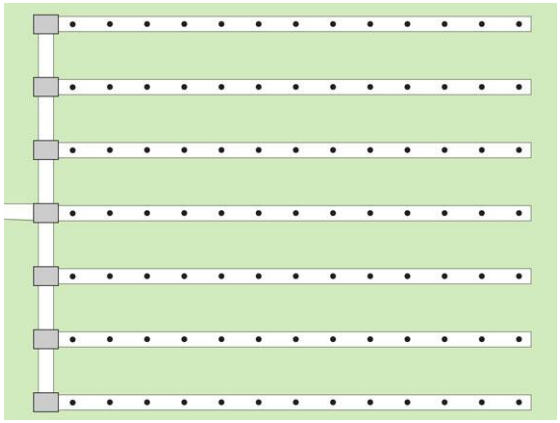
- A trickling filter system works by mimicking the chemical and biological processes of a natural wetland.
- The rocks, or other synthetic growth media, provide a surface on which algae and bacteria can grow.
- This growth media is then fed a stream (trickle) of aerated water, sunlight, and oxygen (air), which assists in the growth of algae, and a gradual reduction in the nutrient levels within the water.



Wastewater trickling filter tank

Commercial trickling filter plants

- Sunlight is important, at least for the upper layer of rocks.
- Therefore, if a mini trickling filter plant is to be formed from a commercial rainwater tank (Option 2), then the top of the tank must be removed and replaced by lateral bracing.
- For Option 1, sunlight should be able to reach most of the treatment cells.



Distribution pipe inflow system

Enhanced inflow system

- In order to achieve a uniform flow through the filter, the inflow system should consist of a grid of pipes, possibly electrical conduit.
- Drainage holes need to be evenly distributed, and large enough not to be blocked by clumps of algae.
- The author suggests as a first trial, 5 mm diameter holes at 200 mm centres.



Flushing system

Backwash options

- Because Option 1 is a free-standing system, it cannot be backwashed in the same way as a commercial pool filter.
- The author suggests that excess algae could be removed by jet washing the trickling filter tower.
- Alternatively, the tower could be disassembled, cleaned and rebuilt; or, replaced with Option 2.

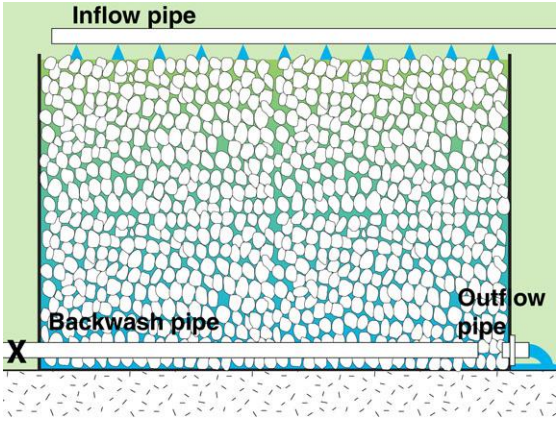
Trickling filter system – Design option 2



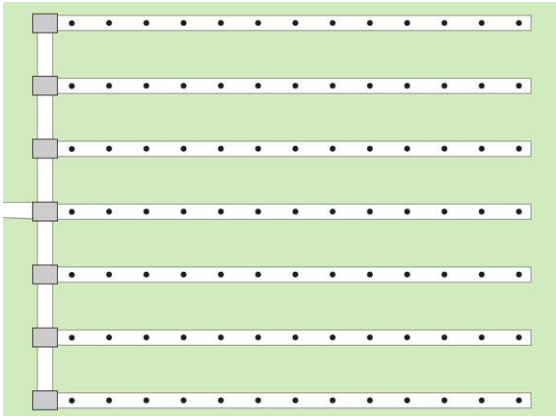
Tank

Introduction

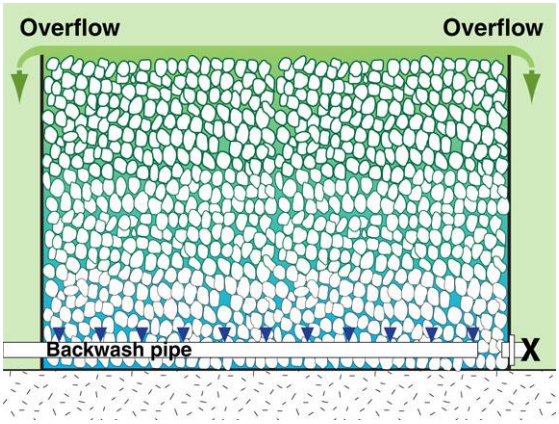
- If you are now convinced that such a treatment system could benefit your property, then you should consider a more permanent solution.
- **Option 2** allows the trickling filter to be backwashed in order to remove excess algae growth.
- Such a tank could be formed from a modified rainwater tank, or a built-for-purpose tank design.



Normal operation mode



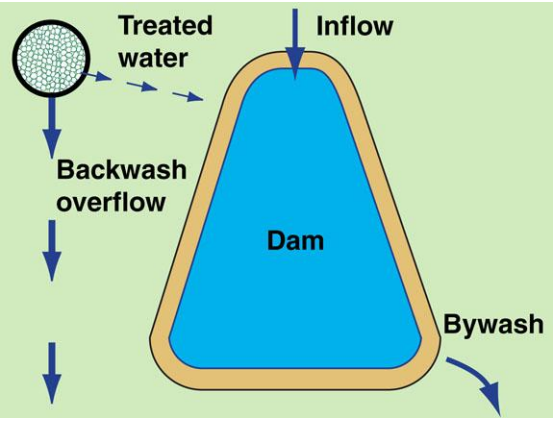
Inflow piping



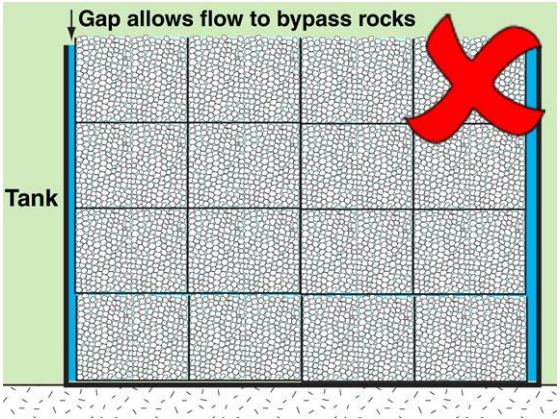
Backwash process

Required design features

- The essential design features include:
  - maximise sunlight entry into the tank (i.e. replace roof with a bracing system)
  - uniform inflow distribution pipe work
  - backwash pipe work installed on the base
  - a system for directing the backwash **away** from the dam.
- It is important to prevent water bypassing around the growth media (i.e. possible not having the rocks in stackable crates).



Diverting backwash from the dam



Flow bypassing is a solvable problem

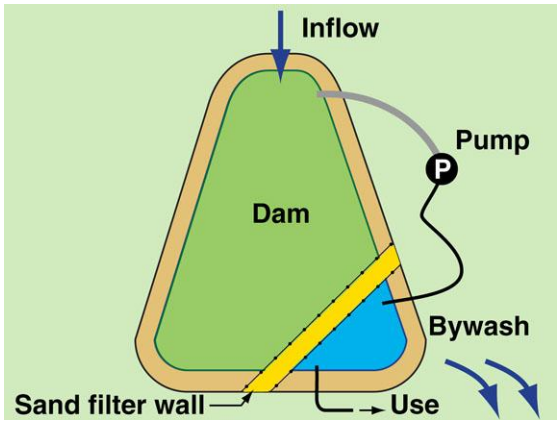
Sand filter – Design option 3



Sand filter (swimming pool filter)

Commercial sand filters (pool filters)

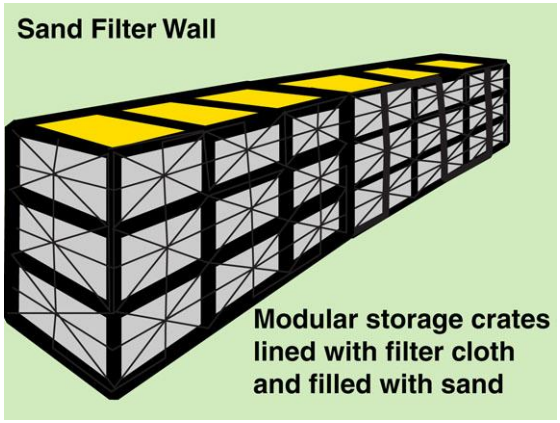
- Sand filters are regularly used as domestic swimming pool filters.
- Similar to cartridge filters, several small sand filters could be set up in parallel and/or series on a portable trailer as a mobile water polishing system.
- Large (in-situ) sand filters are regularly used in stormwater treatment (e.g. filtration, bio-filtration and bio-retention treatment systems).



Dam with sand filter wall

Option 3 – In-dam sand filter

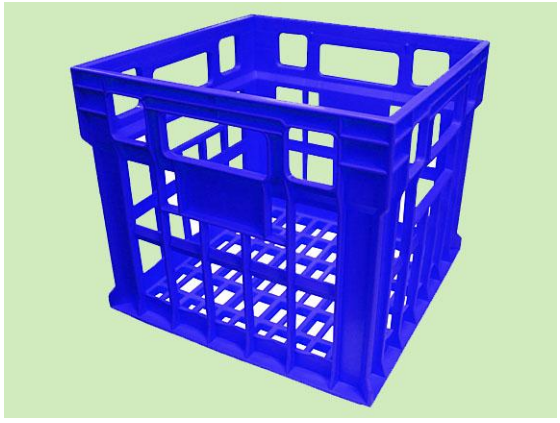
- Sand filters can work well so long as:
  - the back-flush system continues to work, and
  - back-washing and sand replacement are not required more then weekly.
- The 'potential' benefit of sand filtration over a tricking filter concept is its increased potential for phosphorus removal.
- The negative side of sand filtration is the high maintenance.



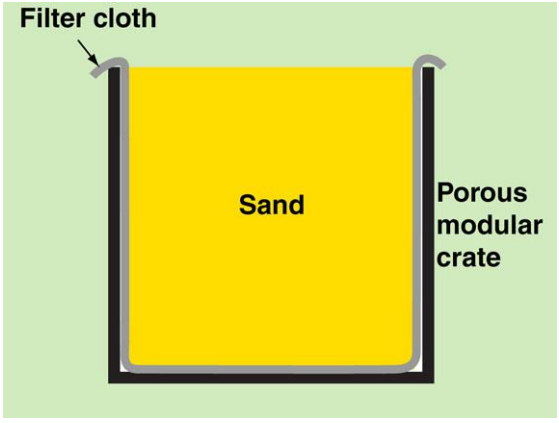
Sand filter wall

Sand filter wall

- A sand filter wall can be assembled from modular units similar to Option 1—except, the plastic storage crates are filled with sand instead of rocks.
- The stackable storage crates must be porous (i.e. not solid plastic).
- The crates must first be lined with filter cloth, possible 'bidim' A24 to A64 thickness (the higher the number, the better).
- The author suggests filling the crates with coarse sand, if available.

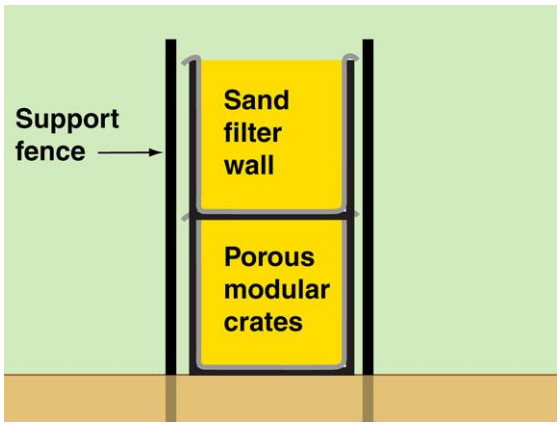


Modular storage crate



Bypassing flows from major storms

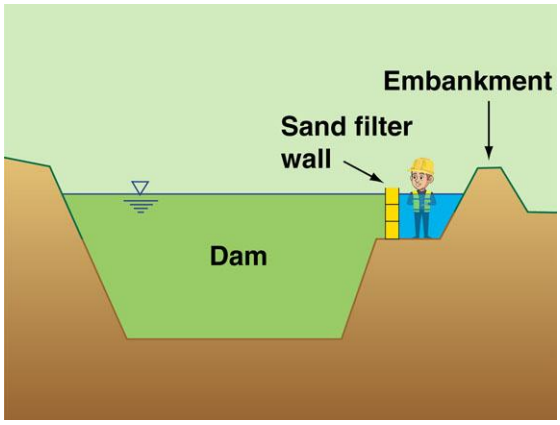
Sand filter – Design option 3



Cross-section of sand filter wall

Additional support of the filter wall

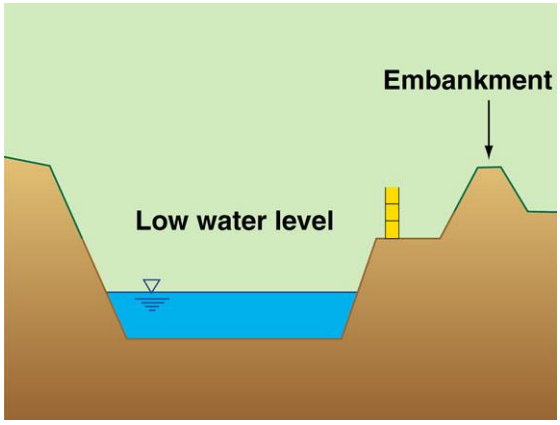
- It is important that the filter wall in recessed into the bed and banks of the dam in order to prevent water bypassing the filter wall.
- In most cases, the filter wall should be stable; however, site conditions in a dam can result in poor 'foundations', which can cause the wall to tilt and collapse.
- The author recommends installing the filter wall inside two strong wire mesh fences, or at least supported by fence posts.



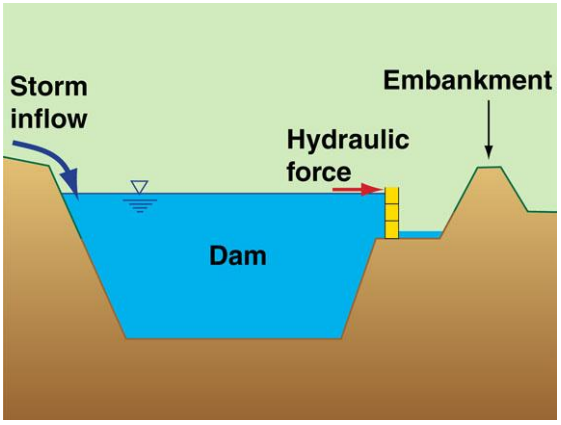
Dam in full condition

Potential adverse hydraulic conditions acting on the filter wall

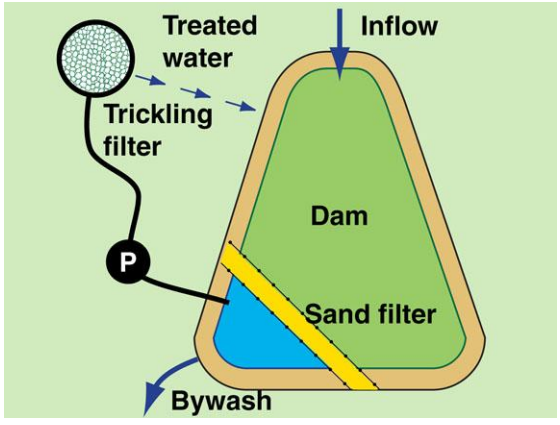
- A section of the dam, or expansion of the dam, can be formed at a suitable depth that would allow a person to install and remove (for cleaning) the filter wall.
- Because the dam could at times drain to a low water level, and then from time-to-time be promptly filled by a severe storm, there could be occasions where the wall is subjected to hydraulic forces, which again supports the use of support posts/fencing.



Low water level condition



Sudden inflow condition

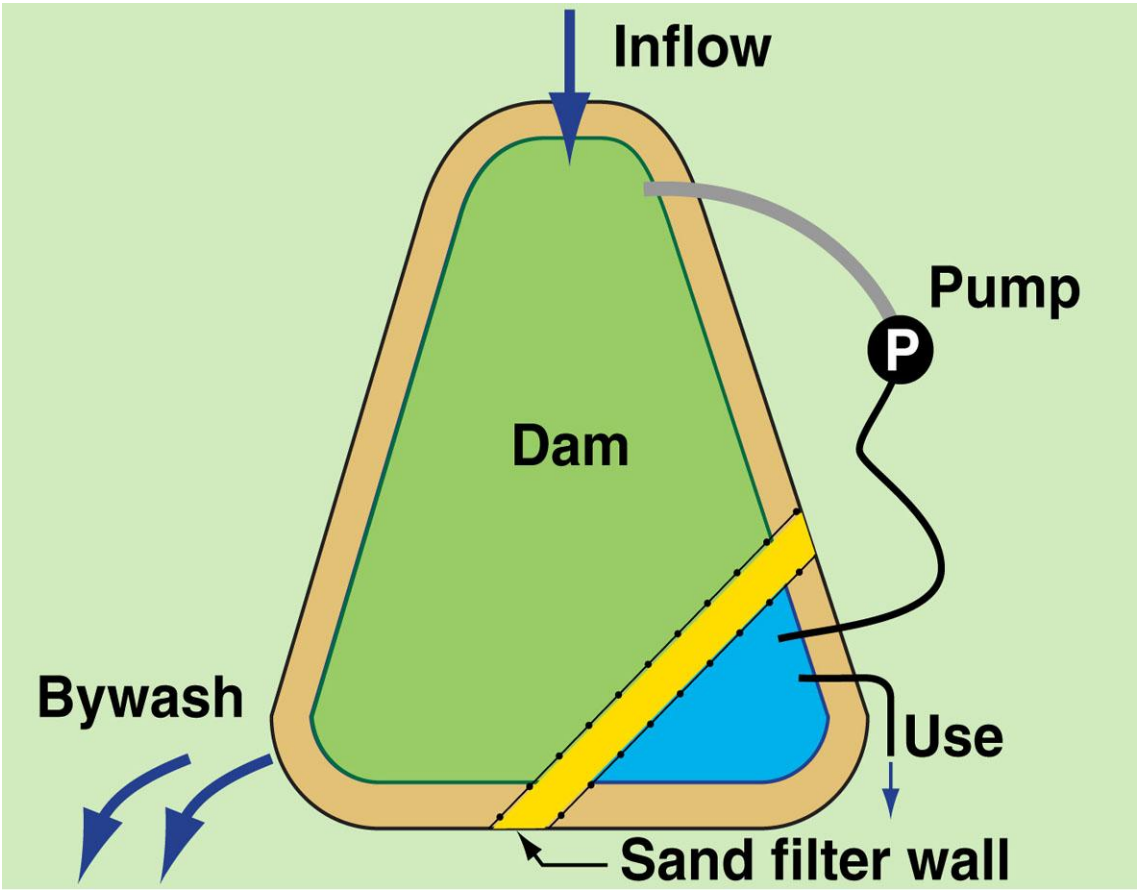


Additional water treatment

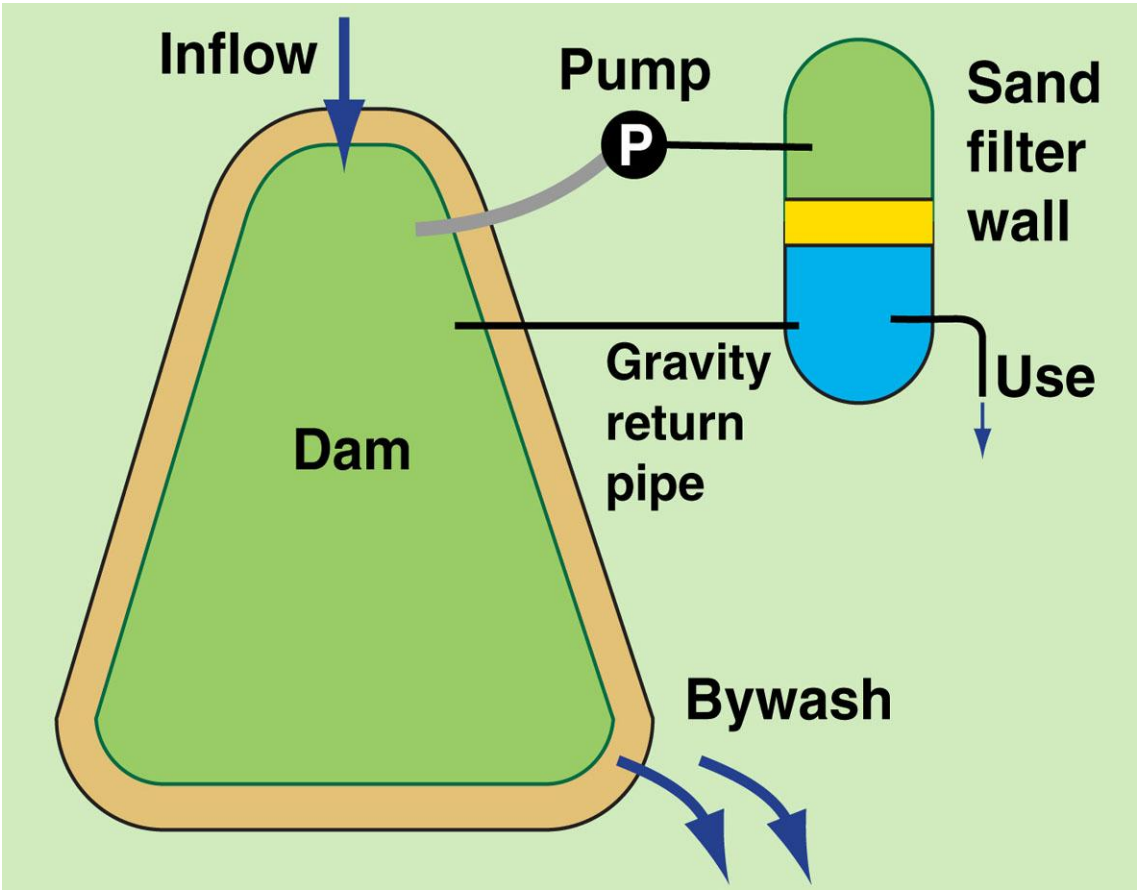
Inclusion of a trickling filter process

- Option 3 in its simplest form would have water constantly being pumped from the 'filtered' side of the wall to the 'unfiltered' side of the wall.
- An enhanced design would incorporate options 1 or 2 into the process.
- **Important:** the top of the filter wall must not be above the crest of an adjacent bywash or spillway.

Sand filter – Design option 3



Alternative layout with any overflow (bywash) not passing over the sand filter wall



Alternative layout which allows full operation over a wide range of dam levels

9. Maintenance and Leakage Issues

Introduction



Spillway rocks displaced by flows

Introduction

- Homes need maintenance, cars need maintenance, and machinery needs maintenance, so why do some landowners fail to maintain farm dams and repair any spillway damage after storm events.
- Dams require annual inspections, as well as inspections after each spillway event.
- Farm dams require maintenance to ensure adequate scour protection, including the health of the grass growing on a bywash.



Annual inspection

Annual inspection

- Look for cracks in the earth that may indicate: slumping or a landslip.
- Look for sections of grass that are growing greener, taller, or healthier than the surrounding grass–this may identify bank seepage that is feeding this grass water.
- Look for areas of damp soil.
- Look for cattle damage to the embankment or bywash.
- Check if there is a change in the potential safety risks downstream of the dam.



Bank slump

Post storm inspection

- Look for the displacement of rocks on the spillway or within the energy dissipation zone—Note: it is normal for rocks to shift and move a bit, but not to be fully removed from the structure.
- Look for any evidence of water passing over the earth embankment (all water should have passed over the bywash or spillway).
- Look for slumping or cattle damage on the earth embankment.



Scour-damaged grass

Repairs to scour protection

- If livestock are damaging the bywash, then consider fencing, or replacing the grass with a gravel–grass (see over page).
- If a bywash is experiencing regular damage due to the overtopping flows, then consideration should be given to replacing the grass bywash with a formal spillway (refer to Chapter 6)

Gravel-grass (a bywash surface condition)



Gravel grass (NSW)

Introduction

- The term 'gravel-grass' is just one of the terms used to describe a form of structural soil that combines the benefits of a gravel surface and a grassed surface.
- Structural soils are used in areas of 'exposed' soil that experience high traffic wear or loadings.
- Structural soils have been used in many locations to improve the structural strength of grassed fields so that they can support overflow car parking from time-to-time.



Concrete pavers with grass (Qld)

Commercial structural soils

- There are numerous products available that can be used to increase the structural integrity of grassed surfaces, including:
  - plastic grids
  - porous concrete pavers.
- In northern Australia (at least), the concrete pavers have had questionable results—it is believed that the concrete carries too much heat down into the soil.



Installation of gravel-grass driveway

Gravel-grass

- Gravel-grass is not a magical solution to flow-induced scour problems.
- Its function is to make the grass more resistant to vehicle, foot and animal traffic.
- When you travel along rural roads you may see grass establishing over the road shoulder, which is a form of gravel-grass.
- The benefits of a gravel-grass surface were demonstrated for 18 years on the author's own driveway in Brisbane (photos shown left and below).



Finished grass driveway (Qld)

Forming a gravel-grass surface

- Recess the proposed final surface elevation by at least 200 mm.
- Raise the surface up to the proposed finished elevation by filling the area with uniformly-sized aggregate (gravel), say 25 mm up to 50 mm diameter rocks.
- As the gravel is being placed, fill all voids with topsoil.
- Spread grass seed (not turf).
- Water in the soil, and if necessary, add more soil to fill all voids.

Rilling (fluting) down the face of the embankment



Fluting erosion on an earth batter (Qld)

Introduction

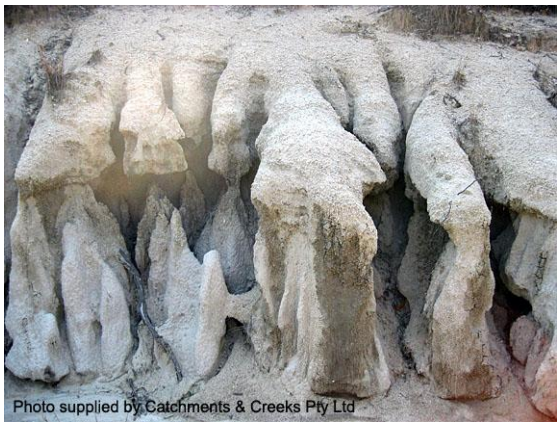
- If the dam's earth embankment is experiencing regular rilling (i.e. several closely-spaced rills), then this form of erosion is:
  - unlikely to have been caused by overtopping flows
  - but is likely to have been caused by rainwater running down the slope.
- This is a form of chemical erosion, not velocity-induced soil scour.



Rill erosion (Qld)

Fluting

- This form of erosion is called 'fluting', which is also the term used to describe the vertical recessions on the Greek and Roman columns attached to ancient buildings.
- The soil is called a dispersive soil.



Highly dispersive/slaking soil (Qld)

The cause of the erosion

- The erosion is caused by the high sodium content of the soil.
- The soil can be very hard when dry, but it appears to 'dissolve' when wet.
- The soil surface sometimes looks like the outer surface of a white ant nest.
- Treatment of the soil involves mixing the soil with gypsum (or equivalent) in order to replaced the sodium with calcium.

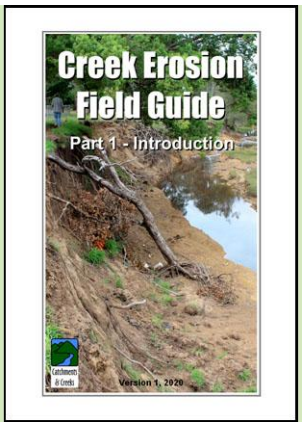


Gully erosion (Qld)

Gully erosion

- Rill erosion on a bywash or spillway can quickly turn into a major gully erosion problem (refer to Chapter 10).

Cracks opening in the soil



Creek Erosion Field Guide

Introduction

- If cracks open up in the earth embankment or the spillway, then they could be caused by:
  - bank undercutting (unlikely)
  - bank slumping (the likely cause)
  - cracking clays (unlikely).
- Guidance on the repair of bank erosion can be found in the 4-part *Catchments and Creeks* field guides on creek erosion.



Stress crack on a river bank (SA)

Landslide

- Bank slumping is a form of landside or landslip.
- The primary cause is excess weight, which often occurs after a storm event when the soil retains a large volume of soil-water that is unable to drain from the embankment soil fast enough.
- The normal solution is to find a way to give the soil some additional lateral support.



Cracking clays (NSW)

Shrinkage cracking

- Cracking clays may be found in some storage basins, but these soils should not be used to form dam embankments, so such problems should not be observed on an embankment.
- If the soils do exist, then try to establish a healthy grass cover to shade the soil and to prevent the soil from drying.



Bank slump (Qld)

Bank slumping

- If a major slump has occurred, then if may not be wise to allow the water level in the dam to come close to its maximum water level.
- The slumped soil should be removed and the embankment reconstructed, possible with the aid of earth reinforcing mesh.
- Ensure the rebuilt embankment has a stable and well anchored toe of the bank.

Leakage Issues



Outlet of tunnel erosion (Qld)



Outlet of tunnel erosion (Qld)



Evidence of seepage (Qld)

Introduction

- Leakages from the storage basin can arise for a number of reasons.
- The task of stopping these leaks requires the landowner to determine the cause of the leakage—unfortunately this is a difficult task!
- A landowner can employ an 'expert', such as a water engineer, or geotechnical engineer, to investigate the leakage.
- Alternatively, a landowners could ask neighbours what is the most common leakage issues in the region.

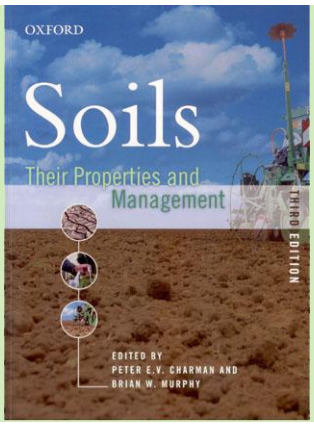
The travel path of a leakage

- Most people would expect that if a leakage occurs, then it must be associated with the fill embankment, and therefore, the blame must rest with the dam's constructor.
- The reality is that unless your dam is fully lined, then the leakage can occur through the base of the dam, its sidewalls, or the fill embankment.
- It is common for dams to leak when they are first built; but eventually, fine silts should begin to seal the base and sidewalls of the dam.

Leakage through the embankment

- Leakages through the constructed fill embankment are likely to be either:
  - tunnel erosion, caused by dispersive soils
  - general soil seepage, caused by a missing impervious core
  - groundwater passing under the fill embankment, which means the leakage started on the base or sidewalls of the dam.

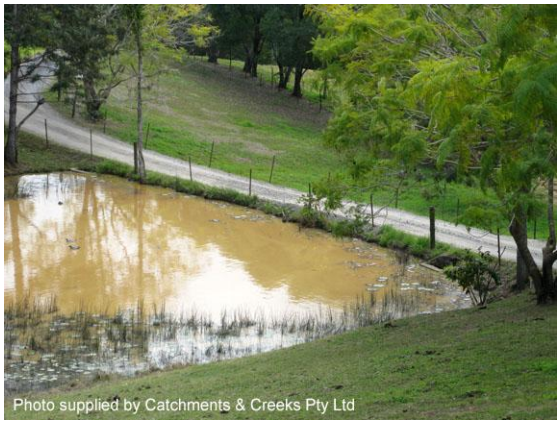
Controlling dam leakage



Charman & Murphy, 2007

Seepage losses

- Charman & Murphy (2007) reports that *'Seepage losses in farm dams constructed to standard specification can range from about 3 m per year down to about 3 cm per year.'*



Turbid water following a storm event

Relying on 'natural' sediment flow

- Water can pass through most 'natural' ground, which is how rainwater is able to travel down to the groundwater level.
- When a dam is first constructed, the excavated base and sidewalls will allow water to infiltrate the soil.
- However, assuming that storm inflows will carry a certain quantity of fine silts and clays, then these soil particles should slowly 'seal' these surface—if these suspended sediments are allowed to settle.



Clayey soil (Qld)

Lining a dam with a 'clay' layer

- If the inflows into the dam are not expected to bring sufficient quantities of suspended sediment, then the storage basin may need to be lined with a stable clayey soil (i.e. not dispersive).



Rubber-lined ring tank (Qld)

Lining a dam with a commercial liner

- Various commercial dam liners are available.

Chemicals to help settle suspended sediments from water



Gypsum (calcium sulfate)

Gypsum

- Gypsum is a naturally-occurring soft crystalline mineral.
- It is normally used as a soil ameliorant to improve soil structure and reduce crusting in soils with structural problems.
- It acts by increasing the electrolyte concentration, which flocculates dispersed clay, and by displacing exchangeable sodium.
- Gypsum, calcium sulphate, at approximately 32 kg per 100m^3.



Polyacrylamide

Coagulants and flocculants

- Coagulants allow clay particle to join and settle faster, while flocculants help to form 'flocs' which can be filtered from the water.
- Polyelectrolytes, long chain natural and synthetic organic polymers, at 0.05 to 0.2 kg per 100 m^3.
- Polyacrylamides: seek expert advice.
- Alum, aluminium sulfate, 1.5 to 8 kg per 100 m^3 —likely toxic impacts.
- Ferric chloride, 1 to 3 kg per 100 m^3— caution, this product is very corrosive.



Bentonite

Bentonite or Volclay

- Bentonite and Volclay are trade names for certain clays.
- These a 'volatile' clays that swell when wet.
- These products are best used in dams made from sandy soils.
- Use of these products is not a guaranteed solution.
- The key is the 'right' application method for the given site conditions (i.e. experience counts).



Sodium tripolyphosphate

Sodium tripolyphosphate (STPP)

- This chemical has the opposite effect of gypsum—it helps to make clay particles disperse, which can allow them to move into a leakage area and block the leak.
- This product is used on soils that are too stable to seal naturally.
- Expert advice and laboratory testing is strongly recommended.

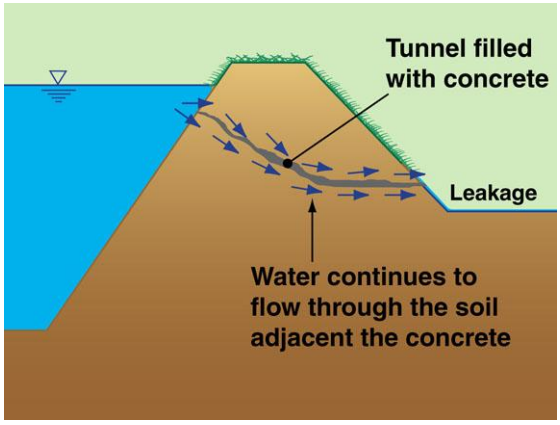
Why it is so difficult to ‘plug’ tunnel erosion



Evidence of seepage (Qld)



Tunnel erosion (Qld)



Ongoing tunnel erosion



Caution

Introduction

- In order to understand how to fix water seepage through soil (i.e. a ‘spring’), and tunnel erosion (a severe case of water seepage), you need to understand dispersive soils and the effects that sodium has on soils.
- A ‘good soil’ needs a small amount of dispersion (sodium) in order to move clay particles around so that the soil can ‘seal’ leaks and therefore hold water.
- A ‘bad soil’ has too much exchangeable sodium, which cause much of the clay to move with the groundwater flow and leave the soil as brown (turbid) runoff.
- If too much clay leaves the soil, it will cause the formation of micro tunnels (springs), which can grow into tunnel erosion, which involves the removal of clay, silt and sand-sized particles.
- The correct scientific reason why sodium is able to do this in a soil would take five pages to explain; however, a non-scientific explanation is to just imagine ‘sodium’ as a water-soluble glue the holds soil particles together, but this bond can fail if the soil becomes ‘wet’.

You CANNOT fill tunnel erosion with concrete, clay or gypsum

- Unfortunately, you **cannot** fix tunnel erosion by filling the tunnel with concrete, expanding foam, or some type of clay-gypsum mixture.
- The reason is, if the tunnel was filled, the soil that now surrounds this filled-tunnel and still dispersive, so a water leak will simply begin to form on the outside of the material that filled the old tunnel.

Repairing tunnel erosion

- In order to repair tunnel erosion, the options are:
  - install a commercial basin liner over the storage basin
  - excavate the embankment to remove all the dispersive soils (not just the tunnel erosion), and rebuild the embankment.

10. Spillway Failures

Introduction



Structural failure

Introduction

- Farm dams can fail for a variety of reasons, including
  - excessive leakage
  - poor water quality
  - embankment failure
  - spillway failure.
- This chapter addresses the occurrence of spillway failures, which typically involve either gully erosion, or the displacement of the rocks, or other materials, used for scour control.



Displacement of rocks

Displacement of rocks

- The stability of rocks in flowing water is not an exact science.
- The author has been studying rock sizing equations for over 30 years, and has drafted several publications on the topic, and even after all of this research, the author cannot guarantee that rocks of a certain size will not move!
- The displacement of a rock has as much to do with how the rock was ‘placed’, as it has to do with the ‘size’ of the rock.



Total failure of a gabion spillway

Gully erosion initiated on the spillway

- Grassed bywash spillways are highly susceptible to soil scour, which is most commonly triggered by high flow velocities passing down the bywash.
- Rock-lined spillways can experience erosion problems if **too many** of the rocks are displaced—some rocks will always be displaced.
- Gabion, rock mattress and concrete lined spillways can fail if the underlying soil is dispersive.



Gully erosion migrating up a slope

Gully erosion migrating up to the spillway

- A common cause of spillway failures is the destructive effects of gully erosion that has migrated up a valley from a downstream trigger.
- The downstream trigger may have been caused by discharges from the farm dam, or may have been caused by problems independent of the dam.
- This form of gully erosion typically needs to be stopped well before the cause of the erosion is known, and those responsible are held to account—timing is critical.

Potential cause of a spillway failure



Flows exceeded the design storm

Underestimation of the potential discharge

- The designer of a farm dam typically determines the dimensions and scour protection of a spillway based on their, or the regulator's, choice of a 'design' storm.
- However, if a bigger storm occurs, and the dam fails (for whatever reason), and this failure causes harm or damage to a downstream property, then the dam owner will be held responsible for these damages, even if their dam had been correctly designed to government-specified design standards (refer to Ch 2).



Inadequate rock size

Insufficient rock size

- It is relatively easy for a designer to use tables 6.8 to 6.11 to size the required spillway rock to the nearest 100 mm.
- However, when the landowner or contractor goes to purchase such rock from their local quarry, they may be presented with a very limited array of available rock sizes.
- If the purchased rocks are too small, then placing **'more'** of these small rocks will **not** prevent a future spillway failure!



Migrating gully erosion

Unstable foundations underlying the spillway

- If gully erosion migrates up a valley towards a spillway, then this gully erosion may undermine the foundations of the spillway, which can cause a complete failure.
- This form of erosion is best controlled by the establishment of a deep cut-off wall.

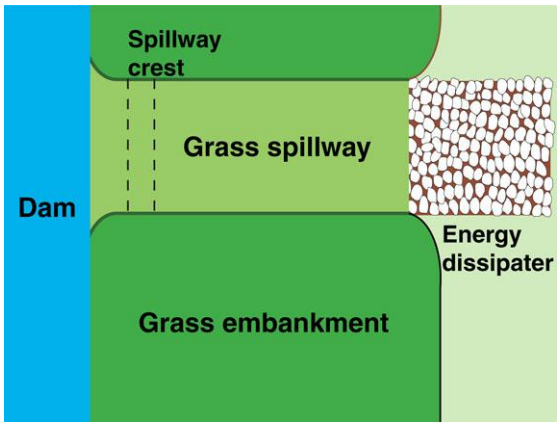


Dispersive subsoil

Dispersive subsoil (unstable foundations)

- If the soils that forms the foundations of a spillway are dispersive, then an extended wet period can cause the removal of this soil, and the undermining of the spillway.
- Even the strongest spillway will fail is the spillway's foundations fail.
- It is worth noting that the engineers that specialise in the design of foundations (geotechnical or structural engineers) are usually different from the engineers that specialise in the design of spillways (hydraulic or water engineers).

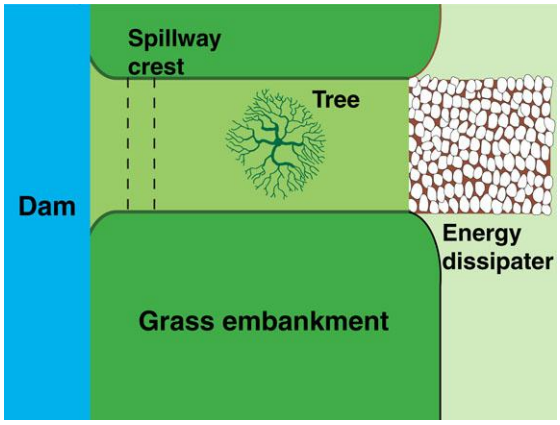
The reason why trees are NOT planted on spillways (repeat)



Plan view of a grass spillway

Trees and shrubs should not be planted on a spillway

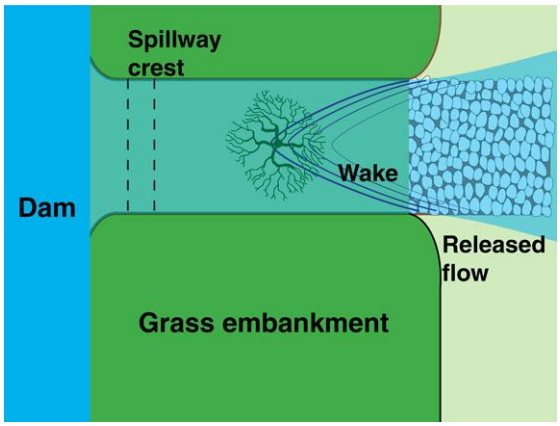
- A spillway can be lined with concrete, loose rock, or rock integrated with flexible grasses.
- In some cases, a spillway can be lined only with grass (i.e. a bywash).
- However, a spillway **must** never incorporate trees, shrubs, or stiff grasses, because these plants can induce turbulence in the high-velocity water, which can cause soil scour, and trigger gully erosion.



(a) Tree planted on a grass spillway



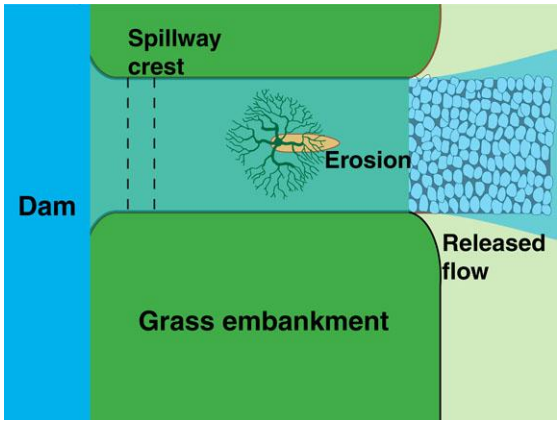
Trees planted on a grass spillway



(b) Turbulent flow generated by the tree

The cause of turbulence and erosion

- The type of objects that can cause flow problems and erosion issues on a grass spillway include:
  - trees
  - shrubs
  - fence posts
  - randomly-placed rocks (often placed on a bywash to help dissipate energy, but in some cases can cause more 'harm' than 'good'), or
  - park furniture, such as a bench seat.

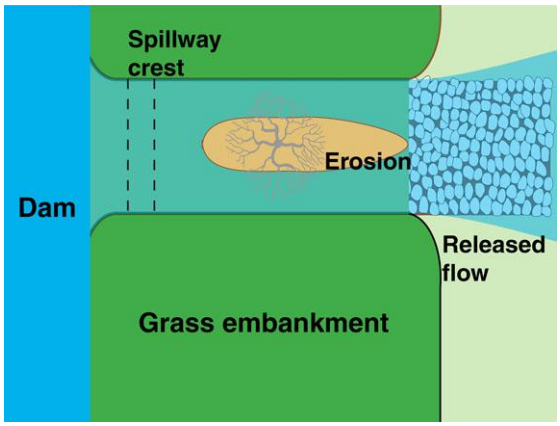


(c) Scour hole formed at base of tree



Scour hole at base of tree

The reason why trees are NOT planted on spillways (repeat)



(d) Expansion of scour hole

Formation of gully erosion

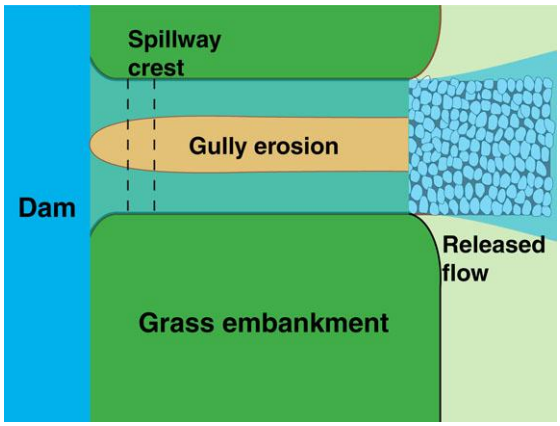
- Once a scour hole is formed in the grass, the spillway flows can quickly (i.e. during one storm event) turn such minor erosion into major gully erosion.
- If the soil that was used to form the earth spillway is slightly dispersive, then this gully erosion can cut a deep scar through the spillway.



Scour hole downstream of tree



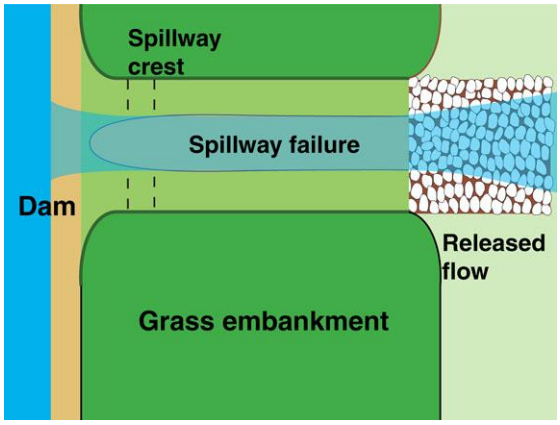
Scour hole



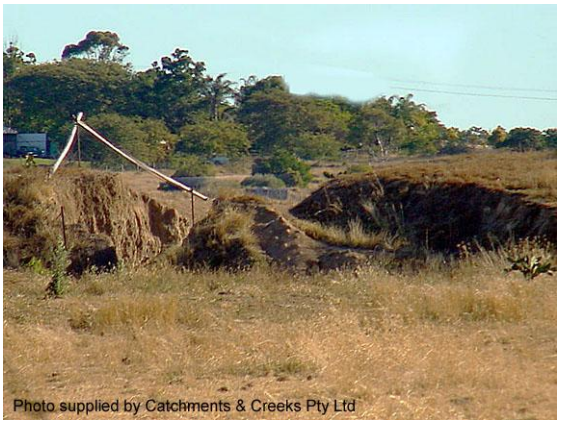
(e) Formation of gully erosion

Dam failure

- A worst-case outcome would involve the collapse of the whole spillway, which will cause the dam to quickly drain its contents.
- It is this sudden release of water than can result in the loss of life downstream because the wave of water can arrive without warning.

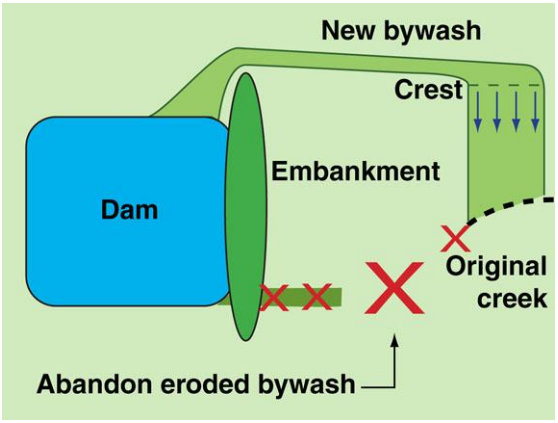


(f) Gully erosion reaches the water basin



Failed spillway

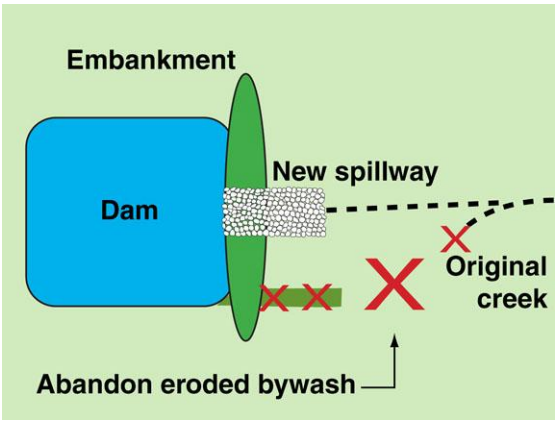
Repair options



New bywash

Option 1: A new bywash built on other side of the embankment

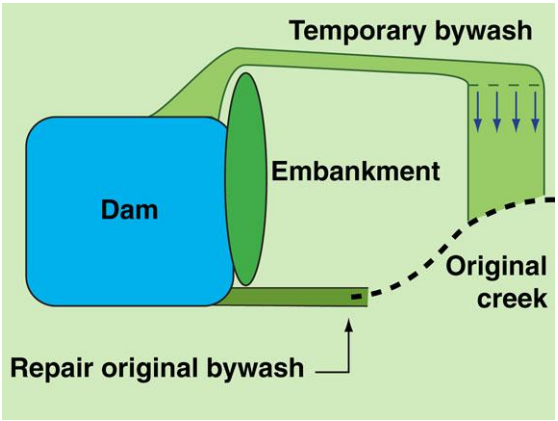
- Consider the possibility of forming a new bywash/spillway on the other side of the embankment.
- Flows should only be allowed to pass down this new bywash after the grass is fully established and healthy.
- When the new bywash is on-line, the old bywash can be taken off-line and repaired, or decommissioned.



New spillway

Option 2: A new spillway built over the embankment

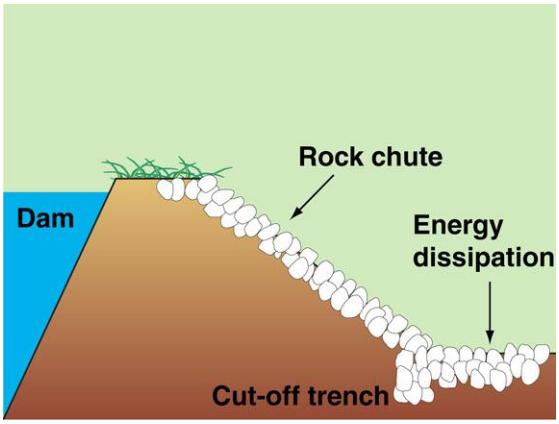
- Consider the possibility of constructing a permanent, or temporary, spillway over the embankment.
- When the new spillway is on-line, the old bywash can be taken off-line and repaired or decommissioned.



Temporary bywash

Option 3: Forming a temporary spillway while the old bywash is being repaired

- When the old bywash is repaired and revegetated, then the alternative bywash can be decommissioned.
- The repaired bywash may have been repaired with a surface treatment that is stronger than the original grass, possibly with:
  - a rock and grass mix
  - synthetic reinforced grass.



Rock lining a damaged bywash

Option 4: Converting a damaged bywash into a stable spillway

- Consider the option of converting the damaged grassed bywash into a formal spillway, either:
  - rock lined
  - rock and grass mixture
  - rock mattresses
  - concrete.

Gully head treatment techniques



Minor gully erosion (Qld)



Gully erosion (SA)



Gully erosion (Qld)



Deep gully erosion (Qld)

Gullies less than 1 m deep

- For shallow gullies, consider the following gully head treatments:
  - Butyl rubber chute
  - Grass chute
  - High density stock grazing
  - PVC (formless) chute
  - Timber drop structure.
- Not all of these techniques will be viable in all circumstances.

Gullies less than 3 m deep

- For deeper gullies, consider the following gully head treatments:
  - Concrete block drop structure
  - Concrete chute
  - Concrete cut-off trench
  - Concrete drop structure
  - Concrete sandbag drop structure
  - Gabion drop structure
  - Grass chute (technically possible)
  - Grouted boulder chute
  - Grouted rock drop structure
  - Gully control dam
  - Gully reshaping
  - Reinforced grass chute
  - Rock chute
  - Rock mattress chute
  - Sandbag chute
  - Sandbag drop structure
  - Stiff grass chute (caution)
  - Soil-cement drop structure
  - Stacked boulder drop structure
  - Steel sheet drop structure
  - Tyre chute.

Gullies more than 3 m deep

- For very deep gullies, consider the following gully head treatments:
  - Commercial drainage chutes (typically used on road batters)
  - Corrugated iron chute
  - Geotextile chute
  - Reinforced grass chute
  - Rock mattress chute (spillway)
  - Stepped drop structure (concrete or gabion)
  - Verandah flume (use with caution).

Gully floor treatment techniques



Gabion weir (Qld)



Leaky weir (NSW)



Pile field (Qld)



Stiff grass filter (Qld)

Gully floor treatment options

- Brushwood filters: locally-obtained tree branches and logs can be used to form a leaky weir that traps sediment and other organic matter.
- Gabion weirs: gabions may initially be slightly porous, but sediment can quickly turn them into impervious weirs.
- Geo log and wire netting silt trap weirs: these are relatively low sediment traps that can function for about a year.
- Hay bale and wire netting silt trap weirs: these are relatively low sediment traps that can function for about a month.
- Leaky weirs: this is a generic term that refers to a pervious weir that is likely to trap sand and silt-sized particles.
- Log weirs: these are generally very low, or partially recessed weirs that primarily act as minor grade control structures.
- Pile field: a pile field can be used in a manner similar to an extremely well anchored brushwood filter.
- Recessed check dams: a buried bed control structure used to control future bed scour, or head-cut erosion.
- Rock check dams: these are a rock-based grade control structure and sediment trap.
- Sandbag weirs: these are a minor grade control structure and sediment trap.
- Stiff grass filters: a well-anchored organic sediment trap (caution!).
- Weirs: this is a general term that includes: brushwood filter/weirs, gabion weirs, geo log weirs, leaky weirs, log weirs, porous check dams, rock check dams, steel pile weirs and reinforced concrete weirs.
- Wire netting silt trap weirs: a durable and easy-to-make leaky weir that can trap sediment and organic matter (e.g. grass and branches).
- This is a type of leaky weir that involves either:
  - wire mesh fencing staked across a gully floor
  - wire mesh rolled into long ‘sausages’ that are staked across overland flow paths in order to reduce the risk of gully erosion occurring, or to reduce the migration of shallow head-cut erosion.

Natural materials used in the control of gully erosion



Gully repair (Qld)

Introduction

- A variety of gully repair options are detailed within this field guide, some provide long-term stability, while others provide only a short-term solution.
- Short-term solutions are fine if you are willing to pass the problem onto the next owner of the land.
- However, wherever possible, gully repairs should aim to provide long-term stability, and should aim to use only natural materials, such as: rock, soil, and vegetation.



Rock (Qld)

Use of rock

- Rock is the natural solution when high flow velocities are involved, which is common at the gully head.
- Rock can work effectively on its own, but it works better when it is combined with the right mix of soil and vegetation.
- The alternatives to rock include: timber, concrete, synthetics, metal and wire.
- It is my personal belief that plastic-based products should never be buried in the ground or placed near waterways.



Soil placement (NSW)

Use of soil

- Gully erosion often occurs in locations where the subsoils have poor structural strength, particularly when they are wet, such as a dispersive or sodic soil.
- The most important thing to know about dealing with ‘problem soils’ is that:
  - so called ‘problem soils’ are natural, and they have existed in our landscape for millions of years
  - the best way to stabilise a problem soil is to cover it with a ‘good’ soil, not filter cloth.



Site revegetation (Qld)

Use of vegetation

- Vegetation usually plays an important role in the long-term stabilisation of gully repair projects.
- Vegetation can even play an important role in arid and semi-arid regions.
- The use of ‘vegetation’ does not mean that 100% coverage is required, or that the organic matter must consist only of living plants—mulches and logs can also play an important role in gully stabilisation projects.

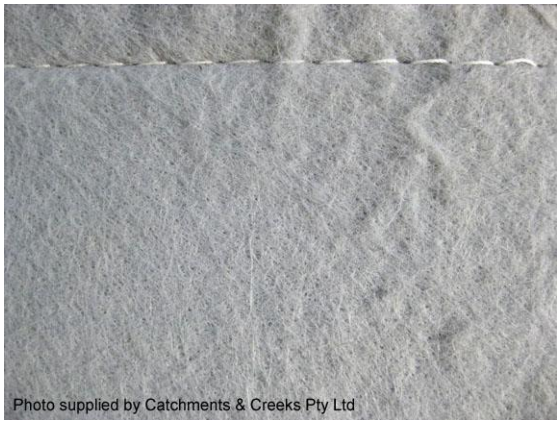
Typical manufactured materials used in the control of gully erosion



Jute or coir blanket (organic)



Jute or coir mesh (organic)



Filter cloth (100% synthetic)



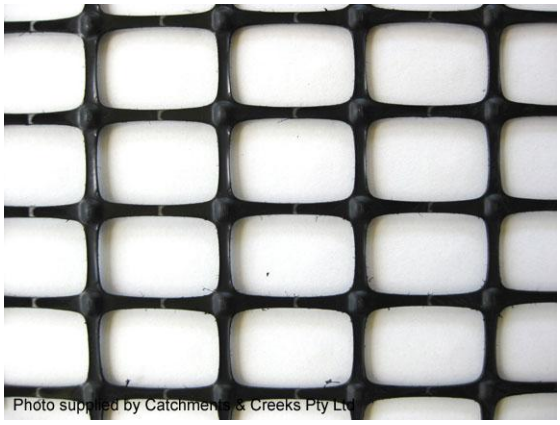
Erosion control mat (composite material)



Gabion



Rock mattress

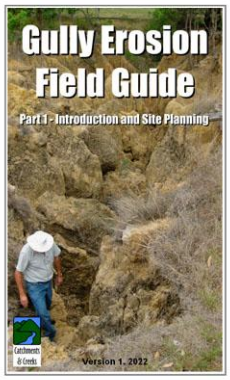


Earth reinforcing mesh (geogrid)



Rockfall netting

Related *Catchments and Creeks* field guides



Gully Erosion - Part 1, Introduction

Gully Erosion Field Guide

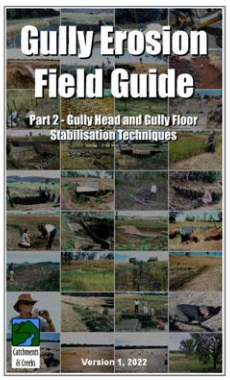
Part 1, Introduction and Site Planning

Catchments & Creeks Pty Ltd, 2022, Bargara Queensland.

157 page PDF document

Version 1, February 2022

Part 1 of this three-part document discusses gully erosion processes and treatment options.



Gully Erosion - Part 2, Gully Head

Gully Erosion Field Guide

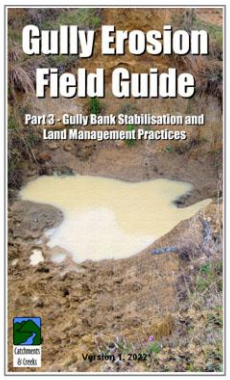
Part 2, Gully Head and Gully Floor Stabilisation Techniques

Catchments & Creeks Pty Ltd, 2022, Bargara Queensland.

129 page PDF document

Version 1, February 2022

Part 2 of this three-part document presents design information on gully head and gully bed stabilisation.



Gully Erosion - Part 3, Bank Stabilisation

Gully Erosion Field Guide

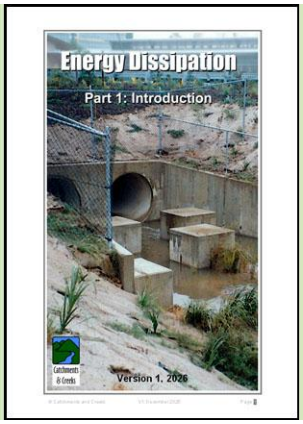
Part 3, Gully Bank Stabilisation and Land Management Practices

Catchments & Creeks Pty Ltd, 2022, Bargara Queensland.

87 page PDF document

Version 1, February 2022

Part 3 of this three-part document presents design information on the stabilisation of gully banks.



Energy Dissipation (Not Finished)

Energy Dissipation

Part 1 – Introduction

Catchments & Creeks Pty Ltd, 2022, Bargara Queensland.

Still in draft as of August 2026.

Possible release date: late 2026.

Discusses the selection and design of energy dissipation structures for stormwater outlets, culverts, batter chutes, and small dam spillways.

11. Spillway Failure Case Studies

Site 1



Site 1 – Gully dam with grassed bywash experiencing severe erosion



Upper region of the bywash

Introduction

- Five of these case studies were farm dams visited by the author during a post-flood training course and field day.
- The final two sites were inspected by the author on a professional basis.
- The author has not conducted a detailed investigation or design of any of these sites.
- These case studies are presented only as general examples of spillway failures.



Deep scour holes on bywash

Site 1: Scour holes

- The lower section of the bywash (i.e. the most downstream section, prior to joining the natural valley floor), followed a curved pathway around the fill embankment.
- This lower section of the bywash should have been straight, not curved!
- Due to the gradient of the bywash, flow velocities would have been fast, and may even have been supercritical.
- Flow turbulence and soil dispersion has generated these scour holes.

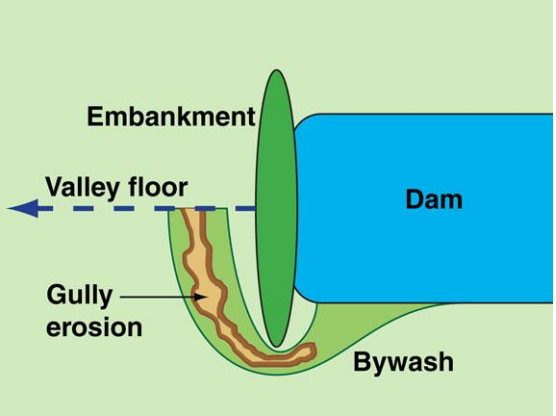


Dispersive soil

Soil conditions

- A visual inspection of the exposed soil by the author indicated that this is a highly dispersive soil.
- This degree of soil erosion is not unusual for these dispersive soils.
- The bywash should have been over-excavated, then the removed soil should have been treated with gypsum (or other, as directed), then replaced and compacted to form the upper surface of the bywash, before the bywash was grassed.

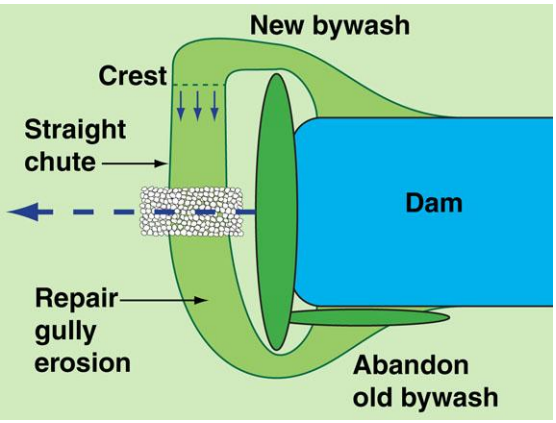
Site 1 – Discussion



Layout of existing erosion problem

Reference document

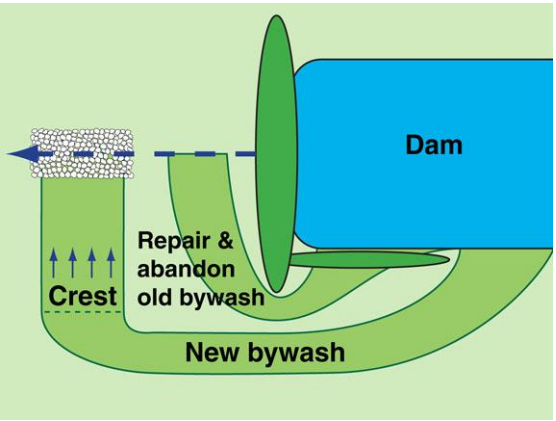
- The repair of gully erosion is discussed in detail within the three-part *'Gully Erosion Field Guide'* freely-available from the *Catchments and Creeks* website.
- Part 2 of the above field guide provides information on the treatment of the gully head and gully floor.
- This diagram (left) displays the general arrangement of Site 1 at the time of the site visit (presented in 'plan view').



Treatment option 1

Treatment option 1

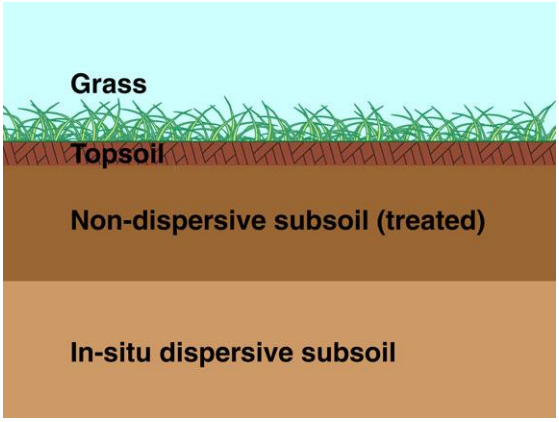
- When dealing with bywash or spillway damage, my first preference is to look for an opportunity to construct a new bywash or spillway on the other side of the embankment.
- The new bywash can be formed and grassed while off-line.
- When the new bywash is stable, it can be brought on-line, and the old bywash can then be taken off-line for repair.



Treatment option 2

Treatment option 2

- In many cases it proves impossible to form a new bywash around the other end of the earth embankment, so I look for an opportunity to construct a new bywash parallel (around) the existing bywash.
- If a new bywash is possible, then again, it will be formed and stabilised while off-line.
- Eventually, when the old bywash is repaired and stabilised, it can be brought on-line as a dual bywash system.



Soil profile of repaired gully erosion

Forming a grassed bywash on a dispersive soil

- Advice on the treatment of dispersive soils is provided within the *Gully Erosion Field Guides.*
- The first preference should be to cover the in-situ soil with non-dispersive soil found somewhere on the farm.
- The second preference is to re-profile the eroded gully, remove a sufficient volume of the dispersive soil, treat this soil with gypsum (well-mixed), then return this treated soil to cover the in-situ soil.

Site 2



Site 2 – A fully recessed dam with grassed bywash (foreground)



Flow path of the grassed bywash displayed in 'blue'



Looking upstream into the inflow channel



Erosion at the base of the inflow channel (visual signs of a dispersive soils)

Site 2 – Soil conditions



Inflow channel (upstream)

Site 2: Soil properties

- This site displayed soil erosion problems within the inflow channel, as well as the outflow channel (i.e. downstream of the bywash).
- The downstream head-cut gully erosion had not yet reached the bywash.
- The in-situ soil displayed visual signs of being dispersive.
- It was noted that the upstream surface soil appeared to be different from the exposed downstream soil.
- (u/s) = upstream; (d/s) = downstream.



Two soil horizons (upstream)



Dispersive fluting (rilling) erosion (u/s)



Slumping within the outflow channel (d/s)



Erosion within the downstream channel

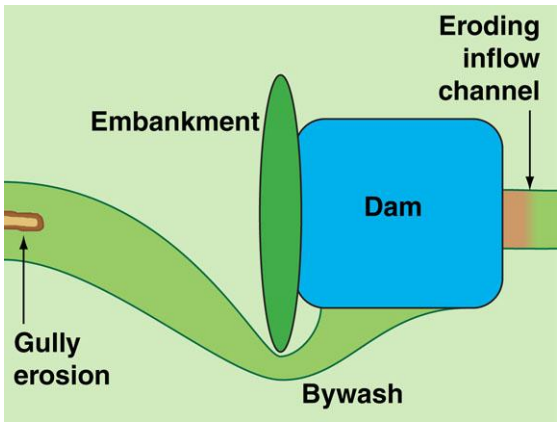


Exposed dispersive downstream soil



Textured soil surface of downstream soil

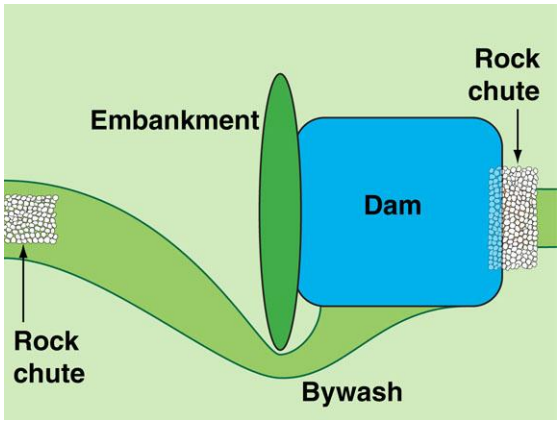
Site 2 – Discussion



Existing site conditions

Existing site conditions

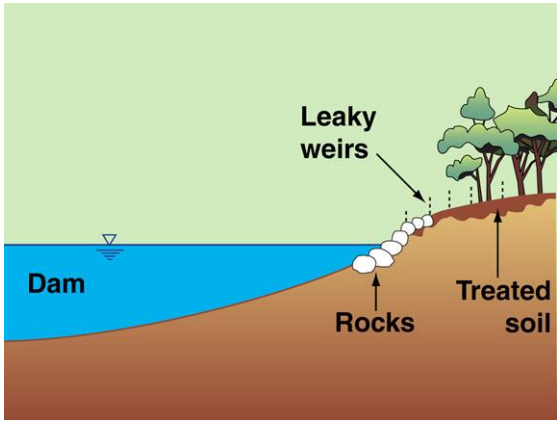
- This dam is fully recessed with the excavated earth being used to form the adjacent non-functioning embankment.
- The author did not investigate the likely cause of the downstream head-cut gully erosion that was migrating up the dam.
- If this gully erosion is allowed to continue, then it is likely that the gully will eventually reach the dam, and cause the dam to fully drain.



Proposed treatment

Proposed treatment

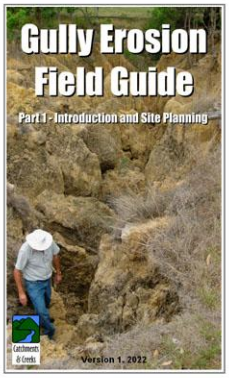
- The primary cause of the soil erosion at this site is the chemical erosion of the dispersive soils (not a velocity problem).
- The first priority should be to either:
  - find a source of non-dispersive soil on the farm, or
  - excavate some of the dispersive soil and treat it with gypsum (or other).
- Non-dispersive soil needs to be placed over the in-situ soil before the placement of rocks or grass.



Stabilisation of the inflow channel

Stabilisation of the <u>inflow</u> channel

- There are several possible treatment options for the inflow channel.
- The most likely treatment option would be:
  - remove soil from the eroded sections of the channel and them re-shape the channel
  - treat the removed soil with gypsum
  - use the treated soil to cover the remaining in-situ soil
  - form a rock chute, and install leaky weirs.



Gully Erosion Field Guide (2022)

Stabilisation of the <u>downstream</u> channel

- The downstream channel needs to be stabilised using one of the many options for treating gully erosion.
- The repair of gully erosion is discussed within the three-part *'Gully Erosion Field Guide'* freely-available from the *Catchments and Creeks* website.
- Part 2 of this gully erosion field guide provides information on the treatment of the gully head and gully floor.

Site 3



Site 3 – Gully dam with the embankment on the left



An extension of the above image showing the embankment and bywash (on the left)



Gully erosion along outflow channel

Site 3: Gully erosion along the bywash

- This farm dam is currently experiencing gully erosion within the outflow channel located between the bywash and the receiving water body (i.e. the nearby watercourse).
- The gully erosion is approximately 2 m deep, and has almost reached the dam.

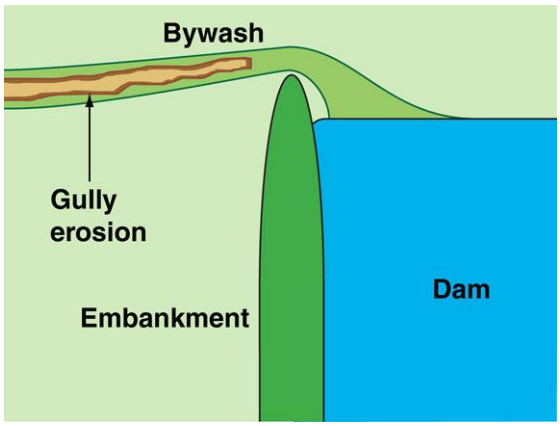


Fluting erosion of a dispersive soil

Soil conditions

- The eroded soils are clearly dispersive, and displays the vertical ‘fluting’ erosion marks that are commonly associated with the erosion of a dispersive soil.

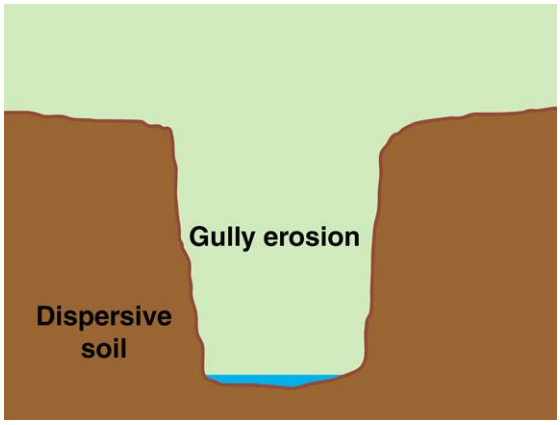
Site 3 – Discussion



Existing site conditions

Existing site conditions

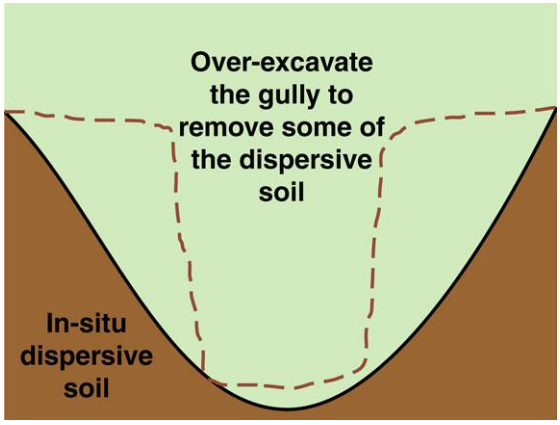
- This is a gully dam located away from a well-defined watercourse.
- The dam is partially recessed, and partially supported by a long earth embankment.



Existing gully erosion

Existing gully erosion

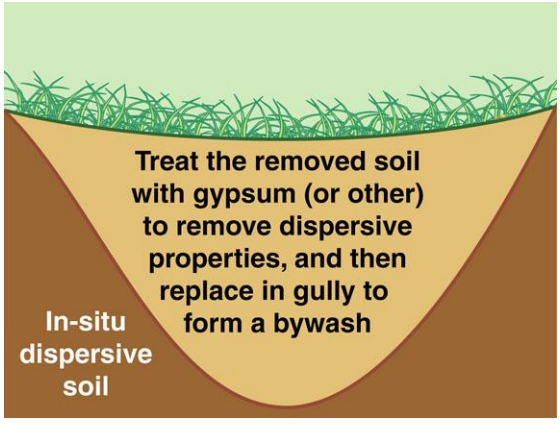
- The gully erosion that has migrated into the bywash, has near-vertical sidewalls.



Over-excavate the gully

Step 1 – Excavated some of the in-situ soil

- Repair of the gully would require:
  - finding a source of non-dispersive soil on the farm, or excavate some of the dispersive soil and treat with gypsum
  - re-shape the channel
  - install a rock chute to feed water from the bywash into the outflow channel
  - using the gypsum-treated soil to cover the re-shaped channel
  - establish a healthy grass cover.



Backfill the old gully

Step 2 – Treat and replace soil to form new bywash

- Alternatively, if sufficient non-dispersive soil can be found on the farm, then the gully could be:
  - backfilled with non-dispersive soil
  - compacted firm, but not rock-hard
  - grassed to form an extension to the existing bywash.
- At the end of the newly extended bywash, a vegetated rock chute can be installed to carry flows down to the elevation of the adjacent floodplain.

Site 4



Site 4 – Gully dam with the start of the bywash in the foreground



Looking down the eroded bywash

Site 4: Gully erosion along the bywash

- This site is a gully dam with a long, low-gradient bywash that eventually turns down a steep slope before entering a watercourse.
- Gully erosion first occurred within this steep section of the bywash, which has resulted in the formation of two head-cuts, one at the downstream end of the bywash, and one halfway along the low-gradient section of the bywash.



Head-cut erosion midway along bywash

Head-cut erosion face midway along the bywash

- This image shows the head-cut which is located halfway along the low-gradient section of the bywash.
- The photo is looking upstream towards the dam.

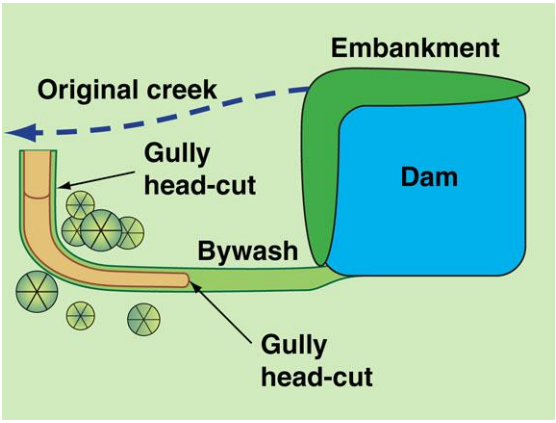


Downstream end of the bywash

Head-cut erosion at the downstream end of the bywash

- This image shows the second head-cut which is located at the downstream end of the bywash.
- The photo is looking up the steep ‘outflow’ section of the bywash where the gully erosion was first triggered.

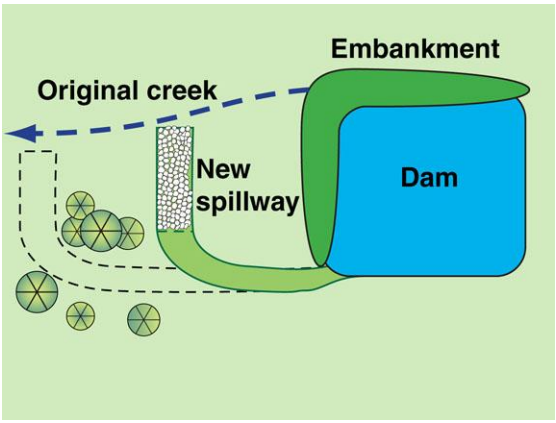
Site 4 – Discussion



Existing site conditions

Existing site conditions

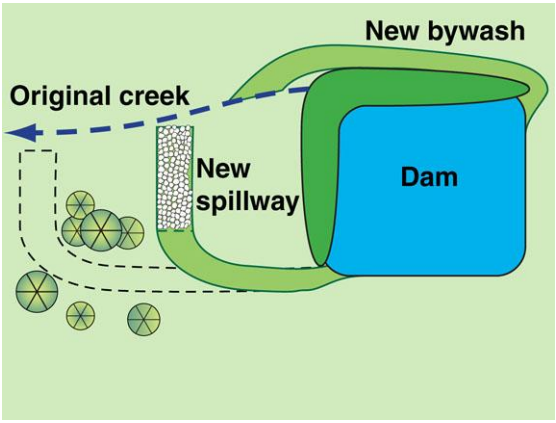
- This image displays the approximate layout of the site during the site visit.



Treatment option 1

Treatment option 1

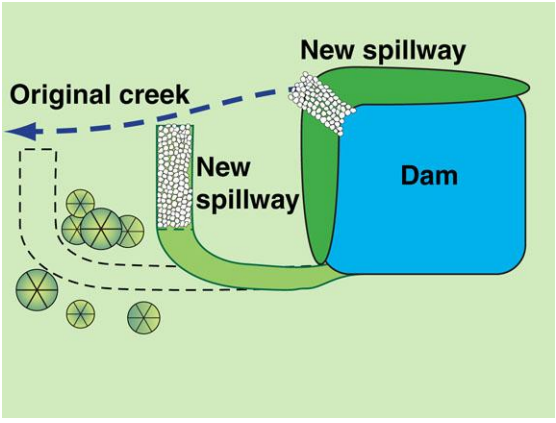
- A new outlet from the existing bywash could be formed by constructing a rock-lined spillway at the location of the upstream head-cut.



Treatment option 2

Treatment option 2

- Consideration should also be given to the formation of a new bywash north of the embankment.
- This alternative bywash could replace the existing bywash, or work in partnership with the repaired bywash.



Treatment option 3

Treatment option 3

- Possibly the least preferred option would be to construct a formal spillway into the existing earth embankment.
- This new spillway could replace the existing bywash, or work in partnership with the repaired bywash.

Site 5



Site 5 – Looking down the bywash towards the approaching gully erosion



Looking upstream along the grassed bywash (free of erosion)

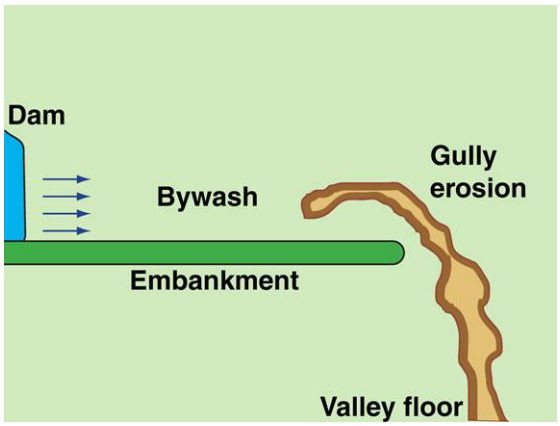


Looing downstream from the gully head



The gully bends around a corner before reaching the natural valley floor

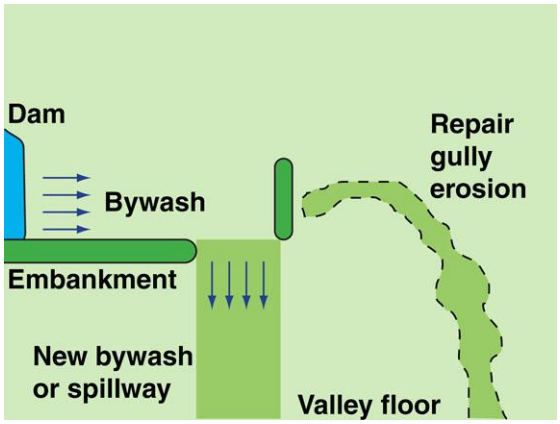
Site 5 – Discussion



Existing site conditions

Site 5: Existing site conditions

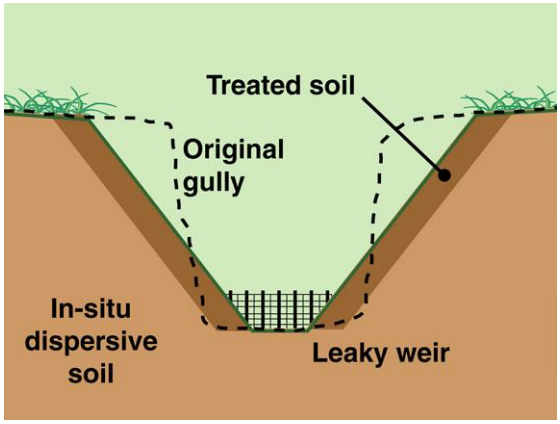
- The gully erosion at this site is obviously severe, and a major concern.
- On the 'plus-side' is the fact that the gully erosion is still some distance from the dam due to the unusual length of the bywash.



New bywash

New bywash

- First option would be to construct a new bywash outlet channel, then take the existing gully off-line.



Stabilisation of the gully banks

Stabilisation of the gully banks

- Information on the repair of gully erosion can be found in Part 2 of the *Gully Erosion Field Guide* (2022).
- Typical treatment would involve:
  - re-profile the gully banks with a dozer
  - remove and treat some of the soil
  - use the treated soil to cover the remaining in-situ dispersive soil
  - install leaky weirs along the base of the newly-formed channel.



Leaky weir (NSW)

Leaky weirs

- The term 'leaky weir' is the general name given to any porous weir structure that can potentially be designed to:
  - slow upstream flow velocities
  - allow coarse sediment to settle out of the water upstream of the weir
  - potentially filter some of the finer sediments (but not clay) via the porous structure of the weir
  - allow the eventual formation of a stepped (terraced) gully floor.

Site 6



Site 6 – An embankment dam discharging into an outflow channel



Head-cut erosion in outflow channel

Site 6: Upper step of the gully head

- This site had gully erosion that was more closely aligned with the description of a waterfall than a typical gully.
- If the gully erosion were allowed to continue, then it would cause the entire de-watering of the dam (which was equally deep).
- The dam was located on a watercourse, and it had an almost constant inflow.

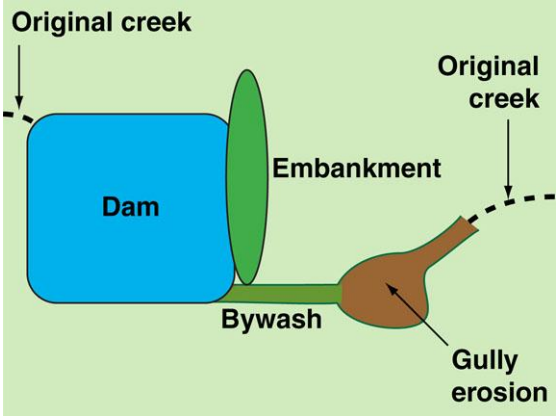


Main gully erosion

Upper and lower steps of the gully head

- The water ‘fell’ in two stages, with a step or bench being formed halfway down the fall.
- The top image shows the upper ‘step’, and the base of this upper step.
- The image to the left, shows both the upper and lower steps, with a final plunge pool at the base.
- The plunge pool at the base was at an elevation that was just above the downstream watercourse.
- Unlike the previous case studies, the in-situ soil did not appear to be dispersive.
- The gully erosion (as shown in these images), exists within the fill embankment, that was formed from the earth excavated from the storage basin (dam).
- The dam had existed for several years, and was constructed by a previous landowner.
- The embankment was covered by dense, mature trees.

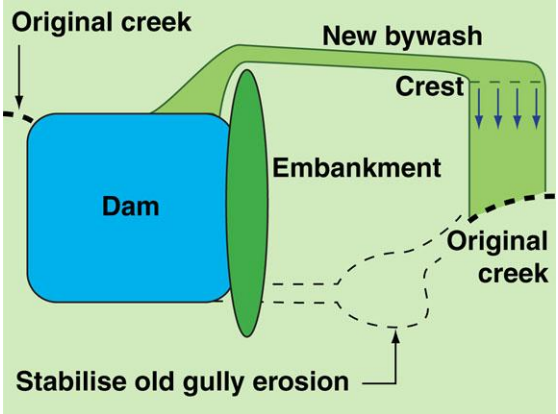
Site 6 – Discussion



Existing site conditions

Existing site conditions

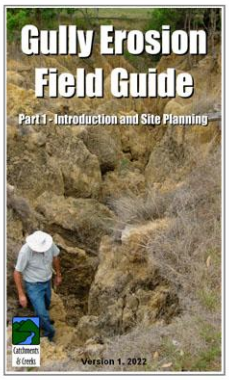
- This diagram presents a very simplified description of the site conditions at the time of the site visit.



New bywash

New bywash

- At this site, a new spillway needs to be constructed on the northern side of the embankment.
- Construction of this spillway would require significant vegetation removal and earthworks.
- Parts of the bywash/spillway would need to be lined with rock.
- When the new spillway is stable, the old bywash would be taken off-line.



Gully Erosion Field Guide (2022)

Stabilisation of the gully erosion

- The typical repair of gully erosion is discussed with the three-part 'Gully Erosion Field Guide' freely-available from the *Catchments and Creeks* website.
- Part 2 of this three-part document provides details of the treatment of the gully head and gully floor.



Gabion drop structure (Qld)

Gabion drop structure

- Gabions are the most common instrument used to stabilise such deep gully erosion.
- Gabions would not be a suitable long-term solution if the existing gully were to remain on-line because the high turbulence caused by the falling water would eventually cause the failure of the wire baskets, and the subsequent loss of rocks.
- Vegetation could protect the gabions, but at this site, the gully is too shaded to achieve good vegetation cover.

Site 7



Site 7 – Gully dam with damage to the energy dissipater



Gully dam and embankment

Site 7: Site conditions

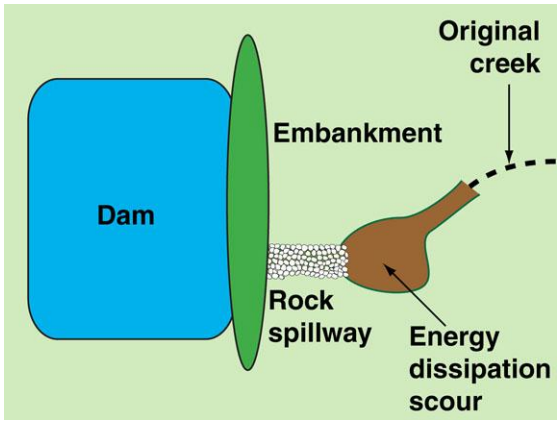
- This is a gully dam (i.e. not located on an active or well-defined watercourse).
- The erosion problem currently exists between the spillway rocks and the earth embankment.
- If the erosion were allowed to continue, it would cause the failure of the embankment.



Existing rock chute / energy dissipater

Existing spillway structure

- This site demonstrates a common design problem where the spillway rocks start at the 'crest', and end at the base of the spillway chute, but do not extent into the energy dissipation zone.
- An appropriate design would have:
  - extend the rock protection upstream of the weir crest (i.e. integrated into the earth embankment); and
  - extend the rock protection downstream into the energy dissipation zone.

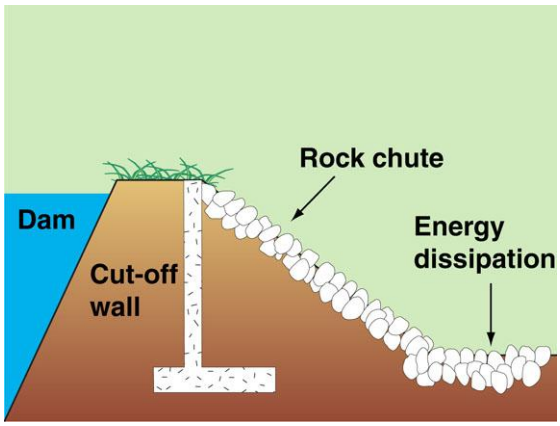


Existing site conditions

Existing site layout

- Possible treatment options are presented over the page.
- Also refer to Chapter 10.
- The typical repair of gully erosion is discussed with the three-part 'Gully Erosion Field Guide' freely-available from the *Catchments and Creeks* website.
- Part 2 of this three-part document provides details of the treatment of the gully head and gully floor.

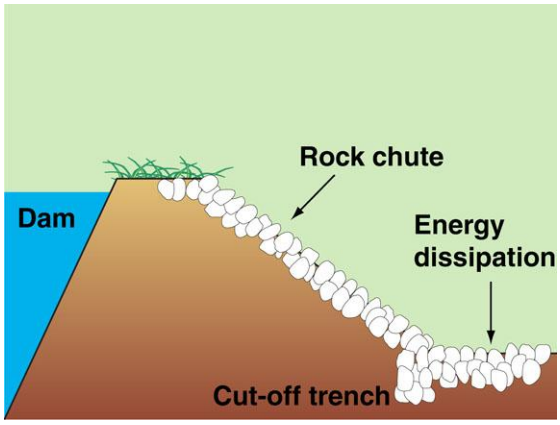
Site 7 – Discussion



Cut-off wall

Treatment option 1 – Cut-off wall

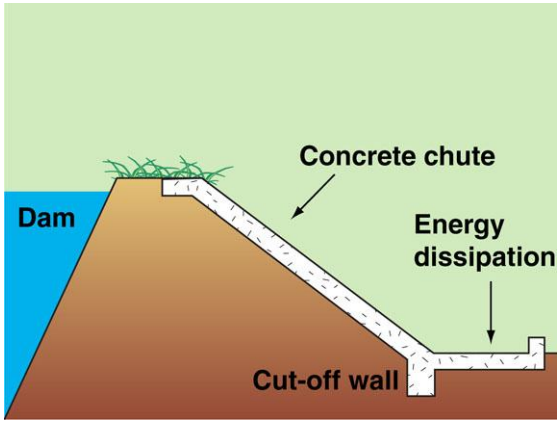
- A cut-off wall is typically constructed when it is essential that the dam and/or embankment are protected from the activities of downstream erosion.
- Typical reasons include: the dam is too expensive to lose, dam failure could result in the loss of life, or dam failure to result in legal action.
- Cut-off walls can be formed from reinforced concrete, cemented concrete blocks, sheet piling, or a gabion wall.



Rock chute

Treatment option 2 – Rock chute

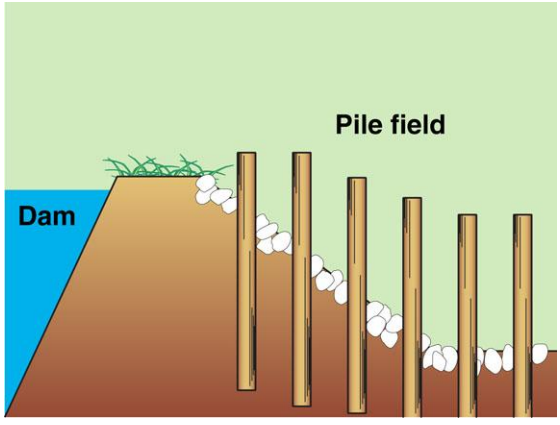
- The most common treatment of damage to a grass bywash is to stabilise the spillway with rock, usually in the form of a rock chute.
- Design details are provided in Chapter 6.
- A rock chute should incorporate:
  - a wide flat-crested trapezoidal crest
  - a straight chute
  - a rock-filled cut-off trench at base
  - an energy dissipater.



Concrete spillway

Treatment option 3 – Concrete spillway

- If an existing rock-lined spillway fails, then a common response is to either stabilised the remaining rock with concrete, or form a reinforced concrete spillway.
- Concrete spillways are either:
  - smooth sloping concrete chutes with large energy dissipation basin, or
  - a stepped chute with smaller energy dissipation basin.

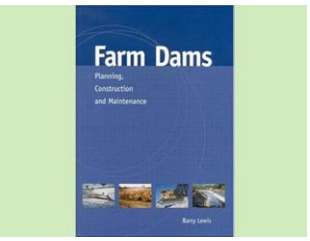


Pile field

Treatment option 4 – Pile field

- Pile fields are not a common treatment for a failed spillway, but in some rural locations, the supply of concrete or large rocks may be very limited, causing land-owners to search for alternative solutions.
- Pile files dissipate flow energy through the generation of turbulence.
- The operation of pile field can also benefit from flood debris becoming lodged in the piles, which can add flow resistance.
- The design requires great care and consideration of how the water will flow.

12. Glossary of terms



The following glossary was largely developed from:

Lewis, Barry. 2002, ***Farm Dams – Planning, Construction and Maintenance***. Landlinks Press, Collingwood Victoria, 3066, Australia. ISBN 0 643 06576 8.

Note: The term 'waterway' includes any overland flow path along which stormwater runoff may travel (being the common usage of this term in rural communities).

Abutment	The natural ground formation between the base of the dam and its crest. The natural material below the excavation surface and in the immediate surroundings formation above the normal river level, or floodplain, against which the ends of the dam are placed.
Ag-pipe	A flexible, perforated, corrugated drainage pipe commonly used in residential and agricultural sub-drainage. Also known as an '*agricultural pipe* or *sub-drainage pipe'*.
ANCOLD	Australian National Committee on Large Dams.
Aquifer	A water-bearing layer of rock, material or sediment below the natural surface within which water is transmitted and can be removed by pumping.
Base of dam	The foundation area of the lowest part of the main body of the dam, the portion excluding the abutments. The base elevation is considered to be at the lowest foundation level of a substantial section of the dam. It excludes isolated pockets of excavation which are not representative of the base extended from heel to toe.
Beaching	Rocks placed on an inclined surface to dissipate the erosive force of waves and/or flow velocity. The term usually refers to dumped rocks, usually on a prepared filter bed.
Bed	The part of a waterway or channel that is usually or normally covered with water when the channel is flowing.
Berm	A horizontal ledge on a dam wall used to help stabilise the slope.
BoM	Bureau of Meteorology.
Catchment yield	The volume of water which flows from a catchment past a given point (such as a stream gauging station) and is generally calculated on an annual basis. It comprises surface runoff and base flow (discharge from groundwater, e.g. 'springs').
Catchment	The drainage area that delivers water to a dam.
CH (soil)	Inorganic clay or high plasticity, fat clay using the Unified Soil Classification system.
CL (soil)	Inorganic clay low–medium plasticity, gravely and sandy clays, silty clays, lean clays using the Unified Soil Classification system.
Clay (soil)	This term can apply to a soil that contains a significant proportion (greater than 35%) of clay-sized particles, or to soil particles that have a diameter less than 0.002 mm.
Cohesion	Degree of bonding between individual soil particles. Loose sands and gravels are non-cohesive, while sticky clays are cohesive.
Contractor	A person or company which is employed to carry out construction works from plans and specifications.

Crest of dam	Used to denote the top of a dam. However, the term ‘crest’ is sometimes applied to the level at which water may overflow the spillway section of the dam. Term ‘top of dam’ is preferred to denote uppermost surface of the dam.
Cut-off wall	An impervious barrier of material or concrete to intercept seepage flows through or beneath the structure. Cut-off wall can also be used to halt the progress of migrating gully erosion.
Dam	A barrier constructed for storage, control and diversion purposes. A dam may be constructed across a natural waterway or on the periphery of a reservoir. When water is stored behind the dam for irrigation or other water supply purposes, the whole complex becomes a ‘reservoir’.
Design flood	The maximum inflow for which the dam is designed.
Design flood level	The maximum expected elevation of the water surface within a storage basin during the maximum expected basin discharge resulting from the maximum design flood event.
Design discharge	The maximum discharge for which the bywash or spillway is designed to safely carry.
Dispersive soil	A soil that is structurally unstable in water, breaking down into its constituent particles (sand, silt and clay) and consequently allowing the dispersive clay fraction to disperse and cloud the water.
Diversion	Any natural or artificial method or means by which part of a waterway is taken from its natural course.
Downchute (Chute)	An inclined open channel through which water flows is directed. Surface may be grass, concrete or beached.
Drawdown (groundwater)	A lowering of the watertable of an unconfined aquifer, or the potentiometric surface of a confined aquifer, caused by pumping of groundwater from wells.
Drawdown (hydraulics)	The generation of a curved water surface as the water flows towards a weir or control structure. This water surface condition can only be generated while the flow is subcritical.
EAT	Means the *Emerson Aggregate Test*—a soil test used to classify the stability of a soil when wet.
Embankment	A raised earth mound built from excavated or imported fill.
Fetch	The free distance which the wind can travel to any point in raising waves, i.e. the distance from furthermost full supply level in the direction of the wind.
Filter cloth	A synthetic material that allows water and some soil particles to pass through it. The size of soil particles held back depends on the material grading. It is typically used as a protective lining for earth structures to separate two soils of different soil textures.
Foundation	The material of the valley floor and abutments on which the dam is constructed.
Freeboard	The vertical distance between the design flood level and the top of the dam.
Freeboard (spillway crest)	The vertical distance between the constructed spillway crest, and the top of the adjacent fill embankment.

Full supply level	The level of the water when the dam is at maximum operating level, excluding times of flood discharge. When a controlled spillway is provided, it is the spillway crest level.
GC (soil)	Clayey gravel, poorly graded gravel-sand-clay mixture.
Geotechnical	Of or pertaining to the practical applications of geological science in civil engineering, mining, etc.
GM (soil)	Silty gravel, poorly graded gravel-sand-silt mixture.
GP (soil)	Poorly graded gravel, gravel-sand, little or no fines.
Gravel–grass	A grassed surface that combines both grass and aggregate rock (i.e. gravel stone of a near-uniform size, between 25 and 75 mm). The surface is more 'trafficable' than normal grass, and more stable than straight gravel.
Groundwater	The segment of water below the natural surface of the ground at a pressure equal to or greater than atmospheric.
GW (soil)	Well-graded gravel, gravel-sand, little or no fines.
Height of dam	The difference in level between the natural bed of the stream or waterway at the downstream toe of the bank and the top of the dam. If it is not across a stream, channel or waterway it is the difference in level between the lowest elevation of the outside limit of the embankment and the top of dam.
Hydraulics	The study of water or other liquid flow in conduits and open channels.
Hydraulic failure of a dam	The hydraulic failure of a dam refers to the dam: (i) exceeding its design maximum allowable water level (ii) exceeding the maximum design discharge over the spillway (iii) the occurrence of water overtopping an earth embankment that was not designed to be overtopped, whether or not any damage did occur to the embankment.
Hydrology	The study of water on the land or under the Earth's surface, its properties, laws, geographical distribution, and so on.
ICOLD	International Commission of Large Dams.
In-situ	A term meaning 'in place'. Rocks, fossils and soil that are situated in the place where they were originally formed or deposited.
Instream	Means located wholly or partially between the banks of a watercourse. In some government legislation it can include dams located within the floodplain of a watercourse, or anywhere below the probable maximum flood.
Large dam	Based on ICOLD World Register of Dams: All dams above 15 metres in height. All dams between 10 m and 15 m, and: – crest length exceeding 500 metres, or – capacity exceeding 1,000,000 cubic metres (1000 ML), or – maximum design discharge exceeds 2000 m^3/s, or – the dam has difficult foundation problems, or – the dam is an unusual design.

Major storm	A storm with a frequency usually less than 1 in 2, to 1 in 10 years. The definition and critical storm frequency may vary from region to region.
MH (soil)	Inorganic silt, micaceous or diatomaceous fine sandy or silty soil, elastic silts using the Unified Soil Classification system.
Minor storm	A storm with a frequency usually greater than 1 in 2, to 1 in 10 years. The definition and critical storm frequency may vary from region to region.
ML (soil)	Inorganic silts and fine sands, rock flour, silt or clayey find sand with slight plasticity using the Unified Soil Classification system.
OH (soil)	Organic clay of medium to high plasticity using the Unified Soil Classification system.
Off-line dam	A dam not located along an overland flow path, or on a watercourse.
Off-stream dam	A dam not located on a watercourse. This could mean the dam is located within the floodplain of a watercourse, but does not protrude into the watercourse.
On-line dam	A dam located along a stormwater runoff overland flow path, but not a watercourse. Caution: in some rural areas, these stormwater flow paths are referred to as ‘waterways', which can cause confusion within government bodies if such a term is used in the description of a dam.
On-stream dam	A dam located on a watercourse.
Optimum moisture content	The soil moisture content (soil–water) that is considered optimum for achieving maximum soil compaction while the soil is being compacted in thin layers less than 150 mm thick (as determined by laboratory testing).
Outlet works (Outlet)	The combination of intake structure, screen, conduits, tunnels and gate-valve meters that permit water to be discharged under controlled conditions from the dam.
Overland flow	Any surface run-off whether flowing as sheet flow or shallow concentrated flow e.g. flow within road reserves, shallow grassed channels and over-bank flows, but not flowing within deep drains, drainage channels or streams.
Permeability	Property of a soil which allows the movement of water through its connecting pore spaces.
Phreatic line	An imaginary line which defines the hydrostatic pressure through homogenous or zoned embankment soils. It is used to indicate the stability of the embankment at full supply and when drawdown occurs, i.e. the storage is suddenly emptied leaving the embankment soils saturated with water.
Piping	Sub-surface tunnel erosion which is caused by soil and water movement.
PMF	Means: probable maximum flood. The PMF defines the extent of land subject to creek or river flooding.
Plastic limit (soil)	The water content at the lower limit of the plastic state of a clay. It is the minimum water content at which a soil can be rolled into a thread without crumbling. In compaction of soils within the embankment this is an important element of construction.

Poorly-graded soil	A soil that consists of particles of near-uniform size, or has significant ‘gaps’ in the distribution of particle sizes. These soils may be difficult to compact to optimum compaction.
Pore pressure	The pressure of air and water in the voids or pores of a soil.
Probable maximum flood (PMF)	The largest flood that could conceivably occur at a particular location, resulting from the probable maximum precipitation (PMP) and, where applicable, snowmelt, coupled with the worst flood-producing catchment conditions that can be realistically expected in the prevailing meteorological conditions.
Pt (soil)	Peat and other highly organic soils using the Unified Soil Classification system.
Referable dam	A dam that, because of its height, volume, or risk to the public, is required to be registered in the relevant State of Territory authority.
Reservoir	A dam or an artificial lake, pond or basin for storage, regulation and control of water, silt, debris or other liquid or liquid-carried material.
SC (soil)	Clayey sand, poorly graded sand-clay mixture using the Unified Soil Classification system.
Seepage	The escape of reservoir water by percolation through, under or around the dam.
Shear strength	The resistance to deformation in soil, either from frictional or structural resistance of the soil grains or by cohesion between the surfaces of the soil particles.
SM (soil)	Silty sand, poorly graded sand-silt mixture using the Unified Soil Classification system.
Small dam	Unless otherwise stated, a small dam shall be assessed as a dam that a reasonably-fit person could walk around in less than one hour. This classification has nothing to do with the classification of ‘referable’ dams.
SP (soil)	Poorly graded sand, gravelly sand, little or no fines using the Unified Soil Classification system.
Spillway	An open channel, weir, conduit, tunnel or other structure designed to allow discharge from the dam when water levels rise above the crest controlling flow down or into the spillway structure. The spillway is principally to discharge flood flows safely past a dam but may be used to release water for other purposes. The spillway may be uncontrolled (a free-overflow spillway) in which case discharge occurs when the dam rises above the crest. If a barrier is used to control the uppermost level of the dam it is referred to as a controlled spillway.
Spillway crest	The uppermost portion of the overflow section which is below the top of the dam.
Structural failure of a dam or spillway	The structural failure of a dam or spillway refers to: (i) the structural failure (erosion) of a bywash or spillway (ii) the erosion, slumping or fracture of an embankment that could result in the uncontrolled release of water from the dam (iii) the unplanned release of water from the dam.

Subcritical flow	Subcritical and supercritical flow are technical terms that refer to specific flow conditions of fluids. Technically, it is a free-surface flow condition which has a Froude number less than one, a depth greater than the critical depth, and a velocity less than the critical velocity.
Subgrade material	Material in cuts, fills and embankments immediately below the foundation material.
Sub-surface flow	Water that flows through the ground, or within a pipe buried in the ground.
Supercritical flow	A free-surface flow condition which has a Froude number greater than one. An important characteristic of water flow is that the faster the flow velocity, the more resistant the water is to a sudden change in direction. This characteristic is a consequence of the supercritical flow conditions.
SW (soil)	Well-graded sand, gravelly sand, little or no fines using the Unified Soil Classification system.
Tailwater	The full supply level of water that inundates upstream land within a storage.
Top of dam	The elevation of the uppermost surface of the dam proper not taking into account any chamber allowed for settlement or kerbs, parapets, guardrails or other structures that are not a part of the main water retaining structure. This elevation is usually the roadway or walkway or the non-overflow section of the dam.
Unified Soil Classification (USC)	A widely used soil classification system that groups soils according to particle size, grading, liquid limit and plasticity index.
Watercourse (engineering usage)	A channel with defined bed and banks, including any gullies and culverts associated with the channel, down which surface water flows on a permanent or semi-permanent basis or at least, under natural conditions, for a substantial time following periods of heavy rainfall within its catchment.
Waterway (rural definition)	A general term for any stream, river, watercourse or creek. This may be flowing but not necessarily continuously, so that it may be a dry bed (depression along which water flows) periodically and also includes man-made artificial cut channels. The legal definition may vary between States and Territories.
Waterway (engineering usage)	A term commonly interchangeable with the term ‘watercourse’. The legal definition may vary from State to State, and region to region.
Well-graded soil	A soil that consists of particles that are distributed over a wide range in size or diameter. Optimum compaction can be achieved.

13. References

ASCE 1992, ***Design and Construction of Urban Stormwater Management Systems***. ASCE Manuals and Reports of Engineering Practice No. 77, and Water Environment Federation Manual of Practice FD-20, American Society of Civil Engineers, New York.

Australian Rainfall and Runoff, 2016, Engineers Australia, ACT.

Burton J.R. 1965, The Water Research Foundation of Australia, Bulletin No. 9 Vol. 1.

Catchments and Creeks 2021, ***Use of Rock in Stormwater Engineering***, Catchments and Creeks Pty. Ltd., Brisbane, Queensland. First released in 2014, with several updates

Catchments and Creeks 2022, ***Gully Erosion Field Guide***, Catchments and Creeks, Bargara, Queensland.

Catchments and Creeks 2022, ***Construction Site Sediment Basins***, Catchments & Creeks Pty Ltd., Bargara, Queensland Version 2, July 2022.

Charman, P.E.V. and Murphy, B.W., 2007. ***Soils – Their Properties and Management***, third edition, NSW Government Department of Natural Resources, Oxford Press, ISBN 9780195517620, and 0 19 551762 8.

IECA (Australasia), 2008, ***Best Practice Erosion and Sediment Control***, International Erosion Control Association (Australasia), NSW.

Lewis, Barry. 2002, ***Farm Dams – Planning, Construction and Maintenance***., Landlinks Press, Collingwood Victoria, 3066, Australia. ISBN 0 643 06576 8.

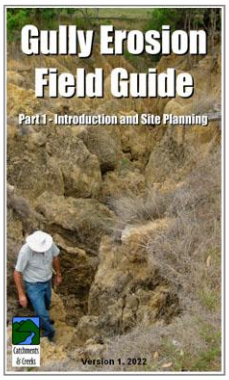
National Water Quality Management Strategy, ***Australian Drinking Water Guidelines 6***, 2011' (Updated June 2025)

Nelson,K.D. 1983, Journal of the Department of Agriculture, Victoria.

Queensland Urban Drainage Manual (QUDM) Institute of Public Works Engineering Australia, Queensland Division and the Department of Energy and Water Supply. Brisbane, Australia, 4th edition, 2017.

Richie, J.A., 1963. ***Earthwork Tunnelling and the Application of Soil Testing Procedure***, Journal of the Soil Conservation Service of NSW 19, 111–29.

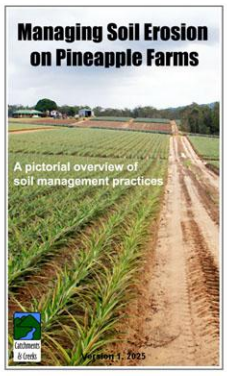
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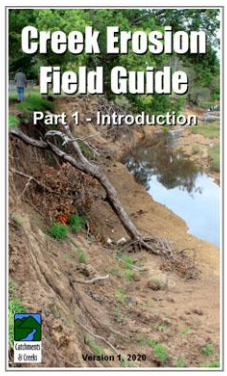
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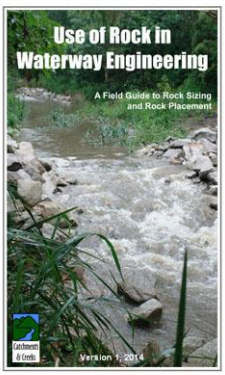
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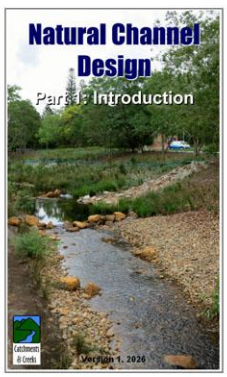
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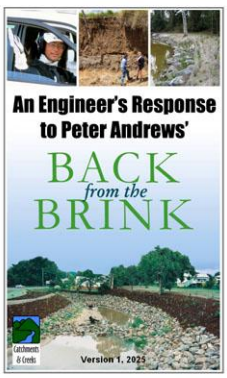
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Engineer's Response to P. Andrews' book