# Your dam: Your responsibility

## A guide to managing the safety of small dams

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Victoria State Government
Environment, Land, Water and Planning

**Department of Environment, Land, Water and Planning**

Cover photo: Cowwarr Weir, courtesy of Southern Rural Water

This booklet is intended only as a guide to owners and operators of small dams. It outlines prudent approaches to normal dam surveillance and maintenance practice with a view to enhancing the long-term safety and operation of small dams. Notwithstanding the detail in some sections, the booklet is not intended as a manual or a source of detailed information to cover all possible eventualities.
The successful planning, design, construction and operation of any particular dam (even for small dams) will depend not only on application of general principles or guidelines, but also on a combination of technical factors that are peculiar to that dam. The significance of these factors in their entirety will generally only be apparent to professionals who are experienced in this work.

In the event of any suspected, imminent or potential failure condition, seek expert advice from a suitably qualified Dams Engineer immediately. Also notify the local Licensing Authority, Police (Ph: 000), the State Department responsible for Water Emergency Co-ordination Centre (Ph: 1300 134 444) and State Emergency Service (Ph: 132 500) as a matter of urgency.

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## Accessibility

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# Preface

'Your Dam, Your Responsibility' was first published in 2002. It was prepared following changes in the Victorian Water Act 1989 to help dam owners understand their responsibilities associated with planning, designing, building, operating and maintaining a dam.

This updated booklet provides some guidance on current practices relating to small dam safety management.

Dam owners are legally responsible for the safety of their dams and accountable for the damage these dams may cause if they fail. Even small dams have the potential to harm people, property and the environment.

The Water Act specifies licensing requirements for the construction and operation of dams, and the take and use of water from them.

This booklet includes:

- guidance on good practice in design, construction and management of small dams
- an outline of the owner's responsibilities for licensing of both new and existing dams.

As the owner of a dam, it is important for you to know that:

- if it fails, you are likely to be liable for any resulting loss of life, injury or damage
- you are likely to incur considerable costs, even if you are able to prove that some or all of the responsibility for a failure lies with others
- the cost of remedial work can easily exceed the original construction cost of the dam.

To minimise the chances of your dam causing these problems:

- employ a Dams Engineer to design and supervise the dam's construction. A Dams Engineer is, as defined by ANCOLD and reproduced in Section 10 hereof: "a professional engineer who is suitably qualified and recognized by the engineering profession as experienced in the engineering of dams and its various sub fields". In general, civil, structural and even geotechnical engineers are not regarded as Dams Engineers
- establish a program of regular inspections and periodic maintenance, and keep appropriate records
- be able to recognise the signs of potential problems and imminent failure
- know what to do and who to contact when such signs appear or if the dam fails.

The first part of the booklet covers these matters in general descriptive terms. The Appendices give more detail on the causes, consequences and remedies for the most common problems experienced by dam owners in Victoria, and outline suggested procedures for routine inspections and surveillance activities.

Detailed information on licensing procedures for small dams can be obtained from your local Licensing Authority, listed in Section 3.4.

# Quick guide for this publication

## Dams "A Risky Business'

There are risks associated with owning a dam. These risks are explained in **Chapter 2** which covers the consequences associated with having a dam and responsibilities of dam owners.

**Chapter 8** is also relevant as it covers dam safety emergency planning and what to do in an emergency with your dam.

## Do I need a licence for my dam?

You may need a licence for your dam depending on its location, height and capacity. The licensing criteria is explained in **Chapter 3** along with what authorities issue licences, the difference between construction and operating licences, and environmental requirements and issues.

**Chapter 4** also has valuable information as it explains dam types, importance of a Dams Engineer being involved, design and investigation elements and planning for construction.

## What if I want to build a dam?

There are many aspects that need to be considered when building a dam. **Chapter 4** explains dam types, importance of a Dams Engineer being involved, design and investigation elements, and planning for construction. **Chapter 5** then outlines the key elements of the dam construction process, and the importance of using a Dams Engineer as well as selecting a suitable construction contractor.

## How do I look after my dam?

Dams are assets that require ongoing management. **Chapter 6** covers general surveillance requirements to maintain the safe and effective operation for existing dams. **Chapter 7** covers operations and maintenance issues for existing dams.

## How do I manage a dam emergency?

An emergency is a situation where there is a dam failure or potential dam failure. To assist in pre-planning to minimise the impact from dam failure, **Chapter 8** covers dam safety emergency planning and what to do in an emergency with your dam.

Refer to **Chapter 8** and **your Dam Safety Emergency Plan** for contact details of authorities to inform during a dam safety emergency where failure of the dam and flooding downstream may occur.

## What can I do if I no longer want the dam on my property?

**Chapter 9** addresses your requirements as a dam owner for decommissioning, removal, and rehabilitation of dams on your land.

# Contents

# 1 Introduction

It makes good business sense to build a dam properly. It is an important investment and an asset supporting the productivity of crops and livestock.

Despite their deceptively simple appearance, there is always the possibility that a dam might partially or totally fail. This could result in loss of life, injury to people or livestock, damage to houses, buildings, railways and roads, or interruption to public utility services (e.g. electricity) as well as environmental damage. If a dam fails, the loss of income resulting from lack of water could have substantial economic consequences.

Dam failures in Australia are seldom reported in the press, and statistics on dam failures are not readily available. This can lead to a false impression that failures of small dams are both rare and of little consequence. However, in 1992, the Australian National Committee on Large Dams (ANCOLD) reported a 23% failure rate for farm dams in NSW (ANCOLD, 1992 p.11).

Victorian legislation highlights the seriousness of the owner's responsibility to make sure that each dam is safe. Having a dam built by someone else or taking over ownership of an existing dam does not clear you of your dam safety and operational responsibilities. To meet that responsibility, you need good safety surveillance and maintenance practices.

Surveillance involves routine and regular inspections of the dam looking for changes that may give an early warning that a problem may be developing.

A property owner who is planning to build a new dam will contribute to its safety by:

- having the dam properly planned and designed
- having it properly constructed to meet design requirements and specifications
- ensuring that professional advice is obtained at each point.

An owner of an existing dam will contribute to the safety of the dam by:

- carrying out safety surveillance procedures
- properly operating and maintaining the dam
- where needed, undertaking safety upgrades.

Sections 2 and 3 of this booklet give more information on the dam owner's legal responsibilities.

Legal requirements that affect dams include the need for:

- a take and use licence for all irrigation and commercial dams, issued by a Licensing Authority
- a construction and operating licence (also known as a works licence) for dams that fall into certain categories, issued by a Licensing Authority
- Local Government Authority Planning Permits required by some local Councils and Shires.

Licensing requirements are explained in more detail in Section 3.

**Appendix A provides some useful hints about how to conduct dam safety inspections.**

**Appendix B provides information on common problems and how to recognise and fix them.**

# 2 Risks posed by dams

## 2.1 Owner's responsibilities

'Failure' of a dam does not necessarily mean the same as its 'collapse'; it may mean failure to meet its design objectives.

Any damage to a dam short of collapse (such as development of cracks, localised slumps or erosion) or any failure to retain water as designed (such as excessive leakage through, under or around the dam) or inability to pass incoming flood waters via the spillway, may be termed a failure of the dam.

If a dam fails, its owner may be held legally liable for all associated damage. To minimise the possibility of failure and the attached liability:

- use a Dams Engineer to design and construct the dam
- make periodic visual inspections of the dam
- monitor conditions that may affect the safety of the dam
- undertake regular maintenance
- carry out repairs where and when required to meet current design and construction standards
- have an experienced Dams Engineer investigate any unusual conditions that could result in partial or total failure.

Incidents involving Victorian dams have ranged from 'near misses' to total failure of the dam. Some incidents have resulted in significant property and environmental damage. Most of the incidents could have been avoided if appropriate planning, design, construction, surveillance and maintenance procedures had been undertaken.

**If you want more information about a dam owner's legal responsibilities, seek advice from your legal practitioner.**

Generally, the Water Act provides that, if there is a flow of water from a person's land onto any other land, and that flow is not reasonable, and the water causes:

- injury to any other person; or
- damage to the property (whether real or personal) of any other person; or
- any other person to suffer economic loss;

then the person who caused the flow is liable to pay damages to that other person for injury, damage or loss.

The Water Act does not extinguish the common law liability of a private dam owner for damage caused by the escape of water from a dam.

## 2.2 Definition of a dam

Under the Water Act, a dam is defined as 'anything in which by means of an excavation, a bank, a barrier or other works water is collected, stored or concentrated'. Water storages constructed fully 'in cut' (below the surrounding natural ground surface) are not covered by this booklet. The contents of this booklet are relevant only to storages that impound water (or other materials) above natural ground surface by means of a man-made construction such as an embankment.

In this booklet, the term dam includes the embankment and all other parts such as spillway, outlet and valves.

A dam may be constructed from earth or other suitable materials. It may be on a hillside, in a gully or on a waterway, or entirely off-stream.

The information in this booklet mainly concerns dams that rely on an embankment or barrier to hold the water, and assumes that the embankment is constructed from earth materials. If your dam is not an earthen dam (e.g. constructed from concrete or other materials) some of the information will not apply. Seek advice from a Dams Engineer.

## 2.3 Potentially hazardous dams

Potentially hazardous dams are those that, due to their size and/or location, could pose a threat to life, property or the environment if they were to fail. The consequences of dam failure are discussed further in Section 2.6.

If you are unsure of the damage your dam could cause if it failed, it is important to have it assessed by a suitably qualified Dams Engineer.

For a dam that is regarded as potentially hazardous, seek the services of a Dams Engineer to:

- design your dam and supervise its construction
- establish a program of regular inspections (surveillance) and periodic maintenance.

In addition, you should:

- be able to recognise signs indicating the development of a problem and how and when this may happen
- know what to do and who to contact when such signs are evident
- be able to demonstrate – and keep records to prove that – you have been diligent in meeting your responsibilities.

The Australian National Committee on Large Dams (ANCOLD) is the national dams engineering body that prepares guidelines on dams. The ANCOLD guidelines, 'Guidelines on the Consequence Categories for Dams 2012', give various consequence categories for dams based on the potential damage or loss of life expected in the event of failure. The consequence categories range from 'Very Low' to 'Extreme'.

ANCOLD guidelines can be obtained from the ANCOLD website https://www.ancold.org.au/ (Note that fees apply to purchase and read ANCOLD guidelines)

A simplified document entitled 'Consequence Screening Tool for Small Dams, May 2014' is available for use by small dam owners that can be downloaded from:

www.water.vic.gov.au

Some dams will require an operating licence (see Section 3) that will contain conditions relating to surveillance and dam safety. However, even if your dam does not require an operating licence, it is in your interests to make sure you keep your dam under surveillance. Compliance with licences to construct, own and operate a dam is a legal requirement.

## 2.4 Likelihood of a dam failing

A dam may fail by water passing under, over, through or around it. To avoid failure, it must be properly connected to the ground and constructed using materials and methods that make it resistant to leakage and erosion.

The most common reasons dams fail in Victoria are:

- Inadequate spillway capacity
- Poor detailing of pipes or other penetrations through or under the embankment
- design is not adequate
- understanding of site conditions is poor
- site preparation is not good enough
- embankment material is not suitable
- embankment placement methods, e.g. soil compaction methods, are substandard
- maintenance or inspection frequencies are inadequate and/or the remedial measures identified in maintenance inspections are not adequately acted upon.

Many failures result in total loss of the dam. Where damage can be repaired, the cost can be very high, possibly more than the original cost to construct the whole dam.

**All dams, even of modest size, should be designed and have their construction supervised by a Dams Engineer. Seek the advice of a Dams Engineer if there are any problems or uncertainties after the dam has been in service.**

## 2.5 Incident or complaint

Where an incident or complaint related to dam safety is brought to the attention of a Licensing Authority, the circumstances will be investigated and, where appropriate, a Direction under Section 80 of the Water Act may be given to the owner to undertake appropriate works.

If the owner fails to comply with the Direction, the Licensing Authority may carry out the necessary works to make the dam safe and recover the costs from the owner, and/or prosecute the owner for not complying with a Direction issued under the powers given in the Water Act.

## 2.6 Consequence of failure

If your dam fails, the sudden release of water and debris could result in loss of life or injury, and damage to downstream properties. Damages could include other dams, houses, buildings, livestock, roads, railways or interruption to public utilities such as electricity and telephone networks. In addition, there could be significant environmental damage. This can take the form of erosion of the waterway or gully, and the loss of flora and fauna downstream, which may take considerable time to recover, if recovery is possible.

Licensing Authorities will determine the consequence category of dam proposals, and a construction licence may contain a condition that the dam is designed by a suitably qualified Dams Engineer according to acceptable and appropriate standards.

The ANCOLD Guidelines on the Consequence Categories of Dams (2012) describes consequence category as categories of dams based on the consequences of potential dambreak failure to human life, property, commerce, infrastructure, the effect on the dam owner's business, political and business credibility, health, social and economic disruption, and environmental impacts.

The consequence categories range from 'Very Low', 'Low', 'Significant', 'High (A, B, C)' to 'Extreme', depending on the impacts failure of the dam would pose to downstream communities and environments. A Dams Engineer can assess the consequence category of an existing or proposed dam.

Dams with Significant or above consequence categories to pose risk to human life (potential for fatalities) and thus have more stringent licensing, design, operation and maintenance requirements.

## 2.7 Insurance

Insurance does not prevent failure; it provides you with the ability to manage financial risk.

Look at a dam like any other asset, such as your house or motor vehicle. However, dams have some important differences. For example, with your house, your main concern is likely to be the consequences of damage to that asset; with a dam, it is limiting the potential for the asset itself to cause damage. In this sense, your dam is not only an asset but also a potential liability.

Look in the direction that outflow from the dam would be expected to take if the dam fails. Is there anything that it could have an impact on?

Remember that your dam's failure could also trigger your neighbour's dam to fail with subsequent damage downstream that you may be liable for.

If this is a possibility, carefully consider the benefits of insurance. Be aware that, like a car, your dam must be kept in a good condition to be accepted for an insurance claim.

**The insurance premium may depend on the insurance company's impression of how well you are able to manage the dam's safety. This may take into account the engineering quality of the dam, your emergency action plans and the consequences of failure. Where negligence of the owner is proved, insurance protection may be in doubt.**

## 2.8 Buying a property with a dam

If you are planning to buy a property that has a dam, check with the local Licensing Authority (refer Section 3.4 for a list of Licensing Authorities) to make certain that the necessary licences and requirements are in order.

Check that the dam is not subject to a Direction under the Water Act to carry out works to make it safe and that it does not carry a charge against the land in respect of works carried out by the Licensing Authority.

# 3 Licensing requirements for dams

## 3.1 Take and use licences

A ‘take and use’/‘surface water’ licence is needed for all dams used for irrigation or commercial purposes, regardless of their location or size. Dams built on your property that are used for domestic and stock purposes do not require a take and use licence. If you intend to take and use water from a dam for any purpose other than domestic and stock use, you must obtain a ‘take and use’/‘surface water’ licence.

You should obtain the water licence before building a new dam, as your licence conditions may need your dam to include particular works to be incorporated into the dam’s construction. Contact your Licensing Authority to discuss water entitlement matters, including availability, trading, and metering of water for your circumstances.

## 3.2 Construction licences

If you are thinking about building a new dam you should contact your local licensing authority and your local council for advice, as you may need a construction licence and/or a council planning permit. All dams constructed on a waterway (“on-stream”) require a construction licence. If you wish to build a dam off a waterway, you will also need a construction licence if the dam is:

- 5 metres or higher and 50 megalitres capacity or larger; or
- 10 metres or higher and 20 megalitres capacity or larger; or
- 15 metres or higher, regardless of capacity; or
- The dam belongs to a prescribed class of dams.

Construction licences also usually require flow bypass arrangements that allow water to pass through or around the dam outside of any authorised filling period. See your local Licensing Authority listed in Section 3.4 for more details and for conditions associated with construction licences.

## 3.3 Operating licences

If you have a take and use licence, in most cases there will also be conditions concerning the operation of the dam. A common condition will be to operate the dam to allow flows to pass downstream of the dam during certain times of the year.

Depending on the size of your dam and its potential consequences of failure – whether or not you have a take and use licence – you may be required to have an operating licence, which may include conditions relating to surveillance and management of the dam’s safety.

Whether or not a dam needs a licence under the Water Act, local council permits may still be required. An operating licence can be valid up to 15 years but is typically issued on an annual basis.

## 3.4 Licensing Authorities

Licensing Authorities regulate the construction of dams and the use of water. In particular they:

- issue take and use licences
- issue construction licences for new dams
- issue operating licences for existing dams
- determine licence conditions relating to safety of existing dams
- investigate complaints about safety threats or dams with known deficiencies and take necessary action
- ensure licence conditions are complied with
- take action where people illegally take water or illegally construct dams.

**The height of the dam or embankment is the difference in level between the embankment crest and the downstream toe of the dam at the point of maximum height. If the dam is on a gully, stream or river, the height is measured from the bed of the waterway.**

The Licensing Authorities are:

- Goulburn-Murray Water
  40 Casey Street, Tatura 3616
  Phone 1800 013 357.
- Southern Rural Water
  88 Johnson St, Maffra 3860;
  1 Tower Rd Werribee 3030;
  132 Fairy St Warrnambool 3280
  Phone 1300 139 510.
- Lower Murray Urban and Rural Water
  741-759 Fourteenth Street, Mildura 3502
  Phone (03) 5051 3400.
- Grampians Wimmera Mallee Water
  11 McLachlan Street Horsham 3402
  Phone 1300 659 961.
- Melbourne Water
  990 La Trobe Street, Docklands, 3008
  Phone 131 722

## 3.5 Licensing process

There are different processes for new and existing dams as described below. A new dam needs to go through a licensing process for the owner to get the relevant approvals.

Once you have determined the licensing requirements for your dam, you need to apply to the Licensing Authority in your area (refer to the Authority list in Section 3.4).

Applications must include any information that Licensing Authorities consider necessary to make a determination. The information is listed on the application form that can be obtained from your local Licensing Authority.

The Licensing Authority may inspect the site to assess water availability, environmental, safety and other site-specific issues.

Depending on the location, size and the hazard posed, the construction and operating licences may specify conditions relating to safety. This may require you to seek the services of a Dams Engineer.

When considering your application to take and use water and to construct the dam, the Licensing Authority must take into account:

- the availability of water at the site and in the catchment
- the impact that taking water and the construction of the dam might have on other users and the environment
- the conservation policy of the government, existing acts, plans, strategies or policies at a catchment, regional or state level.

For new dams, the Licensing Authority will refer your application to the Department, local government and Catchment Management Authorities (CMAs) for comment before it is approved.

The operating licence will have conditions relating to dam safety, particularly relating to the dam's operation and maintenance. These may require you to seek the services of a Dams Engineer.

If the proposed dam is to be constructed on a waterway that is determined to be of high ecological value, you will need to comply with environment requirements for proposed dams as described in Section 3.6.

If the application is refused by a Licensing Authority, the applicant may:

- appeal on the decision to the Victorian Civil and Administrative Tribunal; or
- resubmit an amended application that complies with the Authority's guidelines.

## 3.6 Environmental requirements for new dams (on or off-stream)

To minimise environmental impacts of new dams, a construction licence, if approved, may have conditions that will need to be satisfied, such as avoiding/minimising impacts to native vegetation, fauna, habitats, cultural heritage, water quality, sustainable flows, and other environmental considerations.

A Licensing Authority will only approve an application for the construction of a dam on a waterway with high ecological values if it is satisfied that:

- there is documented evidence that consideration has been given to all available alternatives to constructing a dam at this location
- no reasonable alternatives exist
- environmental requirements are planned for.

For dams on a waterway with high ecological values, the Licensing Authority and/or relevant environmental regulator may require an Environmental Assessment Report, prepared by a suitably qualified environmental consultant(s).

Guidelines for these reports are available from Licensing Authorities.

Environmental requirements in the licence may include, amongst other requirements:

- the design and construction of a fishway approved by the Licensing Authority or relevant environmental regulator.
- meeting environmental flows approved by the Licensing Authority or relevant environmental regulator.
- design and construction of works approved by the Licensing Authority or relevant environmental regulator to:
  - bypass inflows around the dam from November to June inclusive, unless otherwise specified
  - maintenance of an environmental passing flow and meeting specified diversion limits for the waterway downstream of the dam at all times during the year.

**The potential high costs associated with alternative supplies of water would not be considered a sufficient reason alone to construct a dam on a waterway with high ecological values.**

## 3.7 On-site environmental issues for dams on waterways

Below is a number of environmental impacts for consideration for existing and potential future dams, both for construction and during the operation of your dam. This is not an exhaustive list, and further assessment by a suitably qualified environmental professional may be required for your dam and its specific circumstances.

### *Flora and fauna*

Waterways usually provide habitat and water to support a wide range of native plants and animals. When a dam is built in such areas, these habitats can be lost through inundation and the physical barrier the dam poses. There are also changes to water flow patterns.

Existing native instream and riparian (streamside) vegetation can be lost through permanent inundation or removal as a result of dam construction. The dam site may be a creek, marsh, soak or drainage-line that may not flow for many months of the year. These habitats often support fish, invertebrates, frogs and birds that are adapted to these particular conditions. Dams change flowing water to standing water, which will make the local habitat unsuitable for most flora or fauna found at the original site. The major changes can include reduced flows downstream, a reduction in water quality and an increase in water temperature. The combination of these factors can lead to local extinctions of such flora and fauna.

Dams constructed on waterways can act as a physical barrier to migratory and localised movements of aquatic biota, particularly fish. Many species of native fish in Victoria need to migrate in order to spawn and re-colonise. Many species will also move upstream into intermittent streams when there is sufficient flow to access spawning habitat and food.

If fish passage is blocked by dams on waterways, they may eventually become extinct in sections upstream of the barrier.

The impact of a dam as a barrier will obviously depend on the type of waterway it is built on. A dam that blocks the passage of a permanently flowing stream will be of greater concern than a dam on a depression in the middle of a paddock, as there are greater intrinsic values associated with permanently flowing streams.

The introduction of barriers to migration is listed as a Potentially Threatening Process (PTP) under the Flora and Fauna Guarantee (FFG) Act 1988 and must be managed to prevent impacts on flora or fauna.

The State Environmental Protection Policy (SEPP) "Waters of Victoria" Clause 43 states that new and existing structures in/adjacent to waterways must not pose a barrier to native fish movement, and thus new structures on waterways must not block fish migration or must adequately address the passing of aquatic species as part of the design.

### *Sediment transport*

Dams on waterways will capture almost all the sediment carried by water flow. Silt, sand, gravel, and organic matter are trapped behind the dam instead of being carried down the waterway. This starves the waterway of the material needed to replenish gravel bars, rebuild the streambed, and renew floodplain and estuary soils.

The maintenance of dams may require the periodic operation of the outlet works to improve water quality in the dam. Excess sediment input and deposited silt can be lethal to fish, fish eggs and invertebrates, and will smother critical habitat such as spawning sites, nursery grounds and food sources. For invertebrates, sediment input will have a direct impact on the areas of the streambed where they live. Many invertebrates live among the rocks on streambeds and sediment deposition fills spaces between rocks, leaving them with no available habitat. Sediment input to streams is also listed as a PTP under the FFG Act.

Prior to any flushing, the dam owner should notify the relevant CMA and seek advice with regard to waterway health issues.

Building or owning a dam carries responsibilities for the owner, regardless of any responsibilities that may apply to the designer or constructor (if these are different people from the owner). When considering the construction of a new dam, make sure you get the best advice on its design and construction to minimise the chance of dam failure.

# 4 Planning to build a dam

## 4.1 Dam features

Small dams are usually built using suitable materials found locally in the gully or hillside where the dam is to be located. If local materials are not suitable, they may have to be brought in from other areas or properly processed.

An embankment constructed across a valley or on a hillside is usually trapezoidal in section. The sloping water face is called the upstream slope (face) and the downstream side is called the downstream slope.

The main features of a dam (shown in Figure 4.1) are the:

- embankment
- spillway
- outlet works
- environmental (or compensation) flow bypass where required.

It is a requirement of OH&S legislation to ensure that dams and other facilities are safe for people working at or visiting the site. Unsafe conditions may mean liabilities for the owner, designer or operator. See Section 4.7.

**The international and national convention for 'left' and 'right' sides of a dam is determined when looking downstream from the crest of the dam. This is the same as looking in the direction water would naturally flow in the stream or gully.**

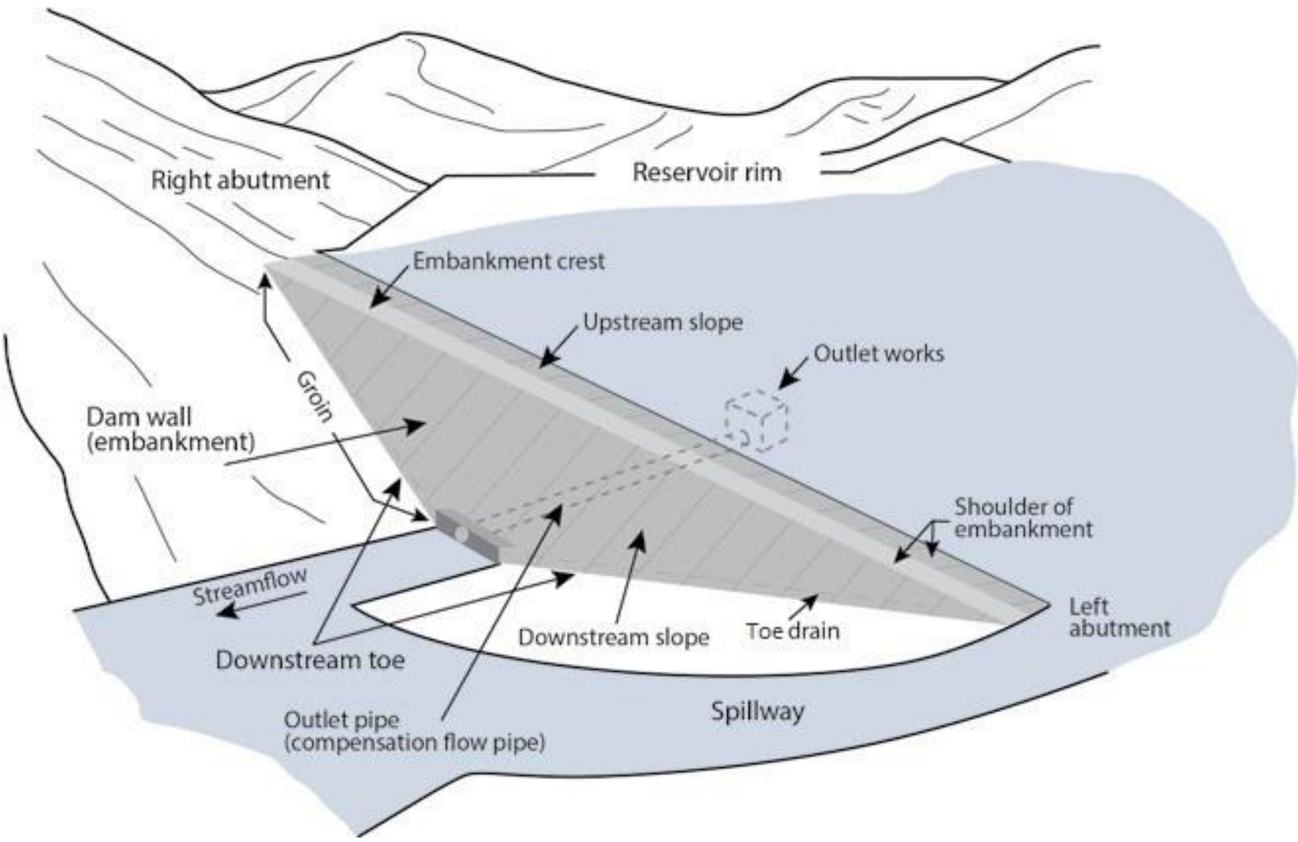



**Figure 4.1 – Dam Features. The spillway may be at the left or right abutment, or both, as appropriate. Freeboard is the difference in level between dam crest and spillway crest (overflow level).**

## 4.2 Services of an engineer

Because of the size and nature of many dams, and because their construction looks deceptively simple and uses familiar technology, it is tempting to think that the services of a Dams Engineer are not required.

A significant proportion of dams fail and a high percentage fail during their first filling, especially in Victoria. This generally means the dam's design, construction or filling rate was not understood.

One of the key reasons for such a failure is the properties of dispersive clay soils. Rapid wetting of the compacted embankment can cause the micro- particles of clay to disintegrate. Detailed assessment of this problem is usually outside the expertise of dam owners or general practice engineers.

Using an experienced Dams Engineer helps to ensure that the structure will be properly designed and built to current industry standards. The cost of engineering services is a minor percentage of the total cost of the work. More importantly, that cost is very small when compared to the cost of reconstructing the dam if it fails and the additional cost of compensation for the damage caused by the failure.

### 4.2.1 Input of Dams Engineers

It is good practice to have dams of any size (whether or not a licence is required) designed by a Dams Engineer.

For some dams and land conditions, the Licensing Authority may require the professional engineering input of a Dams Engineer to design specific works, supervise construction and provide certified plans on completion. Potentially hazardous dams, those with a consequence category of Significant or higher, on-stream dams, and/or dams requiring a construction licence due to their size or uses (see Section 3.2) will require design and certification by a Dams Engineer.

Only a relatively small proportion of professional engineers (even among civil and geotechnical engineers) qualify as Dams Engineers. Dams engineering is a specialised field of civil/geotechnical engineering and requires skills and experience typically not possessed by a general Civil Engineer.

A Dams Engineer can communicate and coordinate all aspects of application, documentation, design and supervision of construction works.

## 4.3 Types of Storages

There are essentially two types of storages, namely on-stream and off-stream.

On-stream storages are located on a waterway, creek or gully where water is directed naturally into the storage as a result of concentration by the upstream topography. The surface area of the full storage is typically a fraction of the catchment area. Off-stream storages are constructed on gently sloping ground with no defined drainage course. The natural catchment area is normally little more than the surface area of the full storage.

The storage is filled either by directing upslope surface runoff by means of diversion contour drains or by pumping from a waterway, spring or borehole.

### 4.3.1 On-stream storages

On-stream storages (Figure 4.2) are usually the most economical form of storage with respect to providing storage volume (high storage volume / embankment volume) ratio.

The disadvantages however include:

- The need for a spillway to accommodate extreme floods without the embankment being overtopped.
  Even for a Very Low consequence category dam ANCOLD suggest a capacity to accommodate a flood in excess of the 1 in 100 year flood. For a Significant consequence category dam ANCOLD suggest a capacity to accommodate a flood in excess of the 1 in 10,000 year flood.
- The possible need to deal with floods during construction
- Potentially poor foundation conditions
- Can be difficult to establish foundation depths in advance of construction due to limited access.

### 4.3.2 Off–stream storages

Off-stream storages (Figure 4.3) usually have a low storage volume / embankment volume ratio.

The advantages however over on-stream storages include:

- Significant lower spillway capacity requirements
- Usually good access to establish foundation conditions in advance
- Construction flood risk minimal

Off-stream storages include what are sometimes referred to as hillside dams, ring tanks and turkey's nest dams.

Hillside dams have a limited natural catchment while ring tanks and turkey's nest dams have no catchment as the dam embankment crest forms the catchment boundary on all sides.

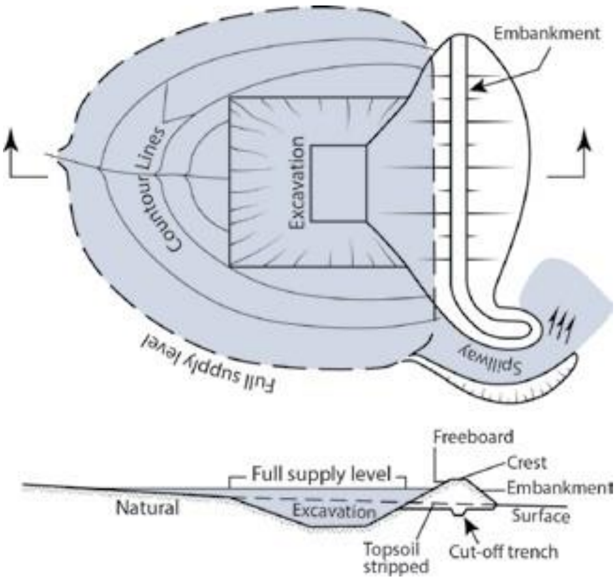



**Figure 4.2 – On-stream storage.**

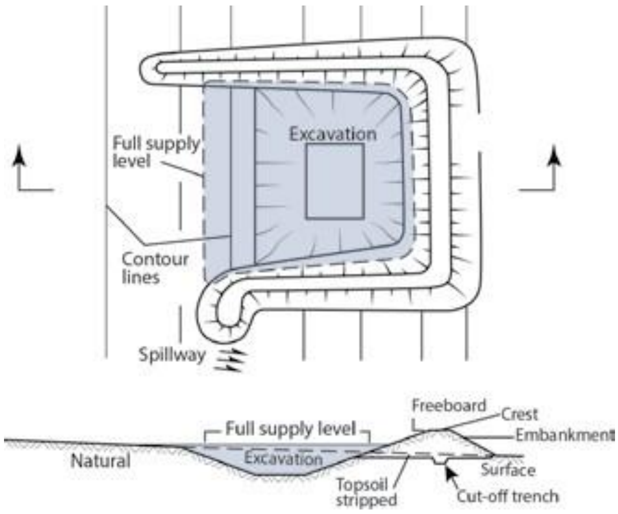



**Figure 4.3 – Off-stream storage (hillside dam).**

**Both ring tanks and turkey's nest dams are frequently considered not to require a spillway because they are filled by pumping and not by incoming streamflow or overland runoff. However, each situation needs to be looked at: if there is any risk that 'over-pumping' may occur (e.g. due to failure of the cut-out switch at the pump) water may overflow the embankment and cause failure. A spillway, or some other means of securing against this risk, may be required.**

**Similarly, the design needs to provide security against overland runoff eroding the outside toe of the embankment, thereby risking failure.**

***Excavated tanks and dragline holes***

As the name implies, these are below ground level storages. The surplus material from the excavation is not used to contain water and so the construction and safety of this type of dam does not normally come under the jurisdiction of the Water Act, or this booklet.

If the purpose of the excavation is to intersect groundwater, the excavation may be considered to be a bore and a construction licence may be required.

A take and use licence is required for irrigation or commercial use of the water, irrespective of whether it is surface water or groundwater.

## 4.4 Site investigations

### 4.4.1 Selecting the dam site

Identifying the best site involves a range of factors including:

- suitable valley or hillside that will catch enough water
- a location that will maximise the available catchment area and minimise the cost of the dam
- suitability of the foundations and materials available at the site
- location of the dam relative to where the water is to be used.
- The dam failure consequence category.

Each of these points will require some degree of compromise to get the most cost-effective result.

Planning matters and impacts on surrounding properties may also need to be considered where council approval for construction is required.

From an economic viewpoint, locate your dam where the required storage volume can be captured with the least earthwork. This is generally possible if the valley is narrow with a steep side-slope and the slope of the valley floor will permit a deep basin. These sites also tend to minimise evaporation losses from the dam. In terms of efficient storage of water, deeper reservoirs with smaller surface areas will have smaller evaporation losses.

Avoid locating the dam where run-off from houses, piggeries, dairies or septic systems can pollute the water.

**When choosing the location take into account the required storage volume and embankment height required and the resulting consequence category (ANCOLD-determined categories of the impacts on human life, property and the environment if the dam failed). Where possible, select a location with the lowest consequence category**

### 4.4.2 Site studies

A wide range of issues needs to be considered. To overlook one or more of them may prove crucial to the dam's operation and safety.

- The catchment is the area of land from which run-off is to be collected. If it is the main source of water supply, make sure that it is capable of yielding enough water to maintain both the supply in the dam and the required releases.
- If the catchment area is too large, it will require a big and expensive overflow system (or spillway) to safely pass excess run-off from heavy rainfall without overtopping the dam.
- A site survey will provide the levels and distances to allow proper calculation of the dam size and material quantities needed for the construction and ultimately the cost of the dam.
- Site tests, including laboratory testing of soils, establish the material properties for the embankment and include:
  - a good understanding of local geology – whether the ground in the vicinity of the reservoir is suitable for the storage of large volumes of water
  - knowledge of the properties of the foundation material beneath the dam – whether it will support the load without excessive deformation, and control seepage within acceptable levels
  - understanding of the materials from which the dam will be built – whether they have adequate strength, durability and impermeability, and where they may most economically be obtained.

**The dam must be matched to its site and it is highly desirable that the same engineer assesses the site and available materials, does the design and specification and also supervises the construction. Constructors (who are sometimes also the owner) may otherwise fail to appreciate the significance of apparently small details in the engineer's specification that will ensure the final structure achieves its intended performance.**

### 4.4.3 Soil testing and problem soils

Soil testing and laboratory tests of samples for the foundation and of the planned borrow materials for the embankment, are important to allow the Dams Engineer to determine their suitability and assess any potential problems with the soils. These may require design solutions to treat or handle the soil properties, specification clauses for compaction and moisture control during construction (see Section 5.4), or may indicate that the soil is not suitable for dam construction. A number of soil properties can only be determined by laboratory testing, in particular the optimum moisture content for compaction. Permeability, soil plasticity and shrink/swell behaviour (which can lead to cracking) are also commonly assessed by laboratory testing.

Small dams tend to be built from a range of soil types from sand to clays. Each general soil type has its own characteristics and problems, which must be considered when designing the dam.

Soils most susceptible to problems are:

- Dispersive clays, which will disintegrate spontaneously in the presence of water. They are very common throughout Victoria and their presence can be suspected if water in local dams and streams normally has a muddy appearance. They may be free of problems during construction of an embankment, but highly problematical when the dam is filled or filling.
- High plasticity clays, which swell and shrink, causing cracking problems. Water can escape through the cracks and erode the embankment. These soils are also difficult to compact without leaving voids internally.

**If the soil type is suspect, get professional advice on soil treatment as the construction procedures on their own cannot make up for poor soil types.**

- Material that does not have sufficient clay to provide strength and impermeability.

Using any of these materials can result in leakage that may lead to piping or tunnel erosion (i.e. the removal of soil unseen within the dam embankment while surface soils remain intact). If such erosion is unchecked, it will lead to rapid failure. It usually becomes apparent as surface leakage only when the internal erosion is already well advanced.

To hold water, the storage basin must also have low permeability and where this is not so, expensive clay lining may be required. It is not unknown that excavation to obtain suitable materials for the embankment has stripped away all protective impermeable material in the storage basin, leaving a clear path for leakage under or around the embankment, or in some other direction.

In some locations, a lack of low permeability soils may dictate the use of a geosynthetic liner such as HDPE. Such liners should only be installed by specialist contractors.

## 4.5 Considerations at investigation stage

### 4.5.1 Environmental

When a Licensing Authority receives an application for any licence for a new dam under the Water Act, whether or not on a waterway, it will refer a copy of the application to (:

- The Department for reasons including:
  - Indigenous cultural values
  - matters of national significance
  - native vegetation (outside the riverine and riparian zone)
  - flora, fauna and river ecology within the affected area.
- The Catchment Management Authority whose region includes the site of the proposed dam, for waterway management consideration.
- The local government municipality covering the site of the proposed dam, for planning requirement and potential impacts on:
  - adjoining properties,
  - visual amenity/impacts
  - native vegetation (outside the riverine and riparian zone)
  - roads and other infrastructure.

Further information is provided in Section 3.6 and Section 3.7.

### 4.5.2 Compensation flow requirements

As a condition of the licence to construct and operate works on a waterway, there will be a requirement for the storage dam to provide a

bypass channel around the dam or an outlet by means of a pipe through the structure.

This will allow predetermined water flows to be passed down the waterway. Your dam will only be permitted to harvest a certain amount of water, depending on the flow patterns of the waterway.

The bypass channel or outlet works (outlet pipe and valve) need to be sized to suit the compensation flow requirements. This outlet pipe has additional benefits in that it is a means for releasing water from the storage in the event of a problem with the dam wall. Sizing of the outlet pipe to meet emergency drawdown/emptying requirements should be considered by your Dams Engineer during the design, and also discussed with the Licensing Authority.

When the dam is full, a spillway is used to pass excess flows.

Your Licensing Authority can provide further guidance on environmental flow requirements.

### 4.5.3 Bypass channels

Authorities responsible for management of on-stream storages may require dam owners to provide a means to limit harvesting of water during seasonal dry periods – usually November to June inclusive, (and/or to provide minimum environmental passing flows year-round). This time period may be altered to suit environmental issues, such as fish passage considerations.

This requirement is to provide security to downstream users and the environment. During this period, either all inflows exceeding a predetermined amount will be required to be released or bypass the dam, or minimum flow rates will be required to be maintained downstream of the dam.

This provision may be a condition of the dam owner's licence. This may mean that, if the outlet pipe arrangement is not appropriate to satisfy the release of water outside the winter-fill period or in the absence of an outlet pipe, the Licensing Authority can require other means to achieve this outcome.

For example, you may need to construct a bypass channel around the water storage so that the water will not enter the dam.

Your Licensing Authority can provide further guidance on environmental flow and bypass requirements.

## 4.6 Dam design for extreme events

Large earthquakes, large storms/flood activity and failure of upstream dams can be considered extreme events. The risk of failure from these events is minimised by using dams engineering design standards and ANCOLD Guidelines incorporating adequate margins of safety. Suitably experienced Dams Engineers will understand the dams engineering design standards required for your particular site and needs.

Emergency preparedness set up well in advance is the only available measure of reducing the impact when a dam failure is about to happen. This is dealt with briefly in Section 8.2.

**ANCOLD is the Australian National Committee on Large Dams. Information about ANCOLD Guidelines is available at the website: www. ancold.org.au. (Note fees may apply to purchase ANCOLD guidelines)**

## 4.7 Health and safety issues

In addition to the responsibilities covered by the Water Act, and regardless of any dam failure, a dam owner may have liabilities to other people in common law and/or under the Occupational Health and Safety Act 2004.

It is a requirement of OH&S legislation to ensure that dams and other facilities are safe for people working at or visiting the site. Unsafe conditions may mean liabilities for the owner, designer or operator.

All dams present a level of risk to persons, especially children wandering around the site (whether entry to the site is authorised or not). Clearly identify and address any features that may present an unacceptable risk. For example, the dam may have a narrow crest that is capable of being driven over, it may have steep upstream or downstream slopes, or may have a steep drop into part of the spillway.

To ensure that your dam is safe for people working or visiting the site and that it complies with OH&S legislation, appropriate safety equipment may be required at the site, such as fencing, barriers, signage, etc. New dams are required to be designed with OH&S considerations in mind to provide a safe working environment.

Leave repairs of dams that are releasing or leaking water to experts. Where an embankment has unusual leakage or has partially failed, exercise caution and seek expert help. It is quite common for well-meaning but ill-informed attempts to repair a leaking dam to actually initiate a dam failure.

Water in a dam can become contaminated or polluted if not replenished or flushed. There is a chance that it can become a danger to those who drink it or to downstream users, even if the initial water quality was satisfactory.

Sometimes flushing is done during periods of high inflows, but this is only possible if the nature and level of the contamination has been determined to be safe.

Maintaining a regular flow release from an outlet pipe can prevent the bottom water becoming anaerobic, which is often identified by the 'rotten egg smell' of hydrogen sulphide (H2S).

# 5 Construction of a dam

## 5.1 Selecting a contractor

Using inexperienced contractors and/or inadequate supervision can develop into an expensive liability. Nothing can take the place of a reputable contractor, using appropriate equipment and experienced machine operators, supervised by a Dams Engineer.

Check the standard of the contractor’s previous work and ask if they have done work under the supervision of a Dams Engineer. Check any references. Neighbours can be a good reference to previous workmanship.

For larger dams or those with particular difficulties, working from plans and specifications prepared by a Dams Engineer ensures a better chance of ending up with a trouble-free dam.

## 5.2 Construction supervision

Construction supervision is an important phase of dam construction. Even the best contractor might be tempted to take an occasional short-cut in the absence of good supervision.

Supervision is meant to ensure that the final product meets the design and specification requirements.

The skills of the designer and the constructor are quite different; there are many subtle but important design issues, even with small dams that can easily be undermined in the construction process. They may not be apparent to the untrained observer, yet have potential to cause costly failure.

If foundation preparation, material selection, outlet/ spillway installation and embankment compaction are not properly carried out, the safety of the dam will be compromised.

It is unwise to construct a dam without an appropriate specification and plan in the contract. The specifications and plans form a coherent set of instructions for the constructor to follow. If things go wrong, either during construction or afterwards, there will be a record of the required standard of construction. This makes it easier for the owner to identify the responsible party at fault in the event of a legal argument.

The Licensing Authority will require a Dams Engineer to certify that a dam of a classification given in Section 3.2, or a consequence category of Significant or higher, has been built in accordance with the submitted plans and specifications.

## 5.3 Dam foundations

All topsoil (the upper layer containing any organic matter such as grass or roots) and vegetation must be stripped from the area where the embankment is to be placed and put to one side. Do not mix this material into, or leave it under, the clayey material to be used for the bank. The organic matter in the topsoil will decay, causing leakage paths to develop later, and may lead to difficulty in obtaining adequate impermeability in the embankment in the short term.

Excavate a core (cut-off) trench along the centreline of the bank to provide good protection against under-bank leakage. The cut-off trench should extend the full length of the bank, including up the abutments. It must be wide enough to allow the construction equipment to achieve the required standard of compaction. Its depth will depend on site soil conditions.

In most cases, it is not difficult to find suitable foundation materials relatively close to the surface, if unsuitable upper soils (including topsoil) are removed. The founding material must be sufficiently stiff and impermeable, and must extend to sufficient depth to allow the storage behind the dam to be retained without significant leakage, but also to avoid any appreciable settlement of the constructed embankment.

In some locations, upper soils below the topsoil are soft, weak or contain gravel or other inclusions (such as calcareous materials) that can form a leakage path. This is one of the reasons for recommending the inclusion of a cut-off trench below the embankment, no matter how low, so that the content of the layers below the embankment can be checked before construction of the embankment begins.

## 5.4 Embankment materials and construction

### 5.4.1 Selection of materials

Most dams (whether on or off-stream) are constructed of earth materials. If your dam is constructed from other materials, much of the following sections will not apply to you. Expert advice will be required in any case.

While construction of dams has to be practical, and is limited by available materials within economical distance, selection of appropriate materials is vital for dam safety and performance. This applies not only to the materials used in the embankment, but also to the materials on which it is founded, as noted above.

The embankment must be capable of securely retaining water. This is generally done by (a) ensuring that the materials for the embankment contain sufficient clay, and (b) ensuring that the materials are adequately compacted.

Designs prepared by Dams Engineers will ensure that these key dam design elements are considered for construction. Soil testing and laboratory testing (see Section 4.4) will inform the design of the dam, selection of materials, and specification of the compaction and other requirements for construction.

Where materials with sufficient clay content are scarce, the outer portions of the embankment can be constructed from less clayey material (as long as it has sufficient strength) while a central core is built with high clay content. Construction of this kind (called 'zoned construction') requires attention to detail from a Dams Engineer and is generally confined to dams more than a few metres high. This is not only for economy, but also for practical reasons that limit the access of compaction equipment for lower dams.

The use of dispersive clays (see Section 7.5.1) for the construction of a dam is generally best avoided, but where used the construction must be performed to a very high standard, in line with the specification designed by a Dams Engineer.

Never attempt a core of non-earth material (such as concrete) without engineering design and supervision.

### 5.4.2 Placement of embankment materials

Place embankment material in horizontal layers of uniform thickness. Good compaction requires that each new layer is bonded onto the previous layer. To achieve the best results, the material must be placed with sufficient moisture to make it pliable just before becoming crumbly and not so wet that it stains the hands or flows under compaction.

Dams designed by Dams Engineers will have a specification prepared outlining the requirements for layer thickness, bonding, compaction effort, and moisture control needed for the embankment materials during construction. Laboratory testing (see Section 4.4) during construction will ensure that the construction meets the engineering specification requirements. The input of a Dams Engineer is highly recommended during planning, design, construction and commissioning of your dam.

The Optimum Moisture Content for compaction is normally determined by laboratory testing. For certain soils, especially for dispersive clayey soils, it is critically important that the placement not be below the Standard Optimum Moisture Content as determined by laboratory tests. Such soils occur in many parts of Victoria.

### 5.4.3 Compaction of embankment materials

The materials in the embankment must not only contain sufficient clay, but also be adequately compacted, with each compacted layer bonded to the one underneath.

The material should be neither too wet nor too dry (the acceptable margins are quite small). It is generally easier to compact and handle material that is a little below its Standard Optimum Moisture Content. This is commonly done with embankments for other purposes, such as roads, but there is a marked increase in the leakage potential of the finished product, so it is not appropriate for dams.

Compaction and moisture control requirements as designed by a Dams Engineer for your dam should be followed to ensure the dam is properly constructed following sound engineering principles. Poor compaction, layer bonding and moisture control can lead to significant problems developing in the dam embankment, including excessive settlement, cracking, seepage, and other defects, which may result in failure of the dam.

**It is tempting, and very common, to use tracked plant for small dams because it is available and is much less costly. Tracks keep the contact pressure low (e.g. to cross soft ground), but good compaction requires a combination of much higher contact pressures and ability to penetrate layers and knead them to ensure good bonding and eliminate leakage paths. Bulldozers, scrapers and tractors may be large machines but they are not designed for soil compaction. In fact, they are designed to create as minimal pressure as possible.**

Good compaction is achieved by using appropriate compaction rollers on soil at just the right moisture content. Even one layer of inadequately compacted material in a bank can result in seepage, leading to failure. Earthfill dams should only be compacted using large, heavy compaction equipment such as “padfoot” and “sheepsfoot” compactors, usually with vibration; landfill compactors with four padfoot roller wheels are also suitable. These have largely supplanted the older static (towed) “sheepsfoot” rollers. A Dams Engineer can advise on the type of equipment best suited to the construction job.

## 5.5 Seepage protection for outlet pipes or structures in embankment

Outlet pipes under the dam wall are used for the controlled release of water from the dam. If not properly installed, they can readily provide a path for leakage, resulting in failure of the embankment and uncontrolled release of water.

Proper installation requires the backfilling and compaction to be carried out with extreme care. In the past cut-off ‘collars’ at intervals along pipes passing under a bank were used to reduce the possibility of leakage. However, it was found that the complications of construction associated with such cut-off collars result in their use actually increasing the possibility of leakage. Since 2000, the accepted good practice is not to provide cut-off collars but now is to provide filter protection to outlet pipes and penetrations through/ under/ around dams.

**Protection for adverse seepage for outlet pipes and other penetrations through embankments is best achieved using a filter collar, also known as a filter patch or filter diaphragm. It is no longer considered best practice to use “cut-off collars” or similar arrangements. Your Dams Engineer is best placed to design appropriate seepage control measures and filter arrangements.**

## 5.6 Outlet pipe control & valve placement

It is best practice to have ‘upstream control’ for pipes through/ under dams, i.e. a valve on the upstream side of the dam, rather than ‘downstream control’, where the valve or control mechanism is located downstream of the dam.

Having full reservoir pressure permanently in a pipe through/ under the dam increases the risk of leakage from the pipe escaping into the embankment, which can result in a piping defect developing. Downstream control means that the pipe remains fully presurised through the embankment, as the only point of reducing or stopping the flow is downstream beyond the dam wall.

Having upstream control allows for flow through the pipe to be stopped if a defect is found. It also means that when full flow is not required, the pressure within the pipe is reduced, which would reduce potential for leakage and the pressure of any leakage into the embankment.

However, the size of the dam and the cost and accessibility issues related to installing valve(s) on the upstream side of the dam may result in a trade-off between best practice and what is “practicable” or reasonable. Your Dams Engineer is best placed to advise on the best valve and flow control arrangements for your dam.

**‘Upstream control’, i.e. having a valve on the upstream side of the dam, is recommended best practice. This means that the outlet pipe can be controlled before the water flows through or under the dam embankment. Consult you Dams Engineer for advice on the most appropriate valve and flow control arrangements for your dam.**

## 5.7 Spillways

When selecting a site for the construction of a spillway, choose an area where there has been no previous disturbance of the natural ground. The usual site is near one of the dam’s abutments.

Confine spillways to locations clear of the embankment so that no flow is likely to go onto and erode the dam wall.

# 6 Safety surveillance

## 6.1 Purpose of regular inspection

Safety surveillance of a dam is a program of regular visual inspection using simple equipment and techniques to monitor the condition and performance of the dam and its surroundings, particularly any changes that may be occurring. It is the most economical and effective way for an owner to maximise the long-term safety and survival of their dam.

Your dam safety surveillance program and maintenance program should be designed and assessed by a Dams Engineer as part of the overall design or ongoing management of your dam.

In some cases, the preparation, and carrying out, of a regular program of safety surveillance may be a condition of a licence. This is especially true for dams with a Significant or higher consequence category, but it also represents good practice and sound risk management.

Potentially problematic trends can be spotted early so that timely maintenance can be carried out.

Always check the water level and spillway flow performance for any unusual changes.

Using a Dams Engineer to carry out inspections can be an advantage as they are more familiar with problems and can provide better security against legal action in the event of a dam problem affecting others.

The main causes of failure, which can often be avoided by effective surveillance and maintenance programs, are:

- seepage/leakage
- slips/slides
- erosion
- cracking
- movement/deformation of embankment
- structural defects (i.e. outlet pipes, spillway)
- spillway or outlet blockage.

## 6.2 Inspection procedures and methods

The procedure for dam safety surveillance is unique to each dam but consists essentially of regular, close and systematic examination of the entire surface of the dam and its immediate surroundings. These procedures form part of a dam safety management program and are already normal practice in the case of large dams.

In the case of small dams, where owners have not sought appropriate advice, there may be a perception that the procedures are unnecessary or an unproductive use of time. There may also be a lack of knowledge of what needs to be done. However, simple and effective surveillance programs can usually be devised for small dams.

**A safety surveillance inspection includes taking appropriate measurements and keeping concise accurate records of observations. Appendix A outlines particular techniques and equipment that might be used.**

For small dams, it is prudent to obtain the advice of a Dams Engineer to set up the program first, using a simple set of pro forma check sheets to record observations. They are just as sensible as having your car checked and serviced regularly – in fact much more sensible, given the potential for costs to you if it fails.

## 6.3 Frequency of inspections

The frequency of inspection required for an effective program of surveillance depends on a variety of factors, including:

- size or capacity of the dam
- condition of the dam
- potential for damage resulting from failure of the dam (represented by the consequence category).

The inspection frequency for a particular dam is the responsibility of the owner. Seek professional advice from a Dams Engineer for the surveillance program for large dams (i.e. typically more than 15 metres high) or those suspected of being of a high risk or consequence category (of *Significant* or greater).

Suggested inspection frequencies are given in Table 6.1, but where licence conditions require a surveillance program certified by a suitably qualified Dams Engineer, the frequency specified by the engineer needs to be complied with.

Table 6.1 details a three-level surveillance program. The first level is a routine visual inspection aimed at the identification of deficiencies by visual observation of the dam, typically undertaken by the dam owner using the equipment and techniques outlined in Appendix A. The second and third levels are the intermediate and comprehensive inspections which are more detailed and are typically carried out by a suitably qualified Dams Engineer.

Table 6.1 is based on the ANCOLD Guidelines on Dam Safety Management (2003). Refer to this document for more information and the definition of terms (note that fees may apply for accessing ANCOLD guidelines).

## 6.4 Inspection checklists

The most thorough way to keep records is to use a checklist to record the findings of regular inspections.

It will remind you of what to look for and become a record of the condition of the dam over time. Such records must be systematically stored so that the information can be readily retrieved.

If a problem is developing, your records will be able to show that you have exercised due diligence It is good proactive management of your asset and may help protect you against liability if your dam causes loss or damage.

Appendix A provides a sample 'Dam Inspection Checklist'. It may need to be modified to suit your particular dam(s).

**Table 6.1 – Suggested inspection frequencies**

| Consequence Category | Routine inspection | Intermediate inspection | Comprehensive inspection |
|---|---|---|---|
| Extreme | Daily | Annual | On first filling then 5 Yearly |
| High A, B, C | Daily to tri-weekly | Annual | On first filling then 5 Yearly |
| Significant | Twice-weekly to weekly | Annual to 2-yearly | On first filling then 5 Yearly |
| Low | Monthly | On first filling, then 5 Yearly | Not required |
| Very Low | Monthly | On first filling, then 5 Yearly | Not required |

## 6.5 Special Inspections (immediately after major storm or earthquake)

Following a regular routine like that outlined above should enable a dam owner to be aware of faults before partial or total failure occurs. Times when additional inspections are recommended include:

- before a predicted major rainstorm (check embankment, spillway and outlet pipe)
- during and after severe rainstorms (check embankment, spillway and outlet pipe)
- during and after a severe windstorm (check upstream slope for damage from wave action)
- after any earthquake or tremor, whether directly felt on the owner's property or reported locally (check all aspects of the dam).

Carry out inspections during and after construction and also during and immediately after the first filling of the storage. Remember, empty the dam if any doubts arise.

## 6.6 Likely problems

A systematic program of safety surveillance maximises the likelihood that any developing conditions likely to cause failure are found before it is too late. Surveillance also identifies problems before they become major repair bills.

As identified in Section 6.4, typical problems (many of which are treatable if found early enough) are most likely to fall into one of the following categories:

- seepage/leakage
- erosion
- cracking
- deformation/movement
- concrete structure defects
- spillway blockage.

Weeds can block spillways, overflow or outlet pipes in a dam. If this happens, overtopping during heavy rain can cause the dam to fail. Section 7.4 outlines some of the simple maintenance activities that can prevent or remedy potentially dangerous conditions. Appendix B lists in more detail the problems that a safety surveillance program might reveal. It also outlines their possible causes, consequences and possible remedial action.

## 6.7 How to deal with problems

When there is a significant concern, it is strongly recommended that the Police, State Emergency Service (SES) and the Department be informed at the earliest opportunity so that appropriate responses can be instigated.

Seek help with a developing problem quickly, before it becomes serious.

Contact a Dams Engineer, and make sure that you provide details about the extent of the problem, its location, how quickly it is changing and the current status of inflows and water level. If the engineer is not familiar with the dam, it is useful to have drawings ready to send.

It may take time for someone to come to the site for a detailed inspection. Depending on the rate the problem is developing, it may be too late.

A key thing to remember is that the impact of a failing dam will be significantly reduced if there is less water in the dam. Be prepared to drain the dam if a serious problem develops or is developing.

# 7 Operation and maintenance of dams

The term ‘operation’ may seem to be applicable only to larger dams with a variety of control equipment (e.g. valves, flood gates and electrical control panels). However, if it is seen as any activity or practice that controls inflows and outflows, or safeguards the dam’s integrity, even small dams without elaborate equipment can – and should – be actively ‘operated’.

‘Operation’ implies that monitoring of performance, and maintenance, are inherently part of the duty of care attached to ownership of a dam, regardless of its size. The following sections deal only with some very basic aspects of operation and maintenance.

It is important to remember that it is a requirement of OH&S legislation to ensure that dams and other facilities are safe for people working at or visiting the site. Unsafe conditions may mean liabilities for the owner, designer or operator. This includes providing safe access to the site.

## 7.1 Routine surveillance

Routine surveillance or inspections can be called operation activities because they are not specifically maintenance. Surveillance/inspections involve observing the behaviour of the dam and recording flows into or out of the dam or water level gauges. It is geared towards securing both safety of the dam (see Section 6) and satisfactory technical performance.

## 7.2 Control of flows

Operation of a dam includes the control of flow of water from or around a dam via bypass channels, outlet works or spillway structures. ‘Control’ refers to activities or design features aimed at ensuring that:

- inflows do not overtop or endanger the dam structure
- outflows achieve the required downstream environmental (compensation) flow rate where this is applicable
- outflows are delivered in such a way as not to endanger the dam or to cause damage downstream (in larger dams this may include flood regulation; in small dams it will include avoiding erosion of the toe of the dam, the spillway channel or the area downstream).

## 7.3 Filling and emptying

The rate of filling or emptying a dam should be controlled. If done too quickly, there can be problems in an earth embankment.

If filled too fast, especially for the first time or after a long dry period, there may be leakage because the material within the bank does not have enough time to get sufficiently wet, expand and seal. This problem is more severe in embankments constructed from dispersive clayey soils and can lead to rapid and complete failure of the embankment.

Even in dams not constructed from dispersive clayey soils, emptying too quickly prevents the moisture in the embankment from draining fast enough. With the water load reduced on the upstream side, the internal pressure in the embankment can cause slumps or slides.

How quickly is ‘too quickly’ will depend on the type of soil in the embankment, but as a first rule of thumb, avoid emptying faster than 300 mm in level per day.

## 7.4 Maintenance

Because many dams fail through lack of maintenance, it is prudent to have a definite and systematic maintenance plan. It will affect the life of the storage.

Decide on the maintenance plan when the construction work on the dam is completed. Your Dams Engineer can give you advice and prepare a simple program to be followed.

A good plan includes the practices to be used, as well as the time of the year when they are applicable. It also includes steps to be taken if particular problems are encountered. Include details of observations and/or repairs (including details of location), no matter how minor, in your maintenance records.

## 7.5 Maintenance problems

The most common problem areas requiring maintenance are outlined below. Some of them are illustrated in Figure 7.1.

Appendix B includes a more comprehensive summary of their causes, consequences and remedies.

### 7.5.1 Dispersive clays

Dispersive clays are common in many parts of Victoria and are often the cause of severe discolouration of reservoirs and streams. Their presence in a dam embankment can result in the loss of material from the embankment by internal erosion and, consequently, major leakage problems and failure. The failure may appear to develop gradually but the final stage often occurs very rapidly, and with little or no warning. A significant proportion of such failures have taken place during the first filling of the dam.

As far as possible, avoid using dispersive clays in construction of a new dam. Where unavoidable, the addition of lime or gypsum, well mixed in with the embankment material, can help to stabilise it. In existing dams, applying these chemicals to the surface layer of the upstream face of the embankment may be beneficial.

As a guide, application rates of 3–5%, well mixed with the upper 20 cm could be used. Obtain professional advice in each particular case from a Dams Engineer. Mixing in the lime or gypsum requires care and its effectiveness can be negated if it is not properly done; professional supervision is strongly recommended.

Compaction of dispersive clays must be carried out to very high standards in accordance with specifications prepared by a suitably qualified Dams Engineer. The moisture content for compaction must be carefully controlled to be at or above the Standard Optimum Moisture Content, which can only be determined by laboratory testing of the material (see also Section 5.4).

### 7.5.2 Leakage and seepage

Water escaping from a reservoir might appear locally (‘leakage’) or over a wide area (‘seepage’). It might be visible on the embankment, at the downstream toe area or at the abutments. The rate of flow might be small or large, steady or increasing, clear or muddy.

Unless the flow is clear and the rate only small and not increasing, most forms of leakage represent the first warning of potentially serious problems and indicate the need for early repair work. The known or suspected presence of dispersive clays in the embankment or foundations would be cause for even greater concern.

It is important that the embankment is well maintained and grass kept relatively short so that seepage is readily identified if it occurs.

Appendix B lists the most commonly encountered forms of seepage and leakage, and the means by which repairs might be made. The only common factor is that, unless the cause is readily apparent and the repairs immediately effective, expert professional advice is needed.

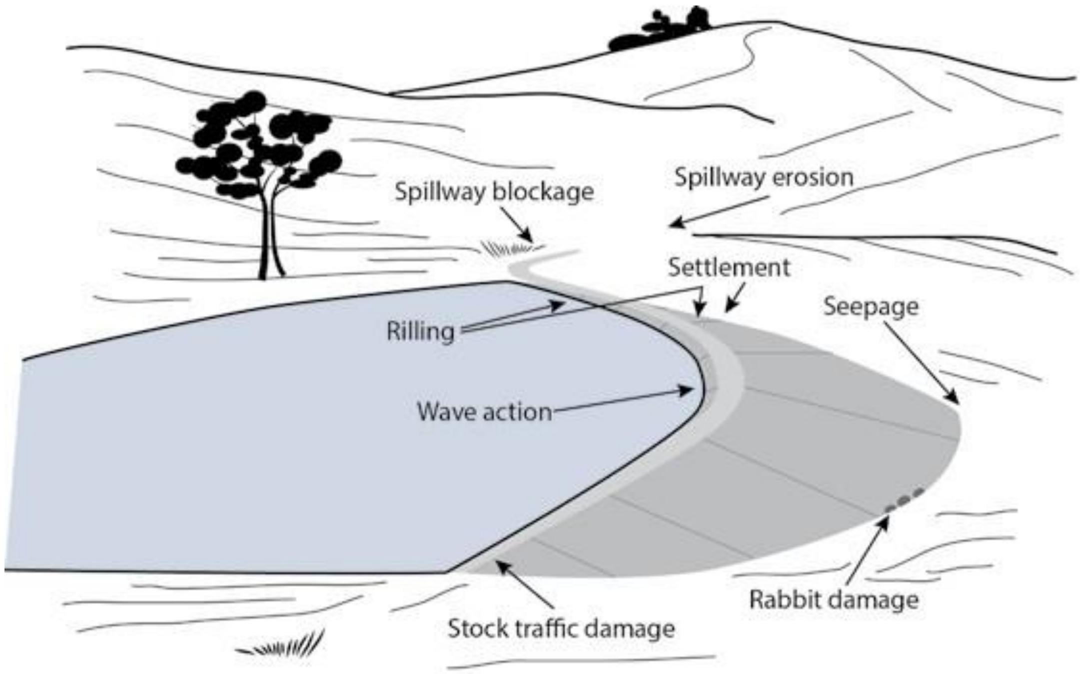



**Figure 7.1 – Common problem areas.**

### 7.5.3 Erosion

Erosion is a problem with many causes and forms, and the presence of dispersive clays will usually increase the speed at which it occurs. The following are among the most common forms of erosion.

#### *Rilling of the bank (small erosion gutters down the bank)*

This usually happens where there is no topsoil and grass cover on the bank. To rectify the problem, pack rills with grass sods or cover the bank with topsoil and sow down. Maintain a good grass cover on the embankment but keep it short to make surveillance easier.

#### *Damage from wave action*

To reduce wave action damage, protect the bank with rocks, hay mulch and netting, or grasses such as kikuyu. For larger dams, more substantial rock protection is warranted and consider establishing windbreaks around the shoreline.

Wave erosion can occur even when rock is placed on the upstream slope for protection.

Constant vigilance is necessary to ensure the upstream slope remains in good condition.

#### *Spillway erosion*

Heavy flows over spillways can lead to erosion. Where this occurs, fill in minor erosion with grass sods, cover with hay mulch and pin down with netting.

Ensure that the spillway remains as level as possible across its entire width to avoid flow concentration. Consider installing a low flow concrete gutter/trench to control erosion and protect the vegetation cover on the spillway from prolonged saturation following a storm. This is not an alternative to the outlet pipe. If erosion persists, more substantial protection is probably required.

### *Sinkholes*

Sinkholes are holes or depressions at the surface resulting from internal erosion that has caused underground cavities into which the surface material eventually subsides. Sinkholes are often a sign of severe and widespread hidden damage, and rectifying the problem is difficult. It is necessary to determine the nature and trace the extent of such damage, and to backfill all eroded areas with well-compacted, non-dispersive clay before dealing with the visible surface holes or depressions in a similar manner.

This is tedious and it is difficult to ensure that the whole extent of the problem has been addressed.

Unless the defect is found to be superficial and associated with flows from rainfall runoff rather than leakage from the dam, seek professional advice.

### *Wind erosion*

Erosion due to wind action can occur when the embankment material has high sand or silt content, and vegetation cover is poor. It is often associated with the passage of stock. Re-establishing good grass cover is the best remedy.

### 7.5.4 Stock damage

Keep stock off the embankment. Construct a fence to exclude stock around the perimeter of the embankment, storage area, spillway and spillway downstream slope as soon as possible after the dam is completed.

Apart from damaging the grass cover and creating ‘stock paths’ that can lead to serious erosion, the water in the storage can become cloudy and polluted by continued stock access. The best alternative is to provide stock water from a trough or install a fenced walkway to a restricted area of the stored water.

It is especially important to keep sheep and cattle from dam embankments constructed from dispersive clay.

### 7.5.5 Pest/animal damage

If left unchecked, animal holes can lead to leakage through an embankment. These need to be dug out and the material re-compacted to reinstate the embankment. Dig out any animal burrows (potentially caused by a variety of creatures, such as ants and insects, rabbits, foxes, wombats, small marsupials, yabbies, etc) and repack with well-compacted, non-dispersive clay. If the burrows are extensive, empty the storage before they are dug out, and seek professional advice. Where yabby holes are found on the upstream face, lower the water level to undertake remedial work.

Maintain effective control of rabbits and other pests and the vegetation which may encourage them.

### 7.5.6 Cracking and movement

### *Cracks*

During dry periods, there will always be minor cracking as the embankment dries out, but good topsoil and grass cover will help minimise this.

Some soil types are more prone to cracking than others and, where these types of soil are common, cracking is often a serious problem.

Transverse cracks running across an embankment can allow water to start seeping through. Where continuous transverse cracks have been found, seek professional advice from a Dams Engineer.

Longitudinal cracks running along the embankment can fill with water during a storm and, as a result, saturate lower layers, which may cause part of the embankment to slump.

Fill large cracks as soon as possible with well-compacted, non-dispersive clay, or fine filter sand mixed with or without bentonite (depending on circumstances). In practice, this can be difficult and it may be necessary to trench out the cracks before filling them so the clay can be compacted. For extensive and deep cracking, it is best practice to engage a Dams Engineer for investigation and design of remediation options.

Waterproof layers, such as a compacted gravel surface on the crest, help prevent drying and cracking.

### *Embankment settlement*

On large dams, it is usual to have special level markers to monitor embankment settlement. On small dams, the settlement can be checked by monitoring the freeboard. The freeboard can be estimated from the difference in height between full water level and the top of the bank. Hard and fast rules cannot be laid down but, it normally would not be less than about one fifth the height of the embankment. The important point is to examine the records to see if settlement is still occurring or if it has settled down. Checks to see whether transverse cracks have developed in the crest; if they have, seek professional advice.

### *Surface slips on embankment*

Slides are major structural defects. They normally require major remedial works such as flattening of batter slopes; improved drainage or addition of rockfill as a stabilising weight at the toe of a slope. Selection of an economical and effective remedy normally requires expert professional advice from a suitably qualified Dams Engineer. In the short term, it may be necessary to drain or pump out the stored water.

## 7.5.7 Defects in associated structures

### *Spillway blockage*

Regularly clear debris, trees, shrubs, fences and tall grass from all parts of the spillway, including the approach area. They will tend to obstruct flow and also catch any floating debris that would normally pass through the spillway. These obstructions can lead to overtopping of the embankment.

### *Outlet pipe blockage*

Cleaning an outlet pipe is a problem if the valve has been closed over the winter because trash, fish and silt can clog the inlet on the upstream side of the embankment. This type of blockage could place a dam owner in conflict with the public regulatory authorities because a condition of approval of a dam on a waterway requires the valve to be operated so as not to diminish flows during the drier months, usually November to April. Regular flushing by opening the valve is recommended to minimise the risk of blockages.

**If a spillway crest is raised as a means of increasing the storage capacity, there is a high risk that the bank will overtop. Do not undertake such work without professional advice.**

**In the event of a blockage, there are different techniques and types of equipment available to dislodge an obstruction (i.e. cleaning rods, flexible sewer pipe cleaners). Most can only be employed when the storage is empty or close to it. People should not be in the water if flow is passing through the outlet. Seek professional advice.**

## 7.5.8 Outlets and valves

All valves used for releasing water from a dam must be properly maintained. If you have a developing problem with your dam you may need to empty it as quickly as possible.

It is recommended that the outlet valve be operated at least four times a year to make sure it is working properly, and will work in an emergency. If it starts to get difficult to operate, a problem is developing that requires attention. Do not wait indefinitely for the spillway to flow first before testing the valve. It is possible to exercise the valve without losing stored water when the spillway is flowing, as the water is being passed downstream anyway.

Make provision at the outlet pipe point of discharge to reduce the velocity of exiting water. For example, an effective concrete outlet structure or a layer of crushed rock topped with a layer of large rocks can be used to minimise erosion. The type of protection will depend on the size and the pressure head of the water.

**Avoid locating water reticulation pipes or other structures within the embankment, as leakage from the pipes, or around the pipes, can cause problems, or even failure of the dam (see Section 5.5).**

**Do not allow trees or other deep-rooted plants within minimum 5 metres (or the anticipated height of the mature growth) of the embankment or spillway. The roots of this type of vegetation could provide a path for leakage through the dam and, ultimately, result in its failure.**

#### 7.5.9 Vegetation

***Trees***

Trees and shrubs can provide windbreaks, which prevent wave action and, therefore, soil erosion, and also give shelter for wildlife. If trees are required, plant them around the foreshore of the water storage, well away from the dam embankment and spillway. The dominant wind direction needs to be considered.

***Total catchment area protection***

To maintain the required depth and capacity of a dam, inflows need to be reasonably free from sediment.

Selective plant use can trap silt and improve water quality. The best protection from sedimentation is to control erosion of the surrounding catchment area. Land with a permanent cover of vegetation, such as trees or grass, makes the most desirable catchment area. If the catchment area is denuded and eroding, you may need to use cultivated areas that are protected by appropriate conservation practices, such as contour tillage, strip-cropping, conservation cropping systems and other land improvement practices.

***Weed control***

Aquatic weeds in dams can block pump and pipe inlets, deter stock from drinking and, in some cases, taint the water. If weeds are treated when they first appear, dams can be kept relatively free of some of the more troublesome species. All plants can become a problem and each may require a different control method. In all situations, consider the same factors in deciding what control methods, if any, to use.

In each case:

- determine the problem
- identify the specific plant causing the problem
- find out what control methods are available
- investigate whether these control measures could cause side effects (e.g. toxicity to fish and livestock) and whether they can be avoided
- decide on a control solution, if suitable.

## 7.6 Modifications

Modifications to your dam which increase the storage capacity will require changes to licences issued for the dam and your water entitlements. Discuss changes with and make relevant applications to your Licensing Authority. Seek professional advice from a Dams Engineer prior to undertaking design and construction works for any significant changes to your dam (any raising would be a significant modification).

***Spillways***

If a spillway crest is raised as a means of increasing the storage capacity, there is a high risk that the bank may overtop. Water pressure loading on the dam wall will also increase due to the added height of water and this may cause embankment slips and instability. Do not undertake such work without professional advice.

***Crest modification***

Placing additional fill on an existing dam can create problems because of poor bonding between the existing and new material. Unobservable drying cracks within the embankment which could form a leakage path when exposed to higher water levels in the dam. Because of the shape of the dam, a simple raising will also result in a narrower crest width making maintenance difficult.

# 8 Dam failure emergency

This Section is likely to have less importance for small dams, but regardless of dam height or volume the owner of any dam that is potentially hazardous should pay attention to this section.

## 8.1 Extreme events

Extreme events such as earthquakes, flood or storm activity make preventative action difficult. While a dam owner can't stop these events occurring, the risk of dam failure from flood and earthquake can be minimised by proper design and construction.

Pre-planning is an important way to minimise the impact from dam failure.

Failure of another dam upstream can also affect your dam. If you are concerned about the condition of any dam, and the matter cannot be resolved locally, contact your local Licensing Authority (see Section 3.4) which can direct work to be done to make the dam safe.

## 8.2 Emergency preparedness

Emergency preparedness is about having a plan of action in case the dam fails or is threatening to do so. Proper operating procedures, adequate inspection, and maintenance and safety surveillance, also play important roles.

The Emergency Action Plan should be directly related to the specific dam's structure and its immediate environment. It will depend on the owner's knowledge of the dam and its operation. Review and, if necessary, update it annually. This is especially true for dams with a history of leakage, cracking, settlement, misalignment or erosion from wave action.

It is imperative to issue an effective and timely warning to downstream residents if a dam is about to fail. The better and earlier the warning the less likely injury will occur and some damage may be avoidable.

The State Emergency Service (SES) is the response agency for major flooding events, whatever the cause of the flood (but see also the Department below).

Where you have a potential failure emergency with your dam, call your own Dams Engineer, police, local Licensing Authority, the Department and the State Control Centre for assistance.

The Department has a key role to play during dam safety incidents and emergencies. It is required to ensure that all things that can be done for life and property safety are being done in the circumstances.

In rural areas, telephone or direct contact will usually be used to warn the nearest downstream residents. When a telephone call is not possible, the person observing the dangerous condition may have to personally warn the nearest downstream residents, campers, etc. If you are the dam owner, keep a listing of the nearest downstream residents and their phone numbers along with the police, SES, local Licensing Authority, the Department and the State Control Centre and other emergency numbers.

The State Control Centre number is 1300 134 444.

## 8.3 How to deal with a dam failure concern

Immediate action is required when a developing condition is recognised:

- **If failure is imminent** (e.g. water is rising and approaching the top of the embankment, or heavily coloured water is leaking from the embankment or foundation), immediately contact:
  - a Dams Engineer for advice
  - the police, SES, local Licensing Authority (Section 3.4) and the State Control Centre
  - your neighbours downstream to inform them that you have concerns but are working on the problem.
- **If failure appears imminent or is in progress** (e.g. water is spilling over the embankment, or the embankment, spillway or foundation is eroding). If there is no chance to save the dam, immediately inform the following that you need help:
  - Police
  - State Emergency Service
  - downstream neighbours
  - local Licensing Authority (Section 3.4)
  - State Control Centre.
- **Where major flooding is expected or is in progress upstream of the dam site**, inform:
  - Police
  - State Emergency Service.
  - downstream neighbours
  - local Licensing Authority (Section 3.4)
- **If an upstream dam is about to fail** and you are concerned about your dam, notify:
  - local Licensing Authority (Section 3.4)
  - State Control Centre
  - Police
  - State Emergency Services.

### 8.3.1 Emergency checklist

An emergency situation could require many people and organisations to be informed at the earliest opportunity. Keep in mind that preservation of human life must always have first priority. Prepare a contact list and keep it accessible and up to date.

A template for a Dam Safety Emergency Plan is available for use by small dam owners that can be downloaded from:

www.water.vic.gov.au

This template provides procedures for various scenarios that could guide people not familiar with dam safety procedures.

An emergency action plan is a licence requirement for potentially hazardous dams. Your engineer should prepare a specific plan for your dam. If you have employees, they should also be familiar with, and have access to, the emergency plan and contact list.

The first calls should be to the police or the local State Emergency Service (SES) who will then warn and if necessary evacuate downstream residents. For smaller dams that don't require a licence, a contact list as per Page 2 of the Emergency Plan (Appendix D) should be maintained.

### 8.3.2 Contact organisations for advice

If there is a problem on a dam, organisations that may be able to provide advice or a service are:

- The Department
- Local Licensing Authority (Section 3.4)
- or a member of the:
  - Association of Consulting Engineers, Australia, Victorian Chapter
  - Local Government Engineers Association.

In any particular area, the best advice can usually be obtained from a Dams Engineer with local experience in design, construction, maintenance and repair of dams.

The State Control Centre number is 1300 134 444

# 9 Removing or decommissioning dams

## 9.1 Removing or decommissioning a dam

You cannot simply walk away from a dam because it is of no further use or is too costly to manage or rehabilitate. Licensing Authorities have powers under the Water Act to issue Directions to undertake works to make dams safe, and/or prosecute the owner for not complying with a Direction. It must be made incapable of storing any water either temporarily or permanently.

A licence is needed to remove or decommission it. Decommissioning is normally done by breaching one or more sections of the dam wall or embankment.

The owner is still responsible for ensuring the safety of residents and development downstream, and of the dam itself while it is in the process of being removed or decommissioned, and indefinitely afterwards if it is decommissioned.

Removal or decommissioning of a dam is not without problems:

- Has an assessment been made of the costs associated with the removal?
- Will the proposed works eliminate any future operation, maintenance, surveillance or remedial work?
- Can the unbreached sections, if any, be left in a permanently stable condition?
- Is the proposed breach wide enough not to impound significant quantities of water under flood conditions?
- Has the short and long-term stability of any sediment deposits within the reservoir area been considered before commencement of the breaching operation?
- Is the breaching process acceptable from safety and damage perspective both at the dam and downstream?

Do not attempt breaching while there is any water in storage unless expert advice is first obtained.

Environmental aspects downstream must be considered before a dam is breached. Siltation/ sediment transport or erosion as a result of decommissioning could become a liability on the dam owner.

The cost of rendering a dam that is of no further use safe (particularly against storm and flood events) could be considerable.

For any dam being decommissioned or breached, obtain professional engineering and environmental advice.

## 9.2 Rehabilitation of site (after removal)

For all dams, a plan for rehabilitation will need to be presented to the Licensing Authority for approval. The plan is required to explain how the land or waterway will be managed to minimise erosion or degradation impacts.

**A dam breach that results in some portion of the dam wall being left in place is not necessarily sufficient action. Any flow obstruction during floods will be an obstacle compared to the natural waterway characteristics.**

It would be difficult to make a defence of due diligence where a flood event erodes the remaining dam structure which results in a sudden release of water or mud flows that causes loss of life or damage to property or the environment.

The site should be reinstated and revegetated to a stable condition. Take care to make sure that no material (usually silt) can be washed downstream or affect other dams.

## 9.3 Maintenance of site until stable

A dam owner needs to check that the following questions can be answered to the satisfaction of the Licensing Authority:

- Has due consideration been given to protect people and property during abandonment works?
- Is the abandoned dam likely to become a future public hazard?
- Is there an environmental plan for re-instating and/ or regenerating the inundated area?
- Have inundation area and waterway erosion control measures been considered until regeneration occurs?
- Have environment authorities been consulted and are proposed plans acceptable?
- Can the dam site and inundated land be disposed of economically?

# 10 Glossary

**Abandonment:** The owner is no longer using the dam. It may or may not have been modified hydraulically and/or structurally to ensure complete and permanent safety to life, property and the environment. This term covers both 'disused' and 'decommissioned' dams as appropriate.

**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 surrounding formation above the normal river level or flood plain against which the ends of the dam are placed.

**ANCOLD:** Australian National Committee on Large Dams.

**(Licence) Application:** An application made in accordance with the Water Act to construct or enlarge a dam for commercial and irrigation use.

**Appurtenant:** Works including, but not limited to, structures such as spillways, either in or beside the dam and its rim; low level outlet works and water conduits such as tunnels and pipelines, either through the dam or its abutments.

**Base of dam:** The area of the lowest part of the dam resting on the foundation excluding the abutments. It excludes isolated pockets of excavation which are not representative of the base extending from (upstream) heel to (downstream) toe.

**Beaching rock (or rock riprap):** Rock placed to dissipate the erosive force of waves on banks. The term can mean dumped or hand-placed rock, usually located on a prepared bed of gravel size material. (Also known as rock riprap)

**Catchment:** The area of land drained by the landform, streams or waterways down to the point at which the dam is located.

**Consequence category:** The ANCOLD Guidelines on the Consequence Categories of Dams (2012) describes consequence category as categories of dams based on the consequences of potential dambreak failure to human life, property, commerce, infrastructure, the effect on the dam owner's business, political and business credibility, health, social and economic disruption, and environmental impacts. The consequence categories range from 'Very Low' to 'Extreme'. Past ANCOLD literature previously referred to this as "hazard category", which is a depreciated term.

**Contractor:** A person or entity employed (contracted) to carry out construction works in accordance with plans and specifications in the construction of a dam.

**Crest of dam:** Also called the embankment crest. The top level of a dam wall or embankment (not the spillway level). The uppermost surface of the dam proper, excluding parapets, handrails, etc.

**Cut-off:** An impervious barrier of material to prevent seepage flows through or beneath a dam. It is also used to prevent seepage flow along structures such as pipelines or spillways.

**Department:** (for the purposes of this publication) the department of the Victorian Government responsible for water.

**Dam:** In general, an artificial barrier, together with appurtenant works, constructed for storage, control or diversion of water, other liquids, silt, debris or other liquid-borne material.

**Dams Engineer:** A professional engineer who is suitably qualified and recognized by the engineering profession as experienced in the engineering of dams and its various sub fields.

**Dam failure:** The uncontrolled release of the contents of a reservoir through fault or collapse of a dam or some part of it.

**Dam owner:** Person or legal entity, including a company, organisation or corporation, which either holds a licence to operate a dam or retains the legal property title on the dam site, dam and/or reservoir, and is responsible for the safety of the dam.

**Dam Safety Emergency Plan (DSEP):** A continually updated set of instructions and maps that deal with possible emergency situations or unusual occurrences at a related dam.

**Decommissioned dam:** A dam that is no longer used but has been made safe so that there is no requirement for operation or maintenance and it does not have a detrimental effect on the environment.

**Design flood:** The maximum flood for which the dam is designed, taking into account the consequences of failure and likely rainfall.

**Dispersive clay:** A clay soil (or clay component of a soil) in which the micro particles break apart (or disperse) in contact with water in certain circumstances. Such clays occur in many parts of Victoria (also in other states) and present special difficulties and dangers for design, construction and operation of earth dams if they are incorporated in the embankment or foundation.

**Embankment:** An earth structure built across a waterway to either protect adjacent land from inundation by flooding or to store water. It also applies to earth structures built to contain water off a waterway.

**Emergency:** Any condition that develops which endangers the integrity of the dam and downstream life and/or property, and requires immediate action.

**Environmental consequences:** The assessable consequences of a dam failure on the environment.

**Extreme event:** An event such as flood, storm or earthquake that has a low probability of occurring but is possible. Its potential forces are used for the design of dam components. It is usually expressed as Annual Exceedance Probability (AEP), being the chance of the event occurring in any one year.

**Foundation:** The material of the floor and abutments on which the dam is constructed.

**Freeboard:** The vertical distance between the spillway crest level and the top of the dam (crest) at its lowest point.

**Full Supply Level (FSL):** The maximum normal operating level of a reservoir, as distinct from flood surcharge. This is also the level of the spillway crest when water is just about to pass through the spillway.

**Hazardous dam:** A dam is hazardous if, because of its size and/or location, it could threaten life, property and/or the environment if it were to fail. ANCOLD guidelines refer to “Consequence Categories” of dams, and the consequences of failure of dams. For the purposes of this document, the term “hazardous” is used to highlight that dam failure consequences can be hazardous to life, property and/or the environment.

**Height of dam/ embankment:** The difference in level between the embankment crest and the downstream toe of the dam at the point of maximum height. If the dam is on a gully, stream or river, the height is measured from the bed of the waterway.

**Impervious:** Describes a relatively waterproof soil such as clay through which water percolates very slowly making it suitable as a water barrier.

**Impermeability:** Describes property of a soil such as clay through which water percolates very slowly.

**Infrastructure:** Includes roads, bridges, water supply systems, waste water systems, recreation facilities and other community investments.

**Inspection:** An examination of a dam in accordance with the ANCOLD Guidelines on Dam Safety Management (2003).

**Interim diversion limit methodology:** A means for estimating the water available for harvestable catchment run-off and permissible annual volumes.

**Licensing Authority:** In Victoria, they regulate the construction of dams and the use of water including surface and groundwater resources. The Licensing Authorities for Victoria are Southern Rural Water, Goulburn-Murray Water, Melbourne Water Corporation, Lower Murray Water, and Grampians Wimmera Mallee Water. Refer Section 3.4

**Maintenance:** Actions required to maintain existing works and systems (civil, hydraulic, mechanical and electrical) in a safe and functional condition.

**Monitoring:** Recording of data from measuring devices and visual observations to check the performance and behavioural trends of a dam and appurtenant structures.

**Optimum Moisture Content:** The moisture content of earthen material with suitable clay content at which the best compaction can be easily achieved. (In the case of a particular soil, the Optimum Moisture Content is defined by a special standardised laboratory test).

**Organic material:** Silt or clay containing plant remains. It has low bearing capacity and is compressible when it rots. Organic materials are not suitable for inclusion in dam construction.

**Outlet works:** The combination of screen, intake structure, conduit, tunnel, control valves and meters that permit controlled release of water from the dam.

**Owner:** Any person, company or authority owning, leasing or occupying the land on which a dam is constructed or proposed to be constructed.

**Permeability:** Property of a soil that allows the movement of water through its connecting pore spaces.

**Piping:** Establishment of a seepage path through an earthen embankment resulting in erosion of material caused by the flow of water.

**Remedial Work:** The work required to repair, strengthen, re-construct, improve or modify an existing dam, appurtenant works, foundations, abutments or surrounding area to provide an adequate margin of safety.

**Reservoir:** An artificial lake, pond or basin formed by a constructed dam structure for storage, regulation and control of water, silt, debris or other liquid or liquid-carried material.

**Reservoir Capacity:** The total storage capacity of the reservoir or dam up to Full Supply Level (not up to flood level).

**SES:** State Emergency Service.

**Seepage:** The exit of reservoir water by percolation through, under or around the dam.

**Spillway:** An open channel, weir, conduit, tunnel or other structure designed to allow discharges from the dam when water levels rise above the Full Supply Level directing flow downstream of of the dam. The spillway is principally to discharge flood flows safely past a dam without overtopping the dam wall.

**Spillway Chute:** An inclined open channel through which water flow is directed below the toe of the dam. Surface may be grass, concrete or beached.

**Spillway Crest:** Usually the highest section floor in the spillway cut, which sets the level of the storage.

**Surveillance:** The continuing examination of the condition of a dam and monitoring procedures in order to determine whether a deficient trend is developing or appears likely to develop.

**Sustainable diversion limits:** The limits set by the Minister for Water that quantify the volume of water that may be allocated for winter-fill licences on unregulated waterways.

**Top of dam (crest):** The elevation of the uppermost surface of the dam proper, not taking into account any camber 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.

**Watercourse:** A type of waterway defined in the Water Act 1989.

**Waterway:** A term in the Water Act that includes any river, creek, stream, or watercourse and a natural channel in which water regularly flows but not necessarily continuously and a channel resulting from the alteration or relocation of a waterway. Detailed definitions are available from your Licensing Authority.

**Waterway with high ecological values:** A wetland or marsh; a waterway with remnant native vegetation (either in-stream or riparian); or a waterway known to support flora and fauna of conservation significance.

# 11 Technical references

These publications have been used to compile some of the information in this booklet, or are relevant to potentially hazardous dams and to dams equal to or greater than the sizes (height and storage capacity) listed in Section 3.2. They are primarily addressed to engineers with specialist expertise in dam design and construction.


- Australian National Committee on Large Dams (ANCOLD), Guidelines on Dam Safety Management, August 2003.
- Australian National Committee on Large Dams (ANCOLD), Guidelines on Risk Assessment, October 2003.
- Australian National Committee on Large Dams (ANCOLD), Guidelines on Selection of Acceptable Flood Capacity of Dams, March 2000.
- Australian National Committee on Large Dams (ANCOLD), Guidelines on Consequence Categories for Dams, October 2012
- Australian National Committee on Large Dams (ANCOLD), Guidelines on Design of Dams for Earthquakes, August 1998.
- Australian National Committee on Large Dams (ANCOLD) Status of Dam Safety in Australia, Bulletin No. 91, 1992.
- Australian National Committee on Large Dams Inc, Guidelines on Regulation and Practice for the Environmental Management of Dams in Australia, June 2014
- Australian National Committee on Large Dams Inc, Guidelines on Design Criteria for Concrete Gravity Dams, September 2013

# Appendix A: Conducting an inspection

Inspections monitor performance in a way that enables early diagnosis of potential problems. They include such things as noting where cracks or leakage has formed, whether there is any deterioration, and how fast or slowly that may be occurring. To be able to conduct a thorough inspection of your own dam, you may need to consult a suitably qualified Dams Engineer who will provide a good insight into what to look for and how to go about it.

This would provide a procedure specific to your dam. The following material is provided to help you understand inspection requirements.

## Establishing reference pegs

To enable reliable monitoring and facilitate recordkeeping, it is essential that there be both a plan of the dam and a set of reference pegs, relative to which any observation or trouble spots can be pinpointed and recorded.

The degree of sophistication of the plan and the reference peg system will depend on the size of the dam, its type and its potential consequence category. Seek advice on this first. As a bare minimum, irrespective of dam size, at least one key reference peg (the primary reference peg) at one end of the dam is needed. Recording of locations will need to convey the level (height) at each location as well as the distance along the dam length. It is preferable to place the key reference peg at a level close to the dam crest level. It needs to be securely in place so that it can be readily found and is unlikely to be knocked out or broken by persons, vehicles, machinery, plants or animals.

Ideally, there should be a backup secondary reference peg, preferably at the other end of the dam, with the distance from the primary peg and any difference in height recorded. If the dam crest is not straight, or if there are difficulties about this procedure, seek professional advice.

With larger dams, potentially hazardous dams, or dams classified with a consequence category of Significant or higher, more sophisticated arrangements are likely to be required, but for small and simple dams the position and level of the reference peg(s) do not need to be precisely defined by a land surveyor.

Similarly, the plan of the dam may not need to be precisely to scale, but there should be a reasonably reliable means of ascertaining the height level of any observation and its distance from the primary reference peg.

## Equipment for inspection

The following items are useful when conducting an inspection:

- Dam inspection check list – a reminder of items to be examined.
- Notebook or diary and pencil – to write down observations at the time they are made, which reduces mistakes and avoids reliance on the memory.
- Camera – to provide photographs of observed field conditions. Colour photographs taken from the same vantage points are valuable in comparing past and present conditions.
- Shovel – useful for clearing drain outfalls and removing debris.
- Stakes and tape – used to mark areas requiring future attention and to stake the limits of existing conditions such as wet areas, cracks and slumps for future comparisons.
- Probe – a 10-millimetre diameter by one metre long blunt end metal rod with right angle ‘T’ handle at one end. The probe can provide information on conditions below the surface such as depth and softness of a saturated area. Soft areas indicate poor compaction or saturated material.
- Hammer – to test soundness of concrete structures.

## Observations to be recorded

A sketch plan of the dam is a helpful aid to recording observations (see Preliminaries). It should be approximately to scale with the locations of all observations indicated on it. All measurements and descriptive details that are required to portray an accurate picture of the dam's current condition must be recorded. This information falls into three categories:

- Location – the location of any questionable area or condition must be accurately described to allow it to be properly evaluated. Note the location along the length of the dam, as well as the height above the toe or distance down from the dam's crest. The same applies to conditions associated with the outlet or spillway
- Extent of area – record the length, width and depth or height of any area where a suspected problem is found.
- Descriptive detail – a description of a condition or observation must be given which is brief but yet containing all relevant details. Some factors to include are:
    - Quantity of seepage from point and area sources
    - Colour or quantity of sediment in water
    - Location, length, displacement, and depth of cracks
    - Is area moist, wet or saturated?
    - Is protective cover adequate (topsoil/grass)?
    - Is surface drainage satisfactory?
    - Do batter slopes look too steep?
    - Are there bulges or depressions on the slopes?
    - Does deterioration appear to be rapid or slow?
    - Have conditions changed? How?

This is not a complete list but serves as an initial guide. If a condition has changed since the last inspection, it must be noted; take a photograph and put in the diary, noting the date and a description of the scene shown in the photograph. Remember, a primary purpose of the inspection is to pick up changes since the previous inspection. If a situation looks as if it is worsening or otherwise causes concern, do not hesitate to get professional help.

Table A1 is a typical form of checklist for noting defects and keeping long-term records of behaviour.

## Inspection procedures

Getting the most out of an inspection requires some preparatory work:

- Review the previous diary entries to note any areas that will require special attention
- If the purpose of the inspection is to re-evaluate suspected defective conditions discovered during the last inspection, examine any available construction drawings for a possible explanation of the situation (but do not speculate, obtain professional advice if there is any doubt or ambiguity in the situation).
- To obtain the best results and allow for consistent recording of findings, it is best to follow a specific sequence when making the inspection, such as:
    - upstream slope
    - crest (top of bank)
    - downstream slope
    - any seepage areas
    - outlet
    - spillway.

This will lessen the chance of an important condition being overlooked. It is best to report inspection results in the same sequence to obtain consistent records.

## General techniques

Walk along and over the dam as many times as necessary to see every square metre. From any given spot, a person usually has a detailed view for 3–10 metres in each direction, depending on the smoothness of the surface or the type of material on the surface, i.e. grass, concrete, rock, brush.

To cover extensive surfaces property, several walks are required.

Where visibility is limited more attention is needed.

Adequate coverage can be achieved using parallel or zigzag paths.

On the downstream slope a zigzag path is recommended to ensure that any defects are detected.

At several points on the slope, stop and look around through 360 degrees to check alignments and to be sure that some important feature of the slope has not been overlooked.

## Particular techniques

The following is a list of methods that can be used to monitor changes over time.

### Sighting

A sighting technique, similar to that used when selecting straight pieces of timber, can be used in identifying misalignment as well as high or low areas along a surface. The technique is illustrated in Figure A-4.

The same method can be used to sight along the crest of a dam (see Figure A-5). Centre the eyes along the line being viewed. Sighting along the line, move from side to side a little to view the line from several angles.

Looking through a pair of binoculars will help to make any variations more obvious.

### Probing

The probe is pressed into the earthen batter slopes, on the crest or at places being inspected. Conditions below the surface, such as depth and softness of a saturated area can then be monitored. Also, by observing the moisture brought up on the probe's surface and the resistance to penetration, it is easier to decide whether an area is saturated or simply moist.

### Pegging-stakes

The best way to find out if there is a leak is to check how fast water is disappearing from a storage by marking the waterline with a peg at regular intervals, say, weekly. If the storage is used for stock or irrigation, try to peg the waterline before and after use. Alternatively, a measuring staff can be permanently set into the storage to make level measurement easier.

Measuring in this way is much better than simply guessing. A suspected leak, when measured, may turn out to be only evaporation loss. Evaporation per day can easily be 5 mm and as much as 10 mm in fine, dry, windy conditions.

### Noting slides and signs of surface movement

Slides are often difficult to spot, because they do not always produce readily noticed cracks at the surface. Their appearance is often subtle, since there may be less than 200 mm of depression or bulging out at right angles to the slope in a distance of perhaps 10 m. On the other hand, when the dam was finished, the bulldozer operator may not have uniformly graded it, and the surface of the slope may have an apparent bulge or concavity when no slide is present. A good familiarity with how the slope looked at the end of construction helps identify any slides, which should be recorded for future information.

A method of monitoring surface movement on the upstream or downstream slope is to place a straight line of stakes down the slope with a string tape attached to the top of each stake. The point at which a slide takes place will cause the uphill stakes to be pulled over; those just downhill of the movement show a slackening of the string tape.

### Noting changes in vegetation

The density or lushness of vegetation can also be an indication of extra moisture at a particular location and the possibility of a leak. Probing the area will usually confirm whether or not a problem is developing.

## Evaluation of observations

The record of observations taken at periodic inspections is used to develop a picture of the dam's performance. Accurate measurements pay off because small changes, which could go undetected if simply looked at rather than measured and recorded, will show a pattern or trend.

Immediately following the inspection, compare the observations with previous records to see if there is any condition, reading or trend that may indicate a developing problem. You can then begin to address any potential problem before it becomes a threat to the dam. When a significant change is detected, carefully examine any design drawings for the dam to see if an obvious reason for the change can be found.

If a questionable change of trend is noted, engage a suitably qualified Dams Engineer experienced in the field of dams engineering to determine if any action, such as increased monitoring or detailed investigation of the condition, is required.

These actions will help ensure the safety, safe operation, and long, useful life of the dam.

### Table A1 – Example dam inspection checklist

| Date: | Owner: | Property: |
|---|---|---|
| **Areas of dam** | **Items to inspect/address** | **Observations/change from last inspection** |
| Upstream slope | Protection | |
| | Uniformity | |
| | Displacements, bulges, depressions | |
| | Vegetation | |
| Crest | Cracking | |
| | Low spots | |
| | Sinkholes | |
| | Vegetation | |
| Downstream slope | Signs of instability and non-uniformity | |
| | Erosion | |
| | Stock activity | |
| | Animal activity | |
| | Obscuring/vegetation growth | |
| | Wetness | |
| | Changes in condition | |
| Seepage | Location | |
| | Extent of area | |
| | Characteristics of area (i.e. soft, boggy, firm) | |
| | Quantity and colour | |
| | Transported or deposited material | |
| | Spring activity or boils | |
| | Piping and tunnel erosion | |
| Outlet | Changes in vegetation | |
| | Outlet pipe and valve condition | |
| | Operation | |
| | Leakage | |
| | Downstream erosion | |
| | Gate valve operation, condition and leakage | |
| Spillway | Condition of crest, chute and floor protection | |
| | Spillway obstructions | |
| | Erosion or back cutting in spillway | |
| Other notes | | |

# Appendix B: Common problems – their causes, consequences and action required

## Preface

The following information is presented to help dam owners identify problems that could arise in and around dams and are likely to cause them to fail. The possible cause and potential consequences are also indicated, and appropriate action recommended.

While a number of the conditions described in the tables can be corrected by routine and periodic maintenance, a significant proportion threaten the safety and integrity of the dam and require the attention of a suitably qualified Dams Engineer.

Quick, corrective action will promote the safety and extend the useful life of the dam, while possibly preventing costly future repairs.

This appendix doesn't cover all the problems that might arise, only the more common ones.

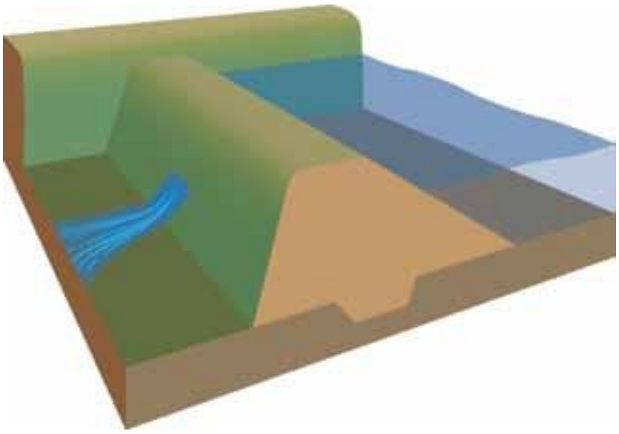
As a general rule, if an owner has any concerns at all they should get help from a suitably qualified Dams Engineer.

The definition of a suitably qualified Dams Engineer is set out in the Glossary. This includes competence and experience in dam design and construction for the relevant type of dam. Experience in construction only is not considered appropriate. Note that even among professional civil and geotechnical engineers, most practitioners are not experienced in dams, which is a specialist area.

Reference materials for this section were sourced in the main from *Department of Conservation and Natural Resources: Your Dam an Asset or a Liability – 1992.*

## Seepage

### Seepage water exiting from a point on the embankment



**Cause:**

- Water has created an open pathway, channel, (or 'pipe') through the dam. The water is eroding and carrying away embankment material.
- Large amounts of water have accumulated in the downstream slope. Water and embankment materials are exiting at one point.
- Rabbits, yabbies, rotting tree roots or poor construction have allowed water to create an open pathway or pipe through the embankment.

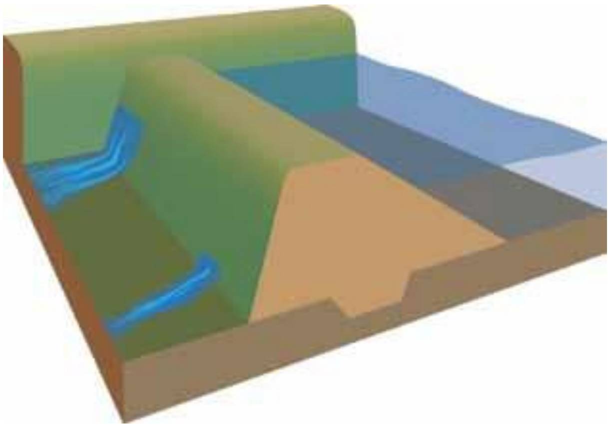
**Harm:**

- Continued flows can saturate portions of the embankment and lead to slides in the area.
- Continued flows can further erode embankment materials. This can lead to failure of the dam.

**Action required:**

- Begin measuring outflow quantity and establishing whether water is getting muddier, staying the same, or clearing up, and whether the rate of flow is increasing or not.
- Check whether surface agitation may be causing the muddy water.
- If quantity of flow is increasing, lower the water level in the dam until the flow stabilises or stops. Be prepared to lower the dam level.
- Search for an opening on the upstream side and plug it if possible with clay, but do not get into the water to do so!
- Prevent rabbit/animal activity.
- Have a Dams Engineer inspect the condition and recommend further actions.

### Large seepage area producing flow



**Cause:**

- A seepage path has developed directly through the embankment or via the abutment.

**Harm:**

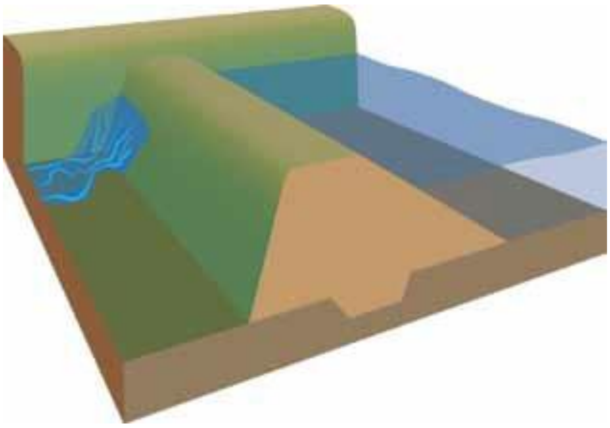
- Increased flows could lead to erosion of embankment material and failure of the dam.
- Saturation of the embankment can lead to local slides, which could cause failure of the dam.

**Action required:**

- Stake out the saturated area and monitor wet area for growth or shrinking.
- Measure any outflows as accurately as possible.
- Dam water level may need to be lowered if saturated areas increase in size at a fixed storage level or if flow increases. Be prepared to lower the dam level.
- Have a dams engineer inspect the condition and recommend further actions.

## Seepage

**Seepage exiting at abutment contact**



**Cause:**

- Water flowing through pathways in the abutment.
- Water flowing through the embankment and out via the abutment.
- Water flowing along the contact surface between the embankment and its abutment.

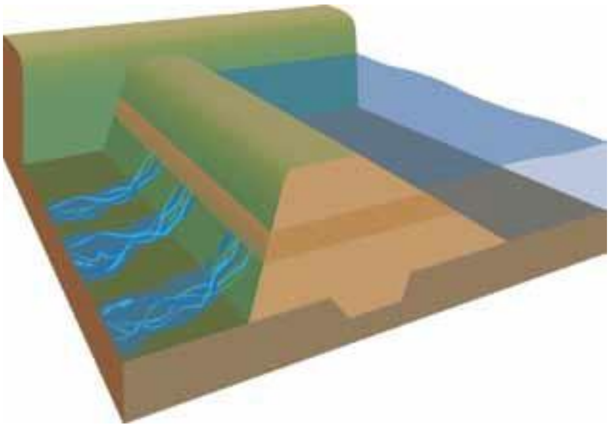
**Harm:**

- Can lead to erosion of embankment materials and failure of the dam.

**Action required:**

- Investigate leakage area to determine quantity of flow and extent of saturation.
- Inspect daily for developing slides.
- Water level in reservoir may need to be lowered to assure the safety of the embankment. Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

**Wet area in a horizontal band in the embankment**



**Cause:**

- Layer of sandy/permeable material in original construction.

**Harm:**

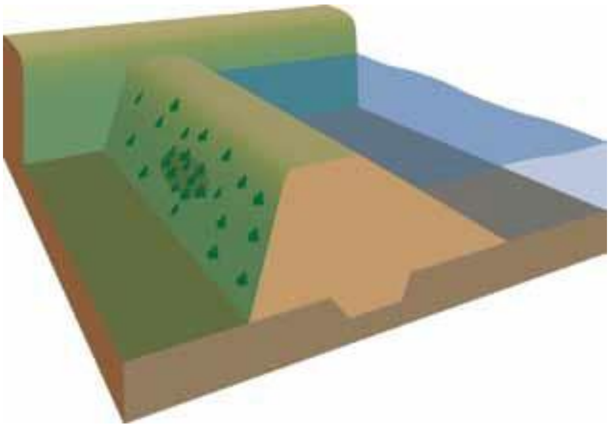
- Wetting of areas below the area of excessive seepage can lead to localised instability of the embankment (slides).
- Excessive flows can lead to accelerated erosion of embankment materials and failure of dam.

**Action required:**

- Determine as closely as possible the amount of flow being produced.
- If flow increases, reduce the dam water level until flow stabilises or stops. Be prepared to lower the dam level.
- Stake out the exact area involved.
- Using hand tools, try to identify the material allowing the flow.
- Have a Dams Engineer inspect the condition and recommend further actions.

## Seepage

**Marked change in appearance of vegetation**



**Some examples of change:**

- More areas of vegetation appear to have grown.
- A given area of vegetation appears darker, lighter, larger or wetter.
- A given area of vegetation appears to have died.

**Cause:**

- Embankment materials are providing increased seepage flow paths.
- Natural seeding by wind.
- Change in seed type during initial post-construction seeding.
- Neglect of dam and lack of proper maintenance procedures.

**Harm:**

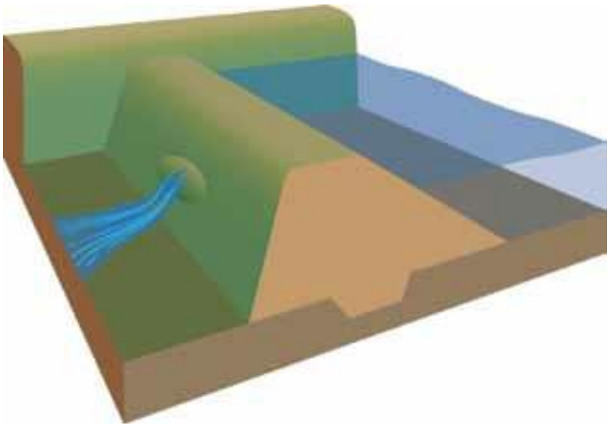
- Can indicate a saturated area.
- Obscures large portions of the dam, preventing adequate, accurate visual inspection of all portions of the dam. Problems, which threaten the integrity of the dam, can develop and remain undetected until they progress to a point that threatens the dam's safety.
- Associated root systems develop and penetrate into the dam embankment. When the vegetation dies, the decaying root systems can provide paths for seepage. This reduces the length of the effective seepage path through the embankment and could lead to possible 'piping' situations (see Glossary).
- Prevents easy access to all portions of the dam for operation, maintenance and inspection.
- Provides habitat for rodents and other animals.

**Action required:**

- Use probe and shovel to establish if the materials in this area are wetter than in surrounding areas.
- Remove all detrimental growth from the dam, including removal of trees, bushes, and growth other than grass. Encourage grass on all ports of the dam to prevent erosion by surface run-off. Remove root systems to the maximum practical extent. Backfill the resulting voids with competent, well-compacted, non-dispersive material. However, the root systems of large and mature trees may penetrate deeply into the embankment and it is recommended that the advice of a Dams Engineer is sought when removing large and mature trees from dam embankments.
- Remove further undesirable growth by cutting or spraying as part of an annual maintenance program.
- Take all cuttings or debris resulting from the vegetation removal from the dam and properly dispose of them outside the reservoir basin.
- If area shows wetness when surrounding areas do not, have a Dams Engineer inspect the condition and recommend further actions.

## Seepage

**Bulge in large wet area**



**Cause:**

- Downstream embankment materials have begun to move.

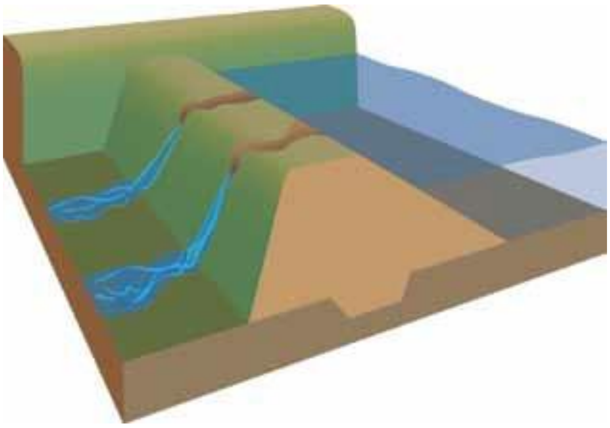
**Harm:**

- Failure of the embankment due to massive sliding can follow these initial movements.

**Action required:**

- Compare the observed embankment cross-section with the end of construction condition to see if observed condition may reflect the end of construction condition or if it represents subsequent movement.
- Stake out affected area and accurately measure outflow.
- Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

**Water exiting through transverse cracks on the crest**



**Cause:**

- Severe drying has caused shrinkage of embankment material.
- Settlement in the embankment or foundation is causing the transverse cracks.

**Harm:**

- Flow through the crack can cause failure of the dam.

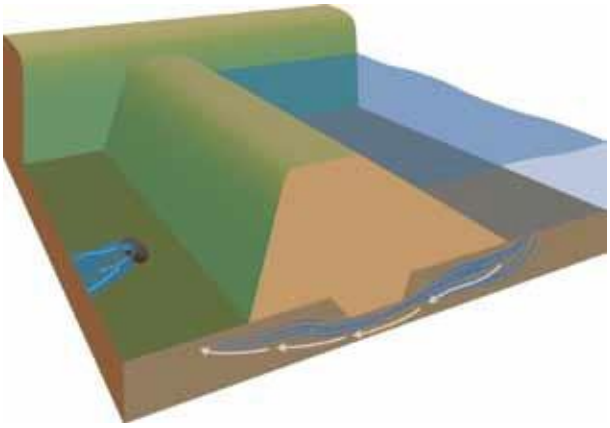
**Action required:**

- Plug the upstream side of the crack with clay to stop the flow but do not get into the water to do so.
- Lower the water level in the dam until it is below the level of the cracks.
- Have a Dams Engineer inspect the condition and recommend further actions.

**Note: The pattern of cracks (e.g. where they are located, how close together they are, whether transverse alone or in conjunction with other cracks, etc) requires engineering experience to interpret it. The real cause of cracks may not be apparent to an unqualified observer.**

## Seepage

**Seepage water exiting from the foundation (sometimes called a 'boil')**



**Cause:**

- Some portion of the foundation material is providing a flow path.
- A sand or gravel layer in the foundation could cause this.

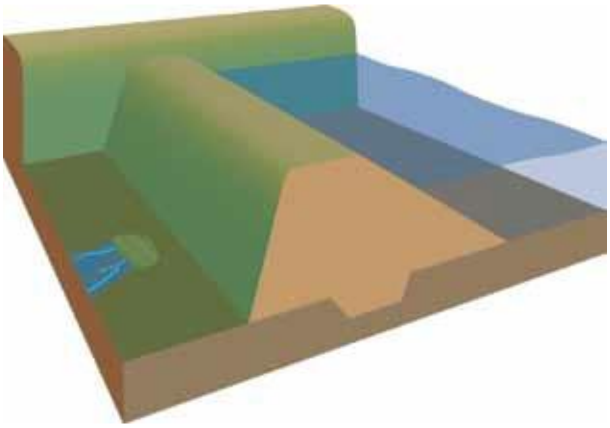
**Harm:**

- Increased flows can lead to erosion of the foundation and failure of the dam.

**Action required:**

- Examine the boil for transportation of foundation materials.
- If soil particles are moving downstream, use sandbags or earth to create a dyke around the boil. The pressure created by the water level within the dyke may reduce the uplift pressure in the boil and control flow velocities and temporarily prevent further erosion.
- If erosion is becoming greater, lower the dam level. Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

**Trampoline effect in large soggy area (i.e. area springy or spongy)**



**Cause:**

- Water moving freely through the embankment or foundation is being controlled or contained by a well-established turf root system.

**Harm:**

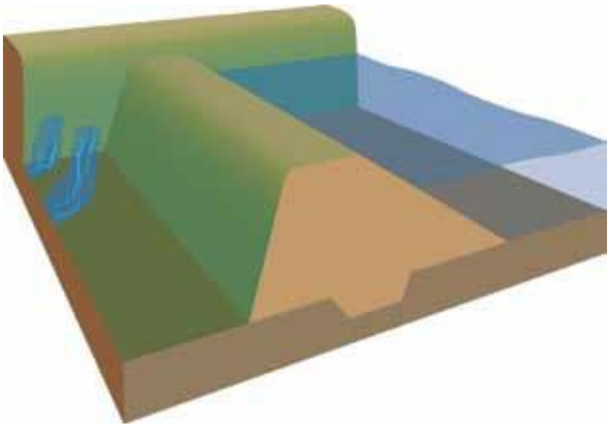
- Condition indicates excessive seepage in the area. If the upper layer of soil in the area is eroded or removed, the erosion of foundation materials could result in failure of the dam.

**Action required:**

- Carefully inspect the area for outflow quantity and any transported materials.
- Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

## Seepage

### Leakage from abutment beyond the dam



**Cause:**

- Water moving through cracks and fissures in the abutment materials.

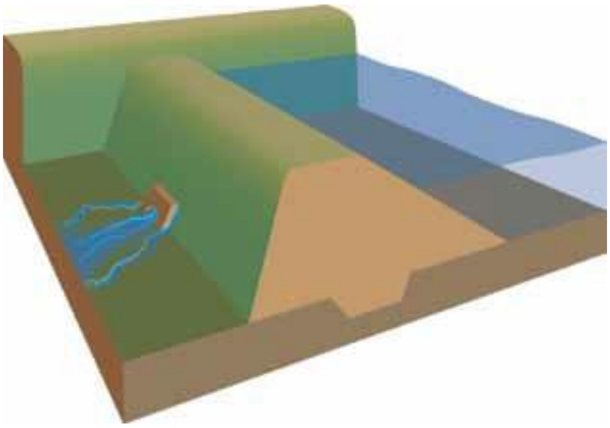
**Harm:**

- Can lead to rapid erosion of abutment and emptying of the dam.
- Can lead to massive slides near or downstream of the dam.
- Failure of abutment and loss of control of the dam (in effect a dam failure).

**Action required:**

- Carefully inspect the area to determine quantity of flow and amount of transported material.
- Have a Dams Engineer inspect the condition and recommend further actions.
- May need to block entry on upstream side, but do not get into the water to do so.
- If erosion is becoming greater, lower the dam level. Be prepared to lower the dam level.

### Seepage water exiting from a point adjacent to the outlet



**Cause:**

- A break in the outlet pipe.
- A path for flow has developed along the outside of the outlet pipe.

**Harm:**

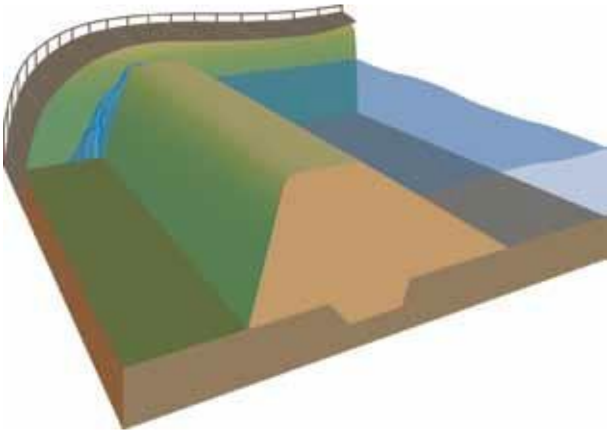
- Continued flows can lead to rapid erosion of embankment materials and failure of the dam.

**Action required:**

- Thoroughly investigate the area by probing to see if the cause can be determined.
- Determine if leakage water is carrying soil particles.
- Determine quantity of flow.
- If flow increases or is carrying embankment materials, lower the dam water level until leakage stops. Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

## Seepage

### Leakage in or around spillway



**Cause:**

- Cracks and joints in geologic formation at spillway are permitting seepage.
- Gravel or sand layers at spillway are permitting seepage.

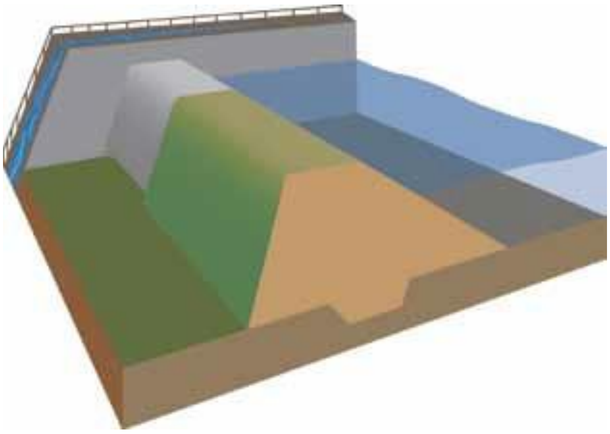
**Harm:**

- Could lead to excessive loss of stored water.
- Could lead to progressive failure if velocities are high enough to cause erosion of natural materials.

**Action required:**

- Examine exit area to see if type of material can explain leakage.
- Measure flow quantity and check for erosion of natural materials.
- If flow rate or amount of eroded materials increases rapidly, lower the dam water level until flow stabilises or stops. Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.
- Consider installing upstream valve on outlet pipe.

### Seepage from crack in concrete or structure construction joint



**Cause:**

- Water is collecting behind structure because of insufficient drainage or clogged weep holes.

**Harm:**

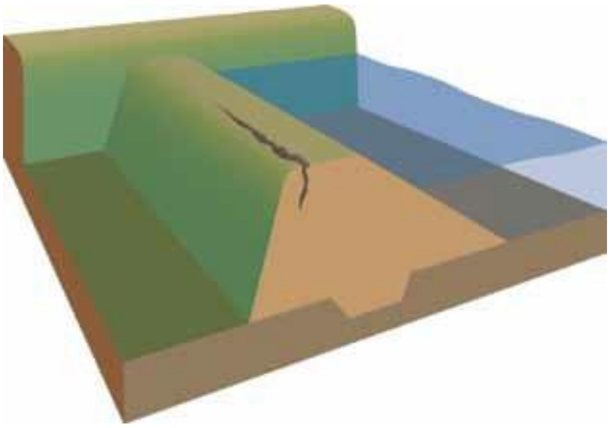
- Can cause walls to tip in and fall over. Flows through concrete can lead to rapid deterioration from weathering.
- If the spillway is located within the embankment, rapid erosion can lead to failure of the dam.
- Excessive flows under the spillway could lead to erosion of foundation material and collapse of portions of the spillway.
- Uncontrolled flows could lead to loss of stored water.

**Action required:**

- Check area behind wall for ponding of surface water.
- Immediately measure flow quantity and check flows for transported drain material.
- If flows are accelerating at a fixed storage level, lower the reservoir level until the flow stabilises or stops. Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

## Cracking

### Longitudinal cracking



**Cause:**

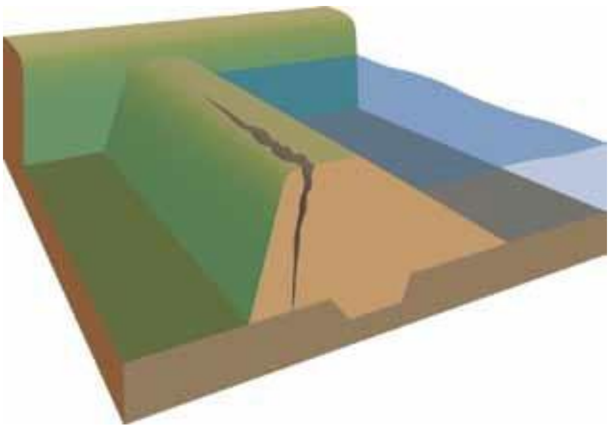
- Drying and shrinkage of surface material.
- Downstream movement or settlement of embankment.

**Harm:**

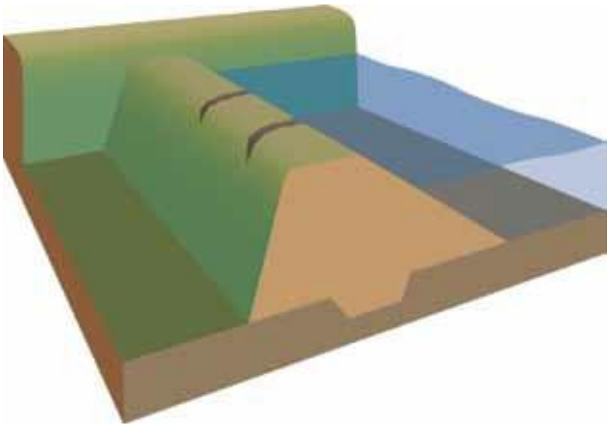
- Can be an early warning of a potential slide.
- Shrinkage cracks allow water to enter the embankment and further weaken the embankment.
- Settlement or slide indicating loss of strength in embankment can lead to failure.

**Action required:**

- If cracks are from drying, dress area with well-compacted material to keep surface water out and natural moisture in.
- If cracks are extensive, or growing in length, width or number, have a Dams Engineer inspect the condition and recommend further actions.



### Transverse cracking



**Cause:**

- Drying and shrinkage of surface material is most common cause.
- Differential settlement of the embankment also leads to transverse cracking (e.g. centre settles more than abutment).

**Harm:**

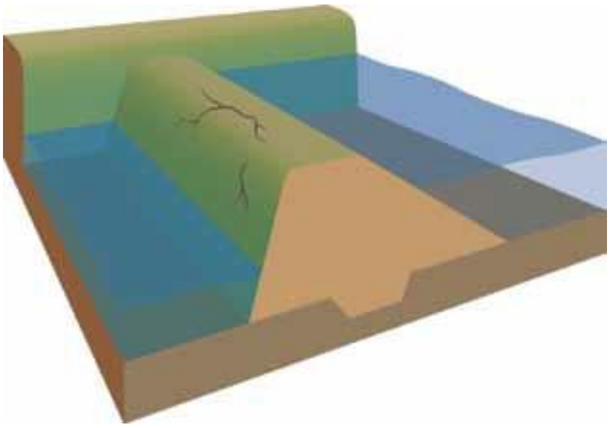
- Shrinkage cracks allow water to enter the embankment and weaken it and may lead to failure.
- Settlement cracks can lead to seepage of reservoir water through the dam causing erosion and failure.

**Action required:**

- If necessary plug upstream end of crack to prevent flows from the reservoir. Be prepared to lower the dam level.
- Clean up cracks and backfill with compacted material.
- If cracks are extensive, or growing in length, width or number, have a Dams Engineer inspect the condition and recommend further actions.

## Cracking

**Cracks due to drying (random pattern)**



**Cause:**

- The soil loses its moisture and shrinks, causing cracks. Usually seen on crest and downstream slope.

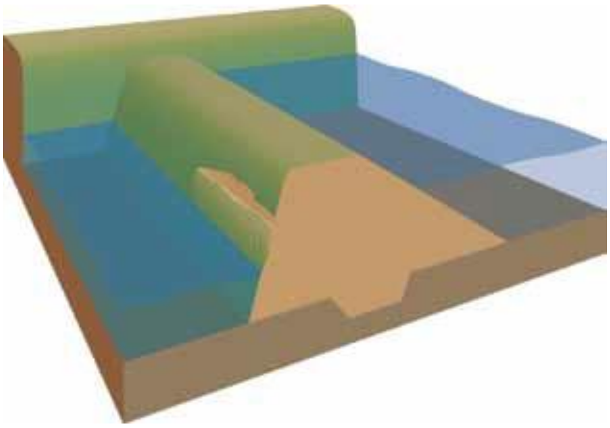
**Harm:**

- Heavy rains can fill up cracks soften the soil and cause small portions of embankment to move along internal slip surfaces.
- Provides points of entrance for surface run-off, leading to deterioration of the crest.

**Action required:**

- Monitor cracks for increases in width, depth, or length.
- On crest, seal surface cracks with a tight impervious material.
- Routinely grade crest to provide proper drainage and fill cracks.
- Cover crest with non-plastic (not clay)
- material to prevent large moisture content variation with respect to time.
- If the cracking is considerable or appears serious, have a Dams Engineer inspect the condition and recommend further actions.

**Slide, slump or slip**



**Cause:**

- Lack of or loss of strength of embankment material.
- Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation.
- Earth or rocks move down the slope along a slippage surface because they were on too steep a slope or the foundation moves.

**Harm:**

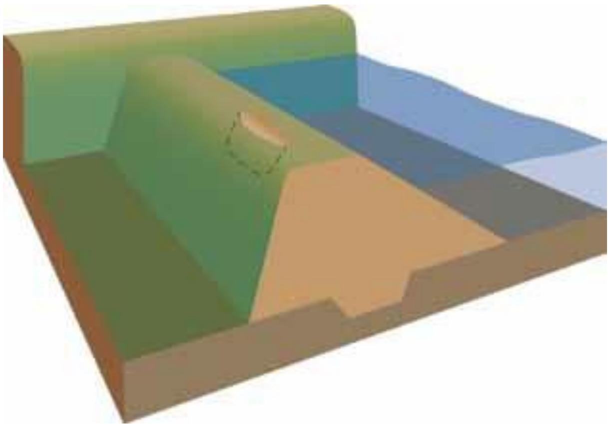
- A slide can reduce the dam's seepage path. This can accelerate the rate of seepage and lead to loss of material.
- A series of slides can lead to obstruction of the outlet or failure of the dam.

**Action required:**

- Evaluate extent of the slide. Monitor slide.
- Draw the dam water level down if safety of dam is threatened. Be prepared to lower the dam level.
- Have a Dams Engineer inspect the condition and recommend further actions.

## Cracking

### Sinkhole in crest



**Cause:**

- Internal erosion or piping of embankment material by seepage.
- Breakdown of dispersive clays within embankment by seepage waters or rain.
- Hole in outlet conduit is causing erosion of embankment material.
- Rodent/animal activity.

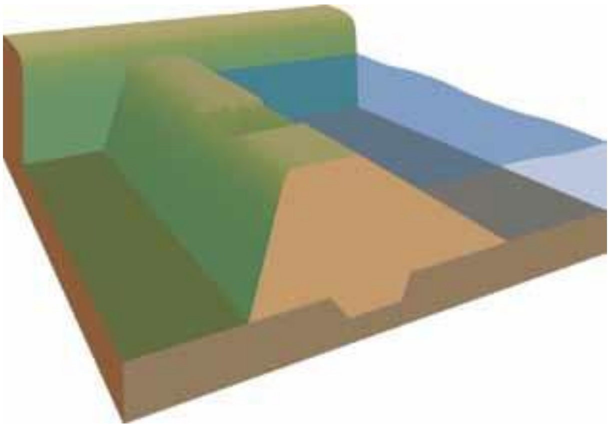
**Harm:**

- A void within the dam embankment could cause localised caving, sloughing, instability, or reduced embankment cross section.
- Entry point for surface water, loss of soil leading to instability of embankment failure.

**Action required:**

- Carefully inspect and record location and physical characteristics (depth, width, length) of sinkhole.
- A Dams Engineer should determine cause of sinkhole and supervise all steps necessary to reduce threat to dam and correct condition.
- Excavate the sinkhole, slope-sides of excavation, and backfill hole with competent material using proper construction techniques. A Dams Engineer should supervise this.

### Low area or dip in crest



**Cause:**

- Excessive settlement in the embankment or foundation directly beneath the low area in the crest.
- Internal erosion of embankment material.
- Foundation spreading toward upstream and/or downstream direction.
- Foundation wind erosion of crest area.
- Improper final grading following construction.

**Harm:**

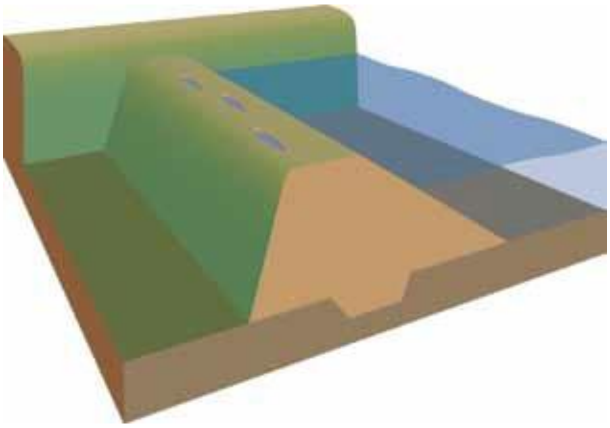
- Reduces freeboard available to pass flood flows safely through spillway and increases risk of dam overtopping and failure.

**Action required:**

- Determine exact amount, location, and extent of settlement in crest.
- A Dams Engineer should determine cause of the low area and supervise all steps necessary to reduce possible threat to the dam and correct condition.
- Re-establish uniform crest elevation over crest length by placing fill in low area using proper construction techniques. A Dams Engineer should supervise this.
- Establish markers across crest of dam and monitor on a routine basis to detect possible future settlement.

## Cracking

### Puddling on crest – poor drainage



**Cause:**

- Poor grading and improper drainage of crest.
- Localised consolidation soft spots or settlement on crest allows puddles to develop.

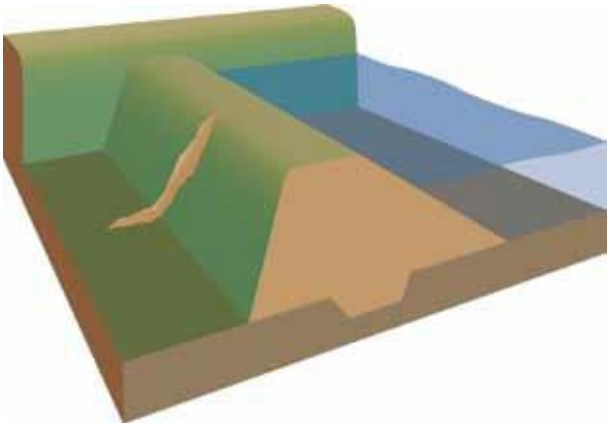
**Harm:**

- Causes localised saturation of the crest and loss of soil strength.
- Inhibits access to all portions of the dam and crest.
- Becomes progressively worse if not corrected.

**Action required:**

- Drain standing water from puddles.
- Regrade and re-compact crest to restore integrity and provide proper drainage toward upstream slope.
- Provide gravel or road-base material to accommodate traffic.
- Perform periodic maintenance and regrading to prevent reformation of low areas.

### Erosion gully on crest and downstream slope



**Cause:**

- Heavy rainfall.
- Poor grading and improper drainage of crest. Improper drainage causes surface runoff to collect and drain off crest at low point in upstream or down-stream shoulder.
- Inadequate spillway capacity which has caused dam to overtop.

**Harm:**

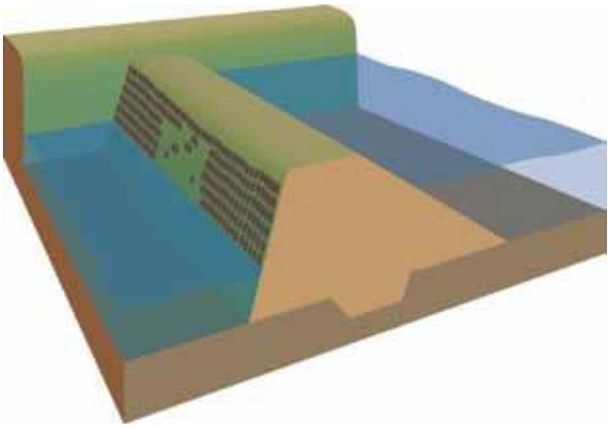
- Can reduce available freeboard.
- Reduces cross- sectional area of dam.
- If allowed to continue, can lead to severe deterioration of downstream slope and shorter internal drainage path.

**Action required:**

- Protect eroded areas with rock or clay.
- Regrade crest to provide proper drainage of surface run-off.
- If gully was caused from overtopping, provide adequate spillway, which meets current design standards. This should be done by a suitably qualified Dams Engineer.
- Re-establish protective cover.

## Miscellaneous

### Broken down or lost rock beaching



**Cause:**

- Poor-quality beaching has deteriorated. Wave action has displaced beaching. Round and similar-sized rocks have rolled downhill.
- Similar-sized rocks allow waves to pass between them and erode small gravel particles and soil.

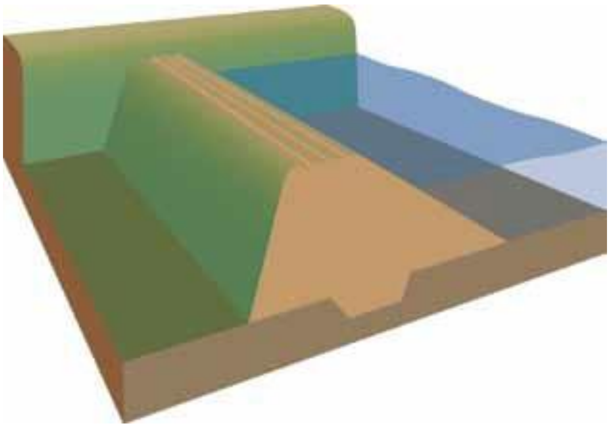
**Harm:**

- Soil is eroded away from behind the beaching. This allows beaching to settle, providing less protection and decreased embankment width. Wave action against these unprotected areas decreases embankment width.
- Causes over- steepness of upstream slope increasing instability and resulting in reduced crest width.

**Action required:**

- Re-establish effective slope protection. Place bedding material.
- Use an engineer to design the gradation and size of rock for bedding and beaching.
- Have a Dams Engineer inspect the condition and recommend further actions.

### Ruts along crest



**Cause:**

- Heavy vehicle traffic without adequate or proper maintenance or proper crest surfacing.

**Harm:**

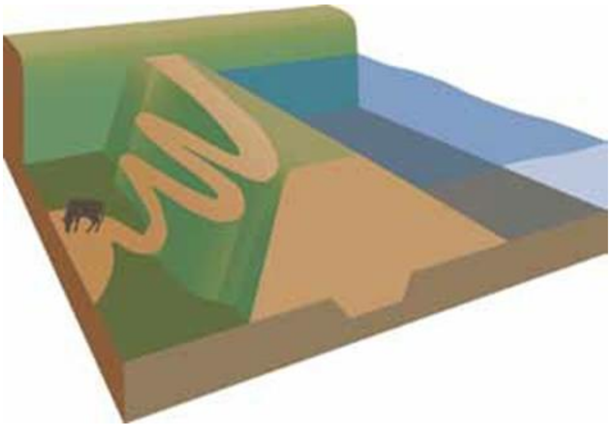
- Inhibits easy access to all parts of crest.
- Allows continued development of rutting. Allows standing water to collect and saturate crest of dam. This may initiate localised tunnel erosion through to the downstream slope, and cause further softening of the crest.
- Loss of soil strength in embankment.
- Vehicles can get stuck.

**Action required:**

- Drain standing water from ruts.
- Regrade and re- compact crest and provide proper drainage toward upstream slope.
- Provide gravel or road-base material to accommodate traffic.
- Perform periodic maintenance and regrading to prevent reformation of low areas.

## Miscellaneous

### Livestock traffic



**Cause:**

- Excessive travel by livestock especially harmful to slope when wet.

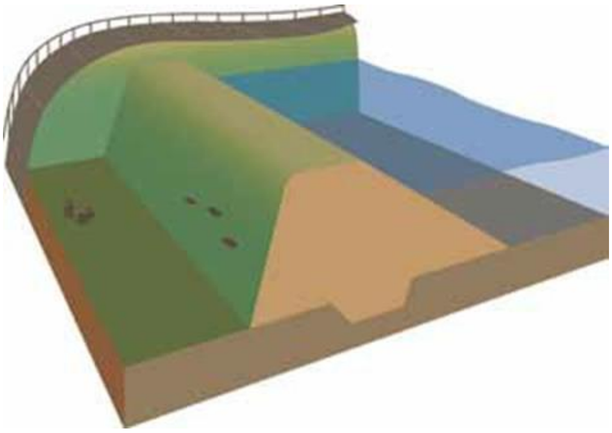
**Harm:**

- Creates areas bare of erosion protection grass cover.
- Causes erosion channels. Allows water to stand. Area susceptible to drying cracks.

**Action required:**

- Fence livestock outside embankment area.
- Repair erosion gully.
- Recover with grass for protection.

### Pest Animal Activity



**Cause:**

- Over-abundance of animal pests.
- Favourable habitat or burrowing conditions at dam.

**Harm:**

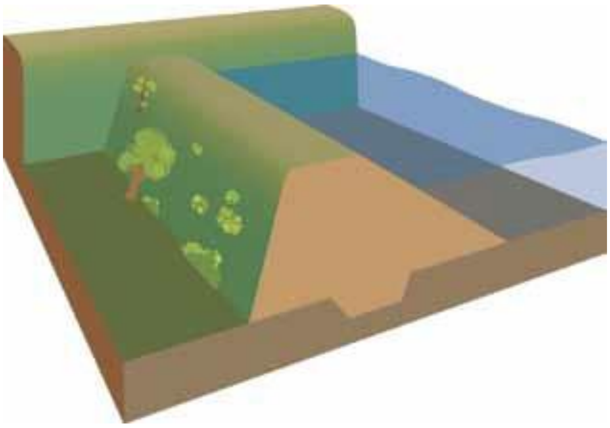
- Burrows can substantially reduce leakage path, leading to piping failure.

**Action required:**

- Control pests to prevent additional damage.
- Provided the diagnosis is correct, determine the extent of burrowing, and dig out the burrow and then backfill with well-compacted, non-dispersive clay, working from upstream to downstream as far as possible.
- If there is any doubt at all as to the cause, size, condition or best remedial methods of these holes/burrows, seek professional advice from a Dams Engineer and environmental/pest experts before any remedial action. Holes in the embankment can increase the risk of 'piping' failure.

## Miscellaneous

### Obscuring vegetation and trees



**Cause:**

- Natural vegetation (self-sown) and/or planted vegetation.

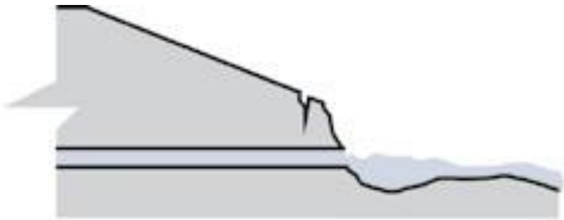
**Harm:**

- Large tree can die. Roots can then create seepage paths.
- Bushes can obscure visual inspection.
- Provides habitat for rodents and animals.
- Trees can fall, creating holes in crest or side slopes.

**Action required:**

- Remove large deep rooted trees and shrubs on or near embankment. However, the root systems of large and mature trees may penetrate deeply into the embankment. It is strongly recommended that the advice of a Dams Engineer is sought when removing large and mature trees and large, woody vegetation from dam embankments. If removed incorrectly, the condition of the dam may be significantly worsened compared with prior to removal.
- Properly backfill void left by tree stump with well-compacted, non-dispersive clay, following the advice and specification of your Dams Engineer.
- Control all other vegetation on the embankment that obscures visual inspection.

### Outlet releases eroding toe of dam



**Cause:**

- Outlet pipe too short (and/or damaged).
- Lack of energy dissipating pool or structure at downstream end of conduit.

**Harm:**

- Erosion of toe over- steepens downstream slope, causing progressive sloughing and slope instability.
- Eroded material causes environmental damage.

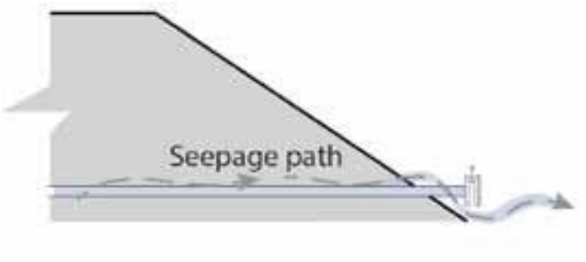
**Action required:**

- Extend pipe beyond toe. Use a pipe of same size and material, and form watertight connections to existing the conduit. It is recommended to have a suitably qualified Dams Engineer inspect the condition and recommend further actions)
- Protect embankment with riprap or other suitable erosion protection over a suitable bedding.
- Install upstream valve or cofferdam arrangement to isolate pipeline and enable inspections and remedial work.

**It is strongly recommended not to retain or plant large, woody and/or deep-rooted vegetation on or within 5-10 m of a dam embankment or spillway. Seek advice from a Dams Engineer for removing large, woody vegetation as roots may penetrate deeply into the embankment. Inappropriate removal may cause further damage.**

## Miscellaneous

### Piping along outlet




**Cause:**

- Fracture or joint failure in outlet pipe.
- Seepage along outside of pipe (poor construction).

**Harm:**

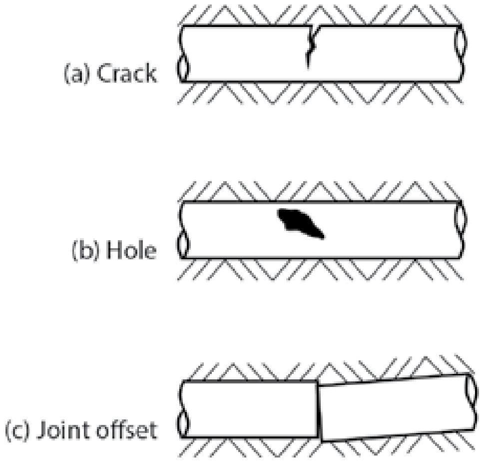
- Will get progressively worse and cause embankment failure.
- Can be difficult to stop once it progresses beyond a seep.

**Action required:**

- Investigate cause by probing and digging.
- Determine if leakage is carrying soil particles and monitor flow rate changes.
- If flow increases lower dam water level as quickly as possible. Be prepared to lower the dam level.
- Have a suitably qualified Dams Engineer inspect the condition and recommend further actions.
- Install upstream valve or cofferdam arrangement to isolate pipeline and enable inspections.

**Outlet pipe damage can be difficult to diagnose because they occur within the embankment.**

### Outlet pipe damage




**Cause:**

- Settlement, impact and/or poor construction.
- Rust (steel pipe) pitting.
- Failure of pipe joints.

**Harm:**

- Excessive seepage, possible internal erosion.
- Provides a path for water to exit or enter the pipe, resulting in erosion of internal materials of the dam and possibly dam failure.

**Action required:**

- Check for evidence of water either entering or exiting pipe at crack/hole/etc.
- Tap pipe in vicinity of damaged area, listening for hollow sound that shows a void has formed along the outside of the conduit.
- If there is any suspicion at all of a progressive failure, request urgent engineering advice from a Dams Engineer. Be prepared to lower the dam level.
- Install upstream valve or cofferdam arrangement to isolate pipeline and enable inspections.

**Do not allow anyone to enter the water to try and block the outlet when water is flowing.**