

APPENDIX E – SMALL DAM GUIDELINES

The Republic of Uganda

Draft Guidelines for Managing Small Dams



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Foreword

The construction of a dam can involve a significant investment. Dam owners need to ensure that their money is well spent and that their dam becomes an asset rather than a liability. A properly constructed dam is an asset, a poorly constructed dam is a liability.

This guide aims to help owners of small dams understand their responsibilities associated with planning, building and operating a dam. It focuses on the technical aspects of dam construction but also explains the responsibilities that dam owners may have under the *Water Act*.

Failures of small dams are common; they threaten local communities and cause property and environmental damage. Most dams that fail are inadequately designed or have been poorly constructed. In the event of a failure, dam owners are responsible and indeed liable for any damage their dam may cause to others.

All existing and prospective owners of small dams will benefit from using these Guidelines.

TABLE OF CONTENTS

PREFACE	vii
1 Introduction	1
2 Risks Posed by Dams	3
2.1 The Owner's Responsibilities	3
2.2 Legal Liabilities of Private Dam Owners	3
2.3 Duty of Care	4
2.4 Definition of Dam	4
2.5 Potential Impact Classification (PIC)	5
2.6 Likelihood of a Dam Failing	6
2.7 Complaint or Incident	7
2.8 Consequence of Failure	7
2.9 Insurance	8
2.10 Buying a Property with a Dam	8
3 Permit Requirements for Small Dams	9
3.1 Take and use Permits	9
3.2 Construction Permits	9
3.3 Operating Licences	9
3.4 Regulating/Licensing Authorities	10
3.5 Licensing Process	10
3.6 Environmental Requirements for New Dams (on or off Waterways)	12
3.7 On-site Environmental Issues for Dams on Waterways	13
4 Planning to Build a Dam	15
4.1 Dam Features	15
4.2 Services of an Engineer	16
4.3 Types of Dams	17
4.4 Site Investigations	21
4.4.1 Selecting the Dam Site	21
4.4.2 Site Studies	22
4.5 Considerations at Investigation Stage	24
4.5.1 Environmental	24
4.5.2 Compensation Flow Requirements	24
4.5.3 By-Pass Channels	25
4.6 Dam Design	25
4.6.1 Standard Designs	25
4.6.2 Extreme Events	26
4.7 Health and Safety Issues	26
5 Construction of a Dam	28
5.1 Selecting a Contractor	28
5.2 Construction Supervision	28
5.3 Dam Foundations	29
5.4 Embankment Materials and Construction	30
5.4.1 Selection of Materials	30
5.4.2 Placement of Embankment Materials	31
5.4.3 Compaction of Embankment Materials	31
5.5 Outlet Pipes or Structures in Embankment	32
5.6 Spillways	33
6 Safety Surveillance	34

6.1	Purpose of Regular Inspection	34
6.2	Inspection Procedures and Methods	35
6.3	Frequency of Inspections	36
6.4	Special Inspections.....	38
6.5	Problems Likely to be Encountered	38
6.6	How to Deal with Problems	39
6.7	Inspection Checklists.....	40
7	Operation and Maintenance of Dams.....	41
7.1	Control of Flows	41
7.2	Routine Surveillance.....	42
7.3	Filling and Emptying.....	42
7.4	Maintenance	43
7.5	Maintenance Problems	43
7.5.1	Dispersive Clays	43
7.5.2	Seepage and Leakage	45
7.5.3	Erosion	46
7.5.4	Stock Damage.....	47
7.5.5	Yabby Damage.....	48
7.5.6	Rabbit and Wombat Damage	48
7.5.7	Cracking and Movement	48
7.5.8	Defects in Associated Structures.....	49
7.5.9	Outlets and Valves	50
7.5.10	Vegetation	51
7.6	Modifications.....	52
8	Dam Failure Emergency Action.....	54
8.1	Extreme Events.....	54
8.2	Emergency Preparedness	54
8.3	How to Deal with a Dam Failure Concern.....	55
8.3.1	Emergency Checklist.....	56
8.3.2	Contact Organisations for Advice.....	57
9	Decommissioning of Dams.....	58
9.1	Removal or Decommissioning of a Dam.....	58
9.2	Rehabilitation of Site	59
9.3	Maintenance of Site Until Stable	59
10	Glossary of Terms	61
11	References and Suggested Further Reading	66
APPENDIX A: CONDUCTING AN INSPECTION		1
APPENDIX B: COMMON PROBLEMS - THEIR CAUSES, CONSEQUENCES AND ACTION REQUIRED		1
APPENDIX C: STANDARD DESIGN GUIDE FOR SMALL DAMS.....		1
APPENDIX D: DAM SAFETY EMERGENCY PLAN.....		1

Disclaimer and Warning

This document is intended for use 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 guide is not intended as a manual or as a source of detailed information to cover all possible eventualities.

The successful planning, design, construction and operation of any particular dam will depend not only on application of general principles or guidelines, but also on a combination of technical factors which are peculiar to that dam and which will generally not be apparent in their entirety or significance to persons other than professionals who are experienced in this work, even for small dams.

Therefore, while this guide has been prepared in good faith, no responsibility is taken by its authors or the Republic of Uganda for any outcome of the application of its guidelines to any particular dam, whether existing or proposed. Readers of this guide are further warned that application of its contents to any particular situation should not be attempted without advice from a professional engineer who is experienced in these matters.

Furthermore, in the event of any suspected, imminent or potential failure condition, expert advice should be sought immediately. Also notify Police, Directorate of Water Development and the National Environmental Management Authority as a matter of urgency.

PREFACE

Even small dams have the potential to cause damage not only to property and the environment, but also injury or death to persons. This document provides some guidance on current practices relating to 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. The Water Act 1995 specifies licensing requirements for the construction and operation of dams and licensing the taking and use of water from them.

This guide concentrates on the planning, construction and operational aspects and the safety management of small dams with a Potential Impact Classification (PIC) of no greater than 1. For PIC 2 and PIC 3 dams, the dam owners must use the more comprehensive Ugandan Guidelines on Dam Safety Management 2005.

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

- ◆ if it fails, you are likely to be held liable for any loss of life, injury or damage which results;
- ◆ even if you are able to prove in a court of law that some or all of the responsibility for a failure lies with others, it is very likely that you will still be considerably out of pocket; and
- ◆ even if a failure does not cause damage outside your property, the cost of remedial work can easily exceed the original construction cost of the dam.

This means that you should:

- ◆ have your dam designed and construction supervised by a suitably qualified and experienced professional engineer;
- ◆ establish a program of regular inspections (surveillance) and periodic maintenance, including the keeping of appropriate records;
- ◆ be able to recognise the signs of potential problems and imminent failure; and
- ◆ know what to do and who to contact when such signs appear.

These matters are covered in general descriptive terms in the first part of the guide. The Appendices list in greater detail the causes, consequences and remedies of problems most often experienced by dam owners in Uganda, and outline suggested procedures for routine inspections and surveillance activities.

1 Introduction



A poorly built or maintained dam can cost the owner more to repair than a dam that is properly built and well looked after.

Photo courtesy of D Plant

It makes good business sense to build a dam properly. It is a business investment for any dam owner; an asset which can assure the health of the crops or livestock which the property supports.

Dams are deceptively simple structures in appearance. Despite outward appearances, there is always the possibility that the dam might experience either partial or total failure and cause damage downstream. 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 (eg. electricity) and cause environmental damage. If a dam fails, the additional loss of income resulting from lack of water could result in substantial economic consequences.

The fact that dam failures in Uganda are seldom reported in the press can lead to a false impression that dam failures are both rare and of little consequence.

This guide is designed to assist both present and future dam owners to understand their responsibilities and legal obligations.

It includes:

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

As a dam owner, you have an important role to play in the dam safety process. Frequent visits to the dam are needed to enable you to observe any problems that may be developing.

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

- ◆ having the dam properly planned and designed;
- ◆ having it properly constructed to meet design requirements and specifications; and

- ◆ ensuring that professional advice is obtained for the above purposes.

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

- ◆ carrying out safety surveillance procedures; and
- ◆ properly operating and maintaining the dam.

Sections 2 and 3 of this guide give more information on the dam owner's legal obligation and liabilities.

Legal requirements that affect small dams include the need for:

- (a) a **Water Permit** for all irrigation and commercial dams, issued by the Directorate of Water Development (DWD);
- (b) an **Environmental Impact Assessment** required by the National Environmental Management Authority (NEMA); and
- (c) any requirement for **Planning Permits**.

2 Risks Posed by Dams

2.1 The Owner's Responsibilities

'Failure' of a dam does not necessarily mean the same as 'collapse' of the dam. More generally, it may mean failure to its design objectives. Hence, 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 any inability to pass incoming flood waters via the spillway, may be regarded as a failure of the dam, though some failures may be more serious than others.

Should a dam fail, its owner is likely to be held legally liable for all associated damage. To minimise the possibility of failure and the attached liability, an owner should:

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

2.2 Legal Liabilities of Private Dam Owners

Owners of private dams may be legally liable for damage caused by the failure of a dam on a variety of different grounds.

These grounds may arise under the Water Act or at common law. Generally the relevant sections of the Water Act provide that if there is a flow of water from the land of a person onto any other land; and that flow is not reasonable; and the water causes:

- (a) injury to any other person; or
- (b) damage to the property (whether real or personal) of

any other person; or

(c) any other person to suffer economic loss;

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

Dam owners with concerns about their potential liability should seek their own legal advice, as the legal situation will vary according to the circumstances of each dam.

2.3 Duty of Care

The 'duty of care' is imposed by society and enforced at law.

It is clear that the duty of care for an owner of a potentially hazardous item is more onerous and far reaching than previously realised. Furthermore, court actions by those alleging breach of duty of care are more likely and the consequences more severe.

To fulfil their duty of care, dam owners must make sure that all things that can go wrong have been checked and measures put in place so that the likelihood and the consequences of a dam failure can be minimised using the best advice and methods reasonably available. Such advice will often be outside the expertise of the owner.

2.4 Definition of Dam

Under Ugandan Regulations Governing Classification of Dams (2005) a dam is defined as any structure designed to store water above the level at which it would normally be retained.

The term 'dam' includes the embankment and all other parts such as spillway, outlet and valves.

Construction of a dam may be from earth or other suitable materials. It may be located on a hillside, in a gully or on a waterway.

Information in this guide mainly concerns those dams that rely on an embankment or barrier for holding the water, and assumes that the 'embankment' is constructed from earth materials. If your dam is not an earthen dam (eg. if it

constructed from concrete or other materials) some of the information in this guide will not apply to your circumstances and you should seek advice from a suitably experienced professional engineer.

2.5 Potential Impact Classification (PIC)

Note:

The Australian National Committee on Large Dams (ANCOLD) is the national dams engineering body which prepares guidelines on dams in Australia.

Ugandan Regulations Governing Classification of Dams (2005) defines the Potential Impact Classification (PIC).

PIC for the dam should be the highest classification obtained from the Risk Classifications shown in Table below:

TABLE : POTENTIAL IMPACT CLASSIFICATION

Life Safety Risk	Environmental Classification	Social Disruption Classification	Economic Risk	Potential Impact Classification
Low	Low or Moderate	Low or Local	Low	1
Moderate	High	Regional	Moderate	2
High or Extreme	Extreme	National	High or Extreme	3

All dams in Uganda would have a PIC. This guide is intended for the owners of dams that have a PIC of no greater than 1.

Any dam, due to their size and/or location, could pose a threat to life, property or the environment if they were to fail. This does not necessarily mean that they are expected to fail.

If you are unsure of the potential damage your dam can cause in the event it fails, it is important to have it assessed by a suitably qualified engineer.

For a dam that is regarded as having a potential impact, you should seek the services of an engineer to:

- ◆ design your dam and supervise its construction; and
- ◆ 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; and
- ◆ be able to demonstrate/keep records to prove that as the owner you have been diligent.

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.

2.6 Likelihood of a Dam Failing



Photo courtesy of B. Lewis



It started as a small leak

Photo courtesy of D. Plant

Photos of dam failures in this guide are examples of one or more of the above conditions.

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 best materials and methods to make it resistant to leakage and erosion.

Although small dam failures do not make their way into the news media very often, it is a fact that across the country a large proportion of small dams fail.

The most common causes for failure of small dams in Uganda are as follows:

- (a) Design is not adequate.
- (b) Understanding of site conditions is poor.
- (c) Site preparation is not good enough.
- (d) Embankment material is not suitable.
- (e) Embankment placement methods are substandard eg. soil compaction methods.
- (f) Maintenance or inspection frequencies are inadequate, and/or remedial measures identified in maintenance inspections are not adequately acted upon.

Many failures result in total loss of the dam. In those cases where damage can be repaired, the costs of repairs can be very high, and possibly greater than the original cost of construction of the whole dam.

Many dams, even of modest size, should be designed and their construction supervised by an experienced dam engineer. The advice of an experienced engineer should also be sought if any problems or uncertainties occur after the dam has been in service.

2.7 Complaint or Incident

Where a dam safety related complaint or incident is brought to the attention of a Regulating Authority, the circumstances will be investigated and, where appropriate, a direction may be given to the owner to undertake appropriate works.

If the owner fails to comply with the direction, then the Regulating Authority may carry out the necessary works to make the dam safe and recover the costs from the owner.

2.8 Consequence of Failure



Cascade effect of upper dam failing needs to be considered

Photo courtesy of Southern Rural Water

If your dam fails, the sudden release of water and debris could result in property losses, loss of life or injury, and damage to downstream properties. Damages could include other dams downstream, houses, buildings, livestock, roads, railways or interruption to public utilities such as electricity and telephone. 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 amount of time to recover, if recovery is possible.

Regulating Authorities will determine the Potential Impact

Classification (PIC) of dam proposals and a construction licence may contain a condition that the dam is designed by a suitably qualified engineer according to acceptable and appropriate standards.

2.9 Insurance

Note:

The risk in owning a dam can be shared by having suitable insurance cover. The premium however, may depend on the insurance company's impression of how well you are able to manage the safety of the dam. This may take into account the engineering quality of the dam, your emergency action plans and the PIC. Dam owners should be aware that in situations where negligence of the owner is proved, insurance protection may be in doubt.

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

As an owner, you should look at a dam like any other asset. The dam is an asset like your house or motor vehicle. However, in certain respects, dams have some important differences. For example, with your house, your main concern about risks is likely to be the consequences of damage to that asset; with a dam, it is a matter of limiting the potential for the asset itself to cause damage. Therefore, there is a sense in which your dam is not only an asset but also a potential liability!

Take a look in the direction that outflow from the dam would be expected to take. If the dam fails, is there anything that it could 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, you should carefully consider the benefits of insurance.

Be aware however, that like a car your dam must be kept in a good condition to be accepted for an insurance claim.

2.10 Buying a Property with a Dam

If you are planning to buy a property that has a dam, it will be in your interest to check with the Regulating Authority to make certain that the necessary licences and requirements are in order. In particular, check that the dam is not subject to an order for carrying out works to make it safe, or that it does not carry a charge against the land in respect of works carried out by the Regulating Authority.

3 Permit Requirements for Small Dams

3.1 Take and use Permits

Where water in the dam is to be used for irrigation or commercial purposes you will also need a **Permit to Take and Use**, whether the dam is on a waterway or not. You will need to hold a 'take and use' permit for the period of time that you wish to take and use water out of the dam.

You need the permit to 'take and use' water before you can get a permit to construct the dam.

3.2 Construction Permits

In all cases where you wish to build a dam on a waterway you will need a once-off **Construction Permit**.

If you wish to build a dam off a waterway you will need a construction permit if the dam:

(a) is 5 metres or higher

or

(b) has a capacity of 25,000 cubic meters or greater.

Typically, a condition of the Construction Permit will require the dam to be designed and the construction supervised by a suitably qualified engineer if your dam:

- ◆ is located on a waterway with high ecological values; or
- ◆ is on a watercourse; or
- ◆ is of the dimensions given in (a), (b) or (c) above, whether or not the dam is on a waterway; or
- ◆ is considered to have a potential impact on the population and the environment downstream, or the economy as a whole.

3.3 Operating Licences

If you have a take and use permit, in most cases, conditions will also be set 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 PIC, whether or not you have a take and use permit, you may be required to have an operating licence that 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, the local Shire or Council permits may still be required.

You can read more about legal issues for dam owners under the Water Act.

3.4 Regulating/Licensing Authorities

Licensing Authorities are responsible for regulating the construction of dams and the use of water in particular they:

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

3.5 Licensing Process

There are different processes for new and existing dams as described below.

A **New dam** to be constructed needs to go through a licensing process where the owner needs to get the relevant approvals.

Once you have determined the permit/licensing requirements

for your dam, you will have to make an application to the Regulating/Licensing Authority in your area.

Applications must include any information that Licensing Authorities consider necessary to make a determination. This will include all of the information listed in 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 Potential Impact, the construction and operating permit may specify conditions relating to safety aspects. This may require you to seek the services of a suitably qualified engineer.

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

- ◆ 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; and
- ◆ the conservation policy of the government, existing acts, plans, strategies or policies at a catchment, regional or state level.

For new dams, the Regulating/Licensing Authority will refer your application to the Directorate of Water Development, National Environmental Management Authority and local government for comment before it is approved.

For **existing dams**, an operating licence is required if the dam has capacity of 25,000 cubic meters or greater.

The Operating licence will have conditions relating to dam safety, particularly relating to operation and maintenance of the dam. This may require you to seek the services of a suitably qualified engineer.

3.6 Environmental Requirements for New Dams (on or off Waterways)

Note:

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

To minimise environmental impacts of new dams, if a construction permit is approved, it may have conditions that will need to be satisfied.

When a Regulating/Licensing Authority receives an Application for the construction of a dam on a watercourse or a waterway with high ecological values, the Authority will only approve the Application if it is satisfied that:

- (a) there is documented evidence that consideration has been given to all available alternatives to constructing a dam at this location;
- (b) no reasonable alternatives exist to the Application; and
- (c) environmental requirements are likely to be met.

In addition, the Regulating/Licensing Authority may require you to undertake an Environmental Assessment Report for dams constructed on a waterway with high ecological values, prepared by a suitably qualified environmental consultant(s). Guidelines are available from Regulating/Licensing Authorities concerning environmental assessment reports.

Environmental requirements in the permit may include:

- ◆ the design and construction of a fishway approved by the Directorate of Water Development (DWD);
- ◆ meeting of environmental flows study approved by the National Environmental Management Agency;
- ◆ design and construction of works approved by the Ministry of Works and the DWD to:
 - (a) by-pass inflows around the dam outside of the Irrigation Season; and
 - (b) maintain an environmental flow in the waterway downstream of the dam at all times during the year.

3.7 On-site Environmental Issues for Dams on Waterways

Flora and fauna

The reason why dams are on waterways is because it is where water naturally collects and therefore will increase the likelihood of filling a dam. However, what is often overlooked is that more often than not, waterways 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 the flow patterns resulting from dam construction and operation.

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, drainage-line and may not flow for many months of the year. However, these habitats often support fish, invertebrates (bugs), frogs and birds that are adapted to these particular conditions. The effect of dams in changing flowing water to standing water will change the local habitat such that it is no longer suitable 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 often lead to local extinctions of such flora and fauna.

Dams constructed on waterways can also act as a physical barrier to migratory and localised movements of aquatic biota, particularly fish. Some species of native fish need to migrate in order to spawn and recolonise. 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 from sections upstream of the barrier. This will also have negative impacts for the species as a whole due to reduced access to critical spawning sites and habitat.

The impact of dam as a barrier will obviously vary depending

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 a potentially threatening process to flora and fauna, and thus must be managed to prevent such impacts on flora or fauna.

Sediment transport

Dams on waterways will capture almost all of 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.

In addition, the maintenance of dams may require the periodic flushing of accumulated sediments to improve water quality in the dam. Excess sediment input and deposited silt can be lethal to fish, fish eggs and invertebrates, and will have effects of smothering critical habitat such as spawning sites, nursery grounds and food sources. For invertebrates, sediment input will directly impact on the areas of the streambed where they live. Many invertebrates live amongst the rocks on streambeds, and sediment deposition fills spaces between rocks leaving them with no available habitat.

4 Planning to Build a Dam

It is important to realise that building or owning a dam carries responsibilities for the owner, regardless of any responsibilities which 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.

4.1 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 then they may have to be brought in from other areas or properly processed.

The 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. More generally, the main features of a dam are shown in Figure 4.1 below.

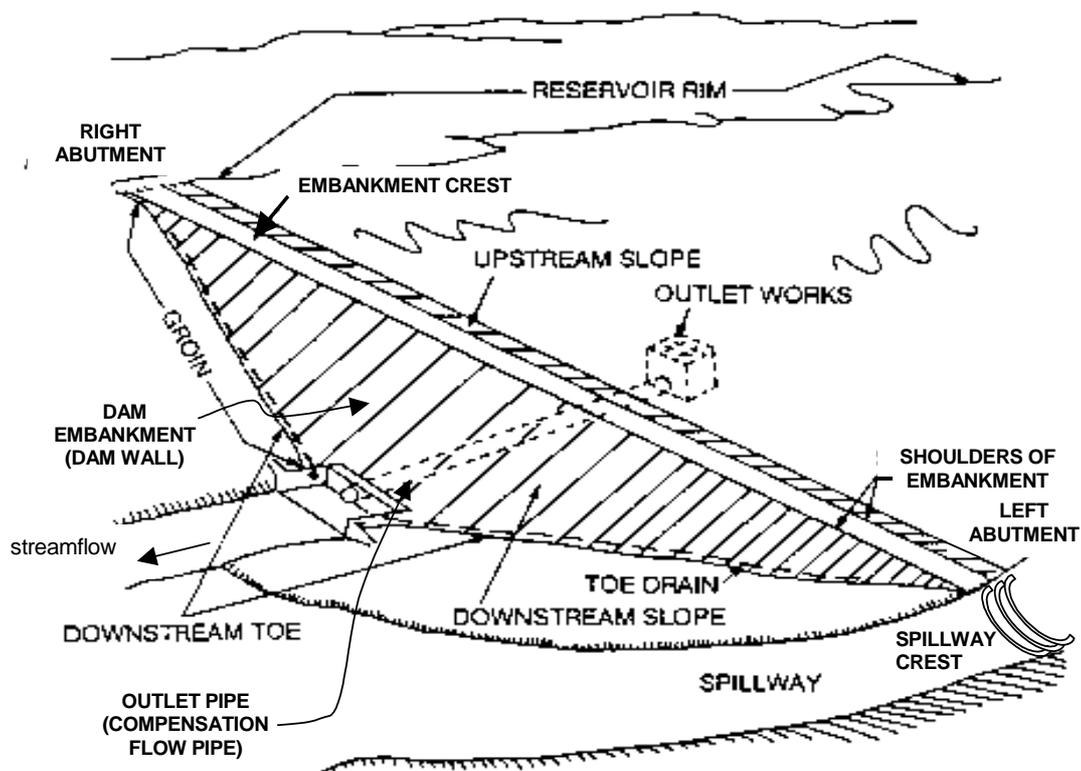


Figure 4.1 Dam Features

Note: Spillway may be located at the left or right abutment, or both, as appropriate.
Freeboard is the difference in level between dam crest and spillway crest (overflow level)

International and national convention for left and right sides of a dam are 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

The main features of a dam are the:

- ◆ embankment;
- ◆ spillway;
- ◆ outlet works; and
- ◆ environmental (or compensation) flow by-pass where required.

4.2 Services of an Engineer

Because of the size and nature of many small dams, and because construction of most small dams looks deceptively simple and uses familiar technology, it is tempting to think that the services of a professional engineer are not required. This is often a mistake.

Not only is it true that a significant proportion of small dams fail, but did you know that a high percentage of dams fail during their first filling? This generally means the design, construction or filling rate of the dam was an aspect that 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 small dam owners. There are also other reasons for such failures.

An experienced dam engineer carrying out the dam design and supervising the construction is beneficial because the structure will be properly designed and built to current industry standards. The cost of engineering services should be a minor percentage of the total cost of the work. More importantly, that cost should be a very small percentage of the greater cost of reconstructing the dam if it fails, not to mention the additional cost of compensation for the damage caused by the failure.

Note also that relatively few engineers are experienced in dam

design and/or construction supervision. Make sure that the professional engineer whom you select has a suitable track record of experience in dams of a size and type which is relevant to you, including experience with earth materials found in Uganda.

When selecting an engineering service, make sure that the engineer has a suitable level of **professional indemnity insurance**, to match the cost of the work and the consequences of failure. This is not only in the engineer's interests, it is also in yours. In addition to professional engineering qualifications, the engineer needs to have:

1. A sound knowledge of relevant dam design principles and methods to ensure safety, economy and durability;
2. An appreciation of local meteorological, hydrological and geological conditions;
3. A knowledge and understanding of current industry practices and standards with respect to dams; and
4. A broad knowledge of other factors which might be relevant in particular situations, including knowledge of legal obligations under the Water Act and awareness of such potential problems as siltation, wave action, other forms of erosion, and pollution.

Qualifications and experience required of professional engineers who are involved in dam safety work are found in the Ugandan Regulations on Qualifications for Responsible Persons in Dam Safety (2005).

4.3 Types of Dams

There are many types of small dams. Those built in a gully or waterway make use of the natural formation to direct water to the dam and those built on sloping ground capture surface run-off (often directed to the dam from contour drains).

Similar principles and problems apply to both types but gully dams are more at risk of failure during heavy rainfall events.



Gully Dam
Photo Courtesy Southern Rural Water

The focus here is on the more common gully and hillside dams but comment is also made on other types of dam.

(a) Gully Dams

These are normally built from material located within the storage area upstream of the dam embankment if they are suitable (*Figure 4.2*). Where possible the outlet pipe should be positioned to make use of all the stored water.

Gully dams must have some way to allow excess flood flows to pass downstream safely. This is usually done by excavating a spillway channel into the adjacent hillside clear of the end (or abutment) of the embankment. The floor level of the spillway adjacent to the embankment then sets the maximum storage level in the dam and must be set some distance below the embankment crest to prevent water overtopping the embankment.

The design of the embankment, outlet works and spillway is best left to an experienced engineer who is aware of the design parameters and construction standards required to provide an adequate structure. Note that a sound design is of no avail if it is not converted into a sound structure by using appropriate construction techniques and processes. The dam must be matched to its site, and for this reason it is highly desirable that the same engineer assesses the site and available materials, does the design and specification and also supervises the construction. It is a matter of record that constructors (who are sometimes also the owner) can readily fail to appreciate the significance of apparently small details in the specification, in terms of assuring that the final structure achieves its intended performance. This is because the contractor's expertise is different from that of the expertise of the engineer. It does not follow that, because a particular or standard technique of construction has been successful many times before, it will be successful this time! That is what is meant above by the phrase 'the dam must be matched to its site'.

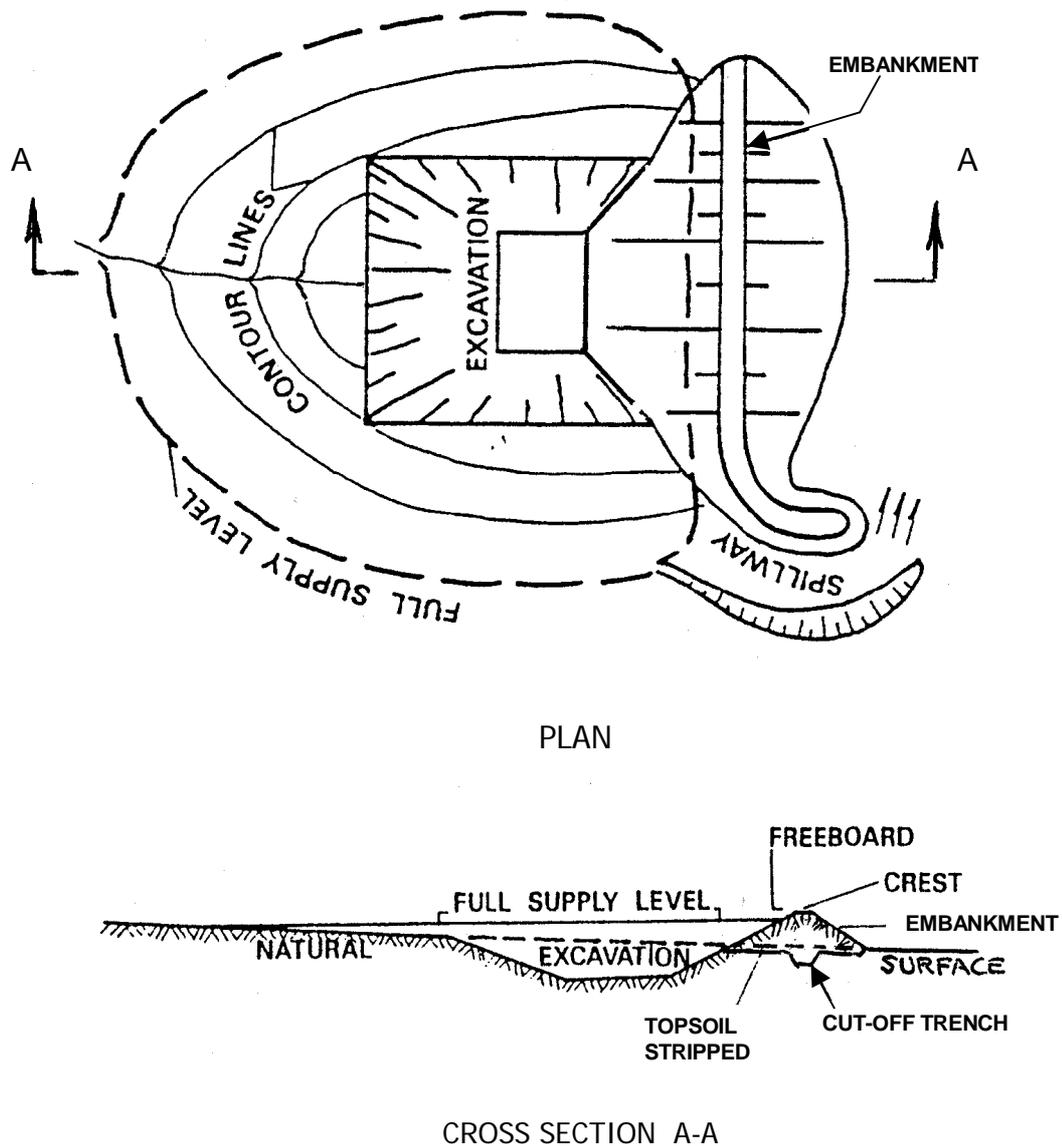


Figure 4.2 - Gully Dam

(b) Hillside Dams

- ◆ This type of dam is not located in a waterway.
- ◆ Usually found in a depression on a hillside, it utilises the surrounding area of the hillside to catch the rainfall run-off directly (*Figures 4.3*).
- ◆ Areas of run-off beyond the embankment are also captured if contour drains are built within the property to capture and direct flows into the dam.

As with gully dams a spillway is required in the natural ground clear of the embankment to prevent overtopping and erosion

of the embankment. Freeboard (vertical distance between spillway level and dam crest) provisions need to be made to prevent overtopping.

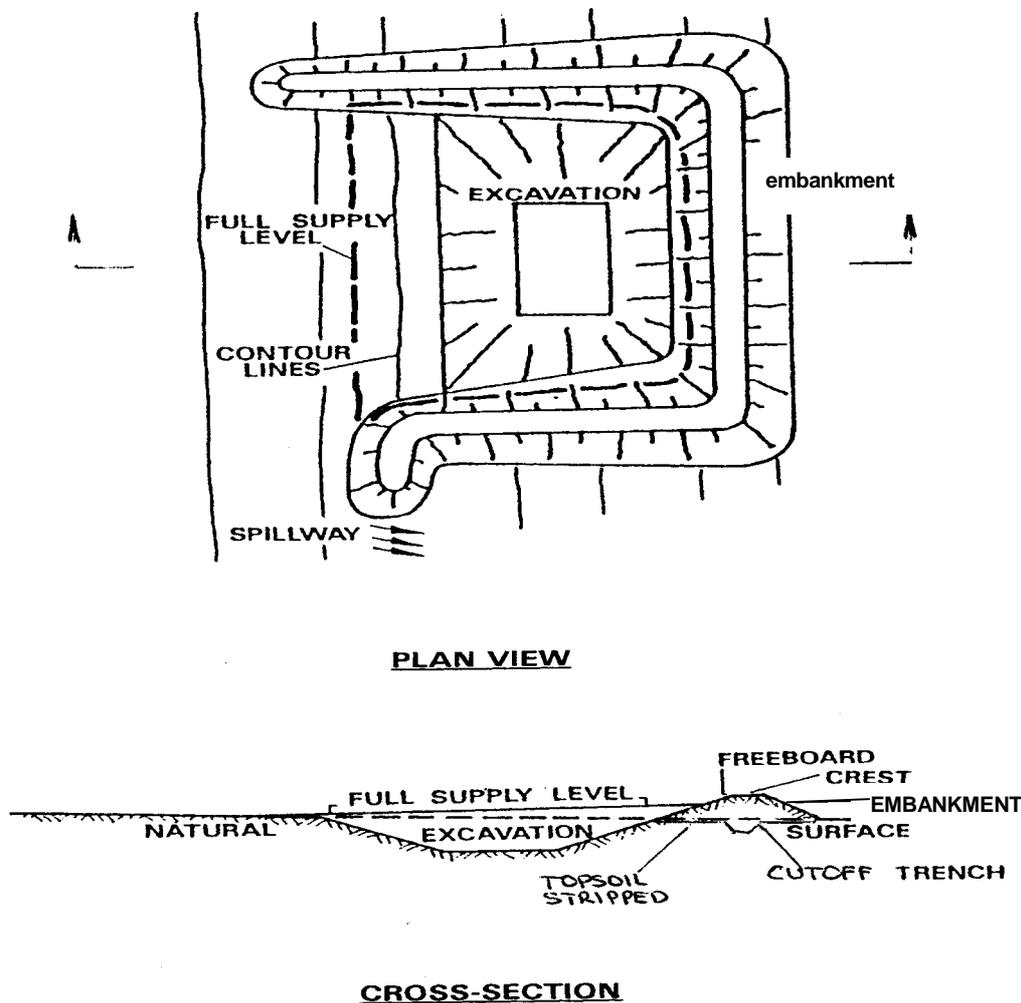


Figure 4.3 - Hillside Dam

(c) Other types of dams are:

1. Ring Tanks

These consist of storage water contained inside a continuous embankment. Materials are sourced from within the embankment if suitable. These types of dams are constructed off-waterways and are usually filled by pumping from a stream or groundwater. Water is usually held partly below and partly above ground level. See note below.

2. Turkey's Nest

This is a similar construction to the ring tank but the material is excavated from outside of the embankment. All water is therefore stored above natural surface level allowing gravity outflow for most of the contents. See note below.

3. 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 therefore the construction of this type of dam does not normally come under the jurisdiction of the *Water Act* or this guide. If the purpose of the excavation is to intersect groundwater, the excavation may be considered to be a bore and a construction permit may be required. **However a Take and Use Permit is required for irrigation or commercial use of the water irrespective of whether it is surface water or groundwater.**

For structures Types 1 and 2 above, it is 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 on its merits: if there is any risk that 'overpumping' may occur (eg. due to failure of the cut-out switch at the pump) water may overflow the embankment, and if so may cause failure. A spillway may be required in these circumstances, or some other means of securing against this risk. Similarly, the design needs to provide security against overland runoff eroding the outside toe of the embankment, thereby risking failure.

4.4 Site Investigations

4.4.1 Selecting the Dam Site

Locating a dam depends on a number of factors including:

- ◆ suitable valley or hillside that will catch the most water;
- ◆ 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; and
- ◆ location of the dam relative to where the water is to be used.

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

There may also be a need to give thought to the visual impact of a proposed dam to your neighbour, as they have a right to object to the structure if it affects their residential amenity.

From an economic viewpoint, a dam should be located where the largest storage volume can be captured with the least amount of earthworks. 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.

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

When choosing the location and size, you should also take into account what would happen if the dam failed suddenly and whether it would result in loss of life, injury to persons or livestock, damage to houses, buildings, roads, highways or railroads.

4.4.2 Site Studies

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

- (a) **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 over all periods of intended use.
- (b) **The catchment area** however should not be too large, as it will then require a big and expensive overflow system (or spillway) to safely pass excess run-off from

Note:

The use of inappropriate or defective materials is a high-risk approach to a business investment.

Note:

If the soil type is suspect get professional advice on soil treatment as the construction procedures on their own cannot perform the impossible on poor soil types.

heavy rainfall without overtopping the dam.

- (c) **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.
- (d) **Site Tests** are conducted to 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 from where they may most economically be obtained.

Small dams tend to be built from a whole range of soil types from sand to the stickiest of black 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 are those that will disintegrate spontaneously in the presence of water. They are very common in arid climates 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 suffer from swelling and shrinkage causing cracking problems. Water can escape through the cracks and erode the embankment. These soils are also difficult to compact without leaving voids internally.
- ◆ Low clay content material that does not have sufficient clay to provide strength and impermeability.

Use of any of these materials can result in leakage that may lead to piping or tunnel erosion (ie. the removal of soil unseen

within the dam embankment while surface soils remain intact). If such erosion is unchecked, this will lead to **rapid failure**; it usually becomes apparent as surface leakage only when the internal erosion has already well progressed.

The storage basin must also be impermeable to hold water 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.

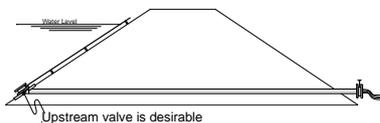
4.5 Considerations at Investigation Stage

4.5.1 Environmental

When a Regulating/Licensing Authority receives an Application for a permit under the Water Act (in respect of a dam), whether or not on a waterway, they will refer a copy of the Application to the relevant authorities for appropriate action. These authorities may include:

- (a) DWD,
- (b) NEMA,
- (c) Ministry of Housing and Construction,
- (d) Local Government.

4.5.2 Compensation Flow Requirements



As a condition of the Permit to Construct and Operate Works on a waterway there will be a requirement for the storage dam to make provision for a by-pass channel around the dam or an outlet by means of 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 by-pass channel or outlet pipe and valve comprising the outlet works will need to be sized to suit the compensation

flow requirements. This outlet pipe has benefits in that it is a means for releasing water from the storage in the event of a problem with the dam wall.

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

4.5.3 By-Pass Channels

Responsible Authorities for management of off-waterway storages may require dam owners to provide a means to limit harvesting of water during seasonal dry periods.

This requirement is to provide security to downstream users and the environment.

During this period all inflows exceeding a predetermined amount will be required to be released or by-pass the dam.

This provision can be a condition of dam owner's licence.

This may mean that, if the outlet pipe arrangement is not appropriate to satisfy the release of water outside dry period or in the absence of a outlet pipe, the Regulating/authority can require other means to achieve this outcome. For example, you may need to construct a by-pass channel around the water storage are so that the water will not enter the dam.

4.6 Dam Design

4.6.1 Standard Designs

The dam engineer can communicate and coordinate all aspects of application, documentation, design and supervision of construction works.

It is encouraged and also good practice to have any size dam (whether or not a licence is required) designed by an engineer.

A standard design is provided in *Appendix C* for those dams that are less than 3 metres high and hold less than 20 megalitres of water and where the consequences of failure are very low or negligible, bearing in mind the likely development that can take place in the future.

Warning: The standard design should not be used for dams which may be classified as potentially hazardous (regardless of size) or for dams of the size ranges given in Section 3.2 of this guide r for dams larger than those sizes. Such dams require design and certification by a suitably qualified and

experienced engineer.

For certain size dams and land conditions, it is not only wise to use the services of an engineer, but the Licensing Authority will actually *require* professional engineering input. This is to design specific works, supervise construction and provide certified plans on completion.

When selecting an engineer, make sure that you not only look at their experience but that they have a suitable level of professional indemnity insurance as per *Section 4.2*. Note again that only a relatively small proportion of professional engineers (even among civil engineers) have experience in dam design or construction. It may be tempting to use a 'general practitioner' consulting engineer because of their proximity or cost, but you are aiming here to guard against possible costs far greater than the consultant's fees.

4.6.2 Extreme Events

ANCOLD is the Australian National Committee on Large Dams.

Large earthquakes, storm/flood activity and failure of upstream dams can be considered extreme events. The risk of failure from these events is minimised by using engineering design standards and relevant guidelines (such as ANCOLD Guidelines) incorporating adequate margins of safety.

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*.

4.7 Health and Safety Issues

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

All dams present a level of risk to persons, especially children wandering around the site (whether entry to the site is authorised or not) and any features that may present an unacceptable risk should be clearly identified and addressed.

For example, the dam may have a narrow crest that is capable of being driven over, or it may have steep upstream or downstream slopes.

Warning: Any repairs to dams that are releasing or leaking water should be left to experts as there have been a number of incidents (including death) involving persons trying to 'save' the dam. Where an embankment is suffering unusual leakage or has suffered partial failure but has not completely failed, caution should be exercised and expert help sought. The nature of the dangers to persons trying to 'save' the dam may not be visible, and may not be recognised even by those who are used to owning dams.

Water quality in a dam can become contaminated or polluted if not replenished or flushed. Therefore there is a chance that it can become a danger to those who drink the water or to downstream users if passed downstream, even if the initial water quality was satisfactory. Sometimes flushing is done during periods of high inflows, but this is only possible after 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 often identified as a 'rotten egg smell' (H₂S or hydrogen sulphide).

5 Construction of a Dam

5.1 Selecting a Contractor

Contractor means earthworks contractor.

Remember bulldozers, scrapers and tractors may be large machines but they are not designed for soil compaction. In fact they are designed to create minimum pressure.

Good compaction is achieved using appropriate compaction rollers on soil at just the right amount of moisture content.

Beware of the 'bargain price' in dam construction!

The use of 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 and working under supervision of an experienced engineer.

Check the standard of previous work and ask if they have done any work under the supervision of an engineer experienced in dams. Check out any references given! Neighbours are a good reference to previous workmanship.

For larger dams or those with particular difficulties, working from plans and specifications prepared by an experienced engineer have a better chance of ending up with a trouble-free dam.

Remember even the best contractor might be tempted to take an occasional short-cut in the absence of good supervision, without recognising the potential technical consequences for the performance and/or safety of the dam.

5.2 Construction Supervision

Construction supervision is an important phase of dam construction. Supervision is meant to ensure that the design factors and specification requirements have actually been included in the final product. Note that the expertises of the designer and the constructor are quite different; there are many subtle but important design issues, even with small dams, which can easily be undermined by the construction process but which are not 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 then the safety of the dam will be compromised.

It is totally unwise to attempt to construct a dam without having

an appropriate specification and plan in the contract. Not only do the specifications and plans form a coherent set of instructions for the constructor to follow, but in the event of things going wrong, either during construction or afterwards, there will be no record as to what the standard of construction should have been, thus making it exceedingly difficult for the owner to point to the person responsible for his loss in the event of a legal argument.

Furthermore, the Licensing Authority will require an engineer to certify that a dam of the classification given in *Section 3.2* of this guide, or a potentially hazardous dam, has been built in accordance with the submitted plans and specifications.

5.3 Dam Foundations

A large number of dams are still being constructed using a method whereby the topsoil is mixed into, or left under the clay material that forms the bank. These dams are more likely to leak or fail. This is because the organic matter in soil layers rots and allows seepage to occur. It's also because topsoil is likely to be more pervious than clay in the first place.

All topsoil (the upper layer containing any organic matter such as grass or roots, however fine) and vegetation must be stripped from the area where the embankment is to be placed and put to one side. This material should not be mixed with the clayey material to be used for the bank.

Mixing topsoil with the bank material to save costs or because of convenience is asking for trouble! The organic matter in the topsoil will decay in due course, causing leakage paths to develop later, and may even lead to difficulty in obtaining adequate impermeability in the embankment in the short term.

A core (cut-off) trench should be excavated 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 first 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 topsoil are soft, weak or contain gravel or other inclusions (such as calcareous materials) which 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 next layers below the embankment can be checked out before construction of the embankment begins.

5.4 Embankment Materials and Construction

5.4.1 Selection of Materials



Piping failure due to excess rock, gravel, silt and no clay being used.



Typical embankment slip resulting from construction or material defects.

Photo courtesy of J Whitewood

Most dam walls (whether on or off waterways) are constructed of earth materials. If your dam is constructed from other materials, then much of the following sections will not apply to you, but 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.

In some cases, 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. However, construction of this kind (called 'zoned construction') requires attention to detail from an engineer, and in any case is generally confined to dams of more than a few metres in height. This is not only for economy, but also because of practical reasons, which limit the access of compaction equipment for lower dams.

In no case is it recommended that a core of non-earth material (such as concrete) be attempted without engineering design and supervision.

5.4.2 Placement of Embankment Materials

Embankment material placement should be done 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. The Optimum Moisture Content for compaction is normally determined by laboratory testing. For certain soils (especially dispersive clayey soils), it is critically important that the placement not be below the Standard Optimum Moisture Content as determined by laboratory tests.

5.4.3 Compaction of Embankment Materials

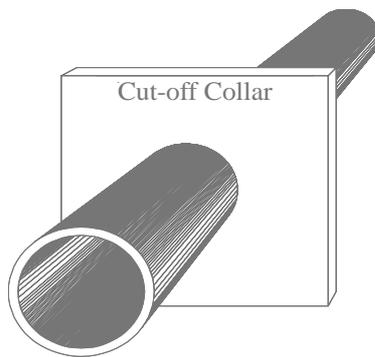
The materials in the embankment must not only contain sufficient clay, they must also be adequately compacted, with each compacted layer bonded to the one underneath. Inadequate compaction can result from:

- ◆ the use of material which is too wet or too dry (the acceptable margins are quite small). Note that it is generally easier to compact and handle material which is a little below its Standard Optimum Moisture Content, and that is commonly done with embankments for other purposes such as roads, but the consequence of doing so is a marked increase in the leakage potential of the finished product, hence it is not appropriate for dams; or
- ◆ The use of tracked plant rather than compaction rollers designed for compacting and kneading the soil layers into each other is asking for trouble. Even one layer of inadequately compacted material in a bank can result in seepage leading to failure. It is very tempting, and very common, to use tracked plant for small dams because it is available and is much less costly, but again, this is inviting trouble! Remember that tracked plant has tracks in order to keep the contact pressure low (for example, to cross soft ground), whereas what is required for good compaction is a

combination of *much* higher contact pressures and ability to penetrate layers and knead them to ensure good bonding and eliminate leakage paths. Proper compaction plant is designed to do these things.

5.5 Outlet Pipes or Structures in Embankment

Refer Compensation Pipes Section 4.5.2.



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 from the dam, 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. Using cut-off 'collars' at intervals along pipes passing under a bank can reduce the possibility of leakage. However, special care is required to ensure adequate compaction in these areas, and this may require (among other things) the use of special small equipment.

Outlet pipes or other works should be placed in original ground rather than in the embankment. As far as possible, the location of such structures in the embankment itself should be avoided. It is likely that they will be damaged during construction of the embankment and/or when any settlement occurs, but such damage will be unseen. Because of difficulties with compacting backfill properly around an outlet pipe it is better to backfill with concrete. *Appendix C* outlines the procedure. **Never use sand or other granular material as pipe backfill or bedding.**

Warning: Even if these suggested practices are used, great care is required especially if such items are incorporated in embankments or foundations of dispersive clays. It is then highly likely that failure will result, unless special care, overseen by an expert, is applied.

Ideally, steel pipe with cement mortar lining and backfilled with concrete should be used. Unlined steel pipe can corrode and perforate within 20 years and lead to internal erosion of the embankment or abutment and result in dam failure. The use of concrete cut-off collars and an upstream guard valve is considered to be highly desirable, but such features themselves

create an additional need for special care and attention to detail in both design and implementation.

5.6 Spillways

When selecting a site for the construction of a spillway, care should be taken to 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. However, spillways should be confined to locations clear of the embankment so that no flow is likely to go onto and damage the dam wall.

6 Safety Surveillance

6.1 Purpose of Regular Inspection



Embankment slip due to poor construction

The purpose of a dam safety surveillance program is to avoid failure of the dam, by giving early warning of any kind of symptom of trouble as early as possible.

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 (ie outlet pipes, spillway); and
- ◆ spillway or outlet blockage.

Note that in some cases, the preparation and carrying out of a regular program of safety surveillance may be a condition of issue of a licence. This is especially true for dams classified as potentially hazardous, but it also represents not only good practice but sound insurance!

Safety surveillance of a dam is a program of regular visual inspection using simple equipment and techniques. It is the most economical and effective means an owner has of maximising the long-term safety and survival of the dam.

Its primary purpose is to monitor the condition and performance of the dam and its surroundings, particularly any changes that may be occurring. Potentially problematic trends can thereby be spotted early and provide adequate warning of their development so that timely maintenance can be carried out. You should always check the water level and spillway flow performance for any unusual changes.

Sometimes it is an advantage to use an engineer experienced with dams. They are more familiar with problems and can provide better security against legal action in the event of a dam problem impacting on others.

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. Such procedures are already normal practice in the case of large dams.

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

A safety surveillance inspection includes taking appropriate measurements and keeping concise accurate records of observations made. Particular techniques and equipment that might be used are outlined in *Appendix A*. For small dams it is prudent to obtain professional engineering advice to set up the program first, using a simple set of pro-forma check sheets to record observations. They are just as sensible – in fact much more so, given the potential for costs to you if it fails- as having your car checked and serviced regularly, even though you do not think the car is about to give up on you yet!

These procedures form part of a dam safety management program and are intended to catch problems early and enable action to be taken to prevent them developing further once detected.

6.3 Frequency of Inspections

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

- (a) size or capacity of the dam;
- (b) condition of the dam; and
- (c) potential for damage resulting from failure of the dam (represented by the hazard category).

Adoption of the inspection frequency for a particular dam is the responsibility of the owner, though professional advice should be sought for large dams (ie. typically for dams larger than 15 metres in height) or those suspected of being of a PIC 2 or a PIC 3 dam. Suggested inspection frequencies are given in *Table 6.1* but where licence conditions require a surveillance program certified by an engineer the frequency specified by the engineer shall be complied with.

As a guide, *Table 6.1* gives suggested frequencies for a two-level surveillance program. The higher level would comprise a full inspection using the relevant equipment and techniques outlined in *Appendix A*. The second level is envisaged as a more frequent quick visual inspection aimed at detection of unusual changes during the period between thorough examinations.

TABLE 6.1 - SUGGESTED INSPECTION FREQUENCIES

QUICK VISUAL INSPECTION			
Severity of Damage or Loss	Dams equal to or higher than 15 metres	Dams smaller than 15 metres	Small dams less than 1 megalitre
High (likely loss of life if the dam fails)	daily	twice- weekly	weekly
Significant (significant property damage if the dam fails)	twice-weekly	weekly	fortnightly
Low	weekly	fortnightly	monthly
COMPREHENSIVE EXAMINATION			
Severity of Damage or Loss	Dams equal to or higher than 15 metres	Dams smaller than 15 metres	Small dams less than 1 megalitre
High (likely loss of life if the dam fails)	weekly	monthly	3-monthly
Significant (significant property damage if the dam fails)	monthly	3-monthly	twice-yearly
Low	3-monthly	twice-yearly	yearly

The above table is a simplified version of the frequency of inspection specified in the Ugandan Guidelines on Dam Safety Management (2005). Please note that the terms “Comprehensive Examination” and “Comprehensive Inspection” are defined differently.

6.4 Special Inspections

(Immediately after major storm or earthquake event)

Following a regular routine like this should enable the dam owner to become aware of faults before partial or total failure occurs. Times when inspections additional to those above are recommended are:

- ◆ 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); and
- ◆ after any earthquake or tremor, whether directly felt on the owner's property or reported by local news media (check all aspects of the dam).

Inspections should be made during and after construction and also during and immediately after the first filling of the storage. Remember, empty the dam if any doubts arise.

6.5 Problems Likely to be Encountered



A systematic program of safety surveillance should maximise the likelihood that any developing conditions likely to cause failure would be found before it is too late. Surveillance will also help early detection of problems before they become major repair bills.

As identified earlier 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;



Photos courtesy of B Lewis

- ◆ erosion;
- ◆ cracking;
- ◆ deformation/movement;
- ◆ concrete structure defects; and
- ◆ spillway blockage.

Weeds can block spillways, overflow or outlet pipes in a dam. If this happens, failure of the dam can occur from overtopping in the event of heavy rainfall.

Section 7.4 (Maintenance) outlines some of the simple maintenance activities, which can be carried out to prevent or remedy potentially dangerous conditions. *Appendix B* lists in more detail the problems that might be revealed by a safety surveillance program. It also outlines their possible causes, consequences and possible remedial action.

6.6 How to Deal with Problems

When a significant concern exists it is strongly recommended that the regulatory authorities and emergency services be informed at the earliest opportunity so that appropriate response can be implemented.

Seeking help with a developing problem needs to be done quickly before the problem develops into something serious.

When seeking help from a dams engineer make sure that you note down enough details to be able to explain the size 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 which can be sent by fax or by e-mail if available.

Remember that it will take time for someone to come onto the site for a detailed inspection. Depending on the rate of development 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. So be prepared to drain the dam if a serious problem

develops or is developing.

Warning: If a leakage problem is occurring, do not place anyone in danger by trying to plug the upstream side of the leak. There is a real danger of people being drawn or sucked into outlet pipes or erosion holes. Seek experienced help. Lives have been lost and others have been put at risk, even recently, trying to save dams using inexperienced persons.

6.7 Inspection Checklists

The most thorough method and best 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 when you last inspected it. Of course, such records must be systematically stored so that the information on them can be readily retrieved.

This can be useful in the event of a problem developing, as you will thereby be able to show that you have exercised due diligence with respect to the dam. It is a similar activity to doing a routine roadworthy check on your motor car. It is not only good pro-active management of your asset, but may also help to protect you against liability in the event of your dam causing loss or damage.

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

7 Operation and Maintenance of Dams

The term 'operation' when applied to a dam may at first be regarded as applicable only to larger dams. Typically, such dams have a variety of control equipment in use as part of the structure (such as valves, flood gates and electrical control panels). However, when we define it as any activity or practice which allows the owner to keep inflows and outflows under control, or which safeguards the integrity of the dam, it can be seen that even small dams without elaborate equipment can be, and should be, operated.

This is because the nature of the responsibility carried by a dam owner is the same for a small dam as for a large one. The only difference is in the scale of the responsibility- and that is then reflected in the smaller scale and sophistication of activities which usually applies for a small dam compared with a large one.

The definition of operation given above also implies that monitoring of performance, and maintenance, are inherently part of the duty of care which attaches to the responsibility of ownership of a dam, regardless of its size.

The following sections deal only with some very basic aspects of operation and maintenance.

7.1 Control of Flows

Operation of a dam includes the control of flow of water from or around a dam via by-pass 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 environmental (compensation) flow rate where this is applicable; and
- ◆ 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).

7.2 Routine Surveillance

Routine surveillance or inspections can also 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 to securing both safety of the dam (see Section 6) and satisfactory technical performance.

7.3 Filling and Emptying

Be aware that the rate of filling or emptying a dam should be controlled. If done too quickly problems can occur in an earth embankment.

If filled too fast, especially for the first time or after a long dry period, the material within the bank does not have enough time to get sufficiently wet, expand and seal. Therefore leakage may occur. In the case of embankments constructed from dispersive clayey soils, this problem is more severe 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, and 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, emptying faster than 0.2m in level per day should be avoided.

7.4 Maintenance

Because many small dams fail through lack of maintenance, it is prudent to have a definite and systematic maintenance plan.

The maintenance plan should be decided upon when the construction work on the dam is completed. It will affect the life of the storage if you do not maintain it properly.

A good plan should include the practices to be used, as well as the approximate time of the year when they are applicable. Your engineer can give you advice and prepare a simple program to be followed. The plan should also include steps to be taken if particular problems are encountered. All records of maintenance activities should include details of observations made, repairs carried out (including details of location), no matter how minor.

7.5 Maintenance Problems

The most common problem areas or causes requiring maintenance are listed 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 more common in some parts of the world than others. Their presence in the ground is often the cause of severe discolouration of reservoirs and streams, but that is not the main issue here. The issue is that their presence in a dam embankment can result in the loss of material from the embankment by internal erosion and

consequent 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 has taken place during the first filling of the dam.**

As far as possible the use of dispersive clays in construction of a new dam should be avoided but, where unavoidable, the addition of a small proportion of lime or gypsum, well mixed in with the embankment material, can help to stabilise it. In existing dams, application of 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 20cm could be used but professional advice should be obtained in each particular case, using a professional engineer who has particular experience in this area. Furthermore, the activity of mixing in the lime or gypsum requires care, and its effectiveness and expense can be negated if it is not properly done, hence **professional supervision is strongly recommended.**

Compaction of dispersive clays must be carried out to very high standards in accordance with specifications prepared by an experienced engineer. The moisture content for compaction must be carefully controlled to be at or marginally above the Standard Optimum Moisture Content, which can only be determined by laboratory testing of the material (see also *Section 5.4.2*).

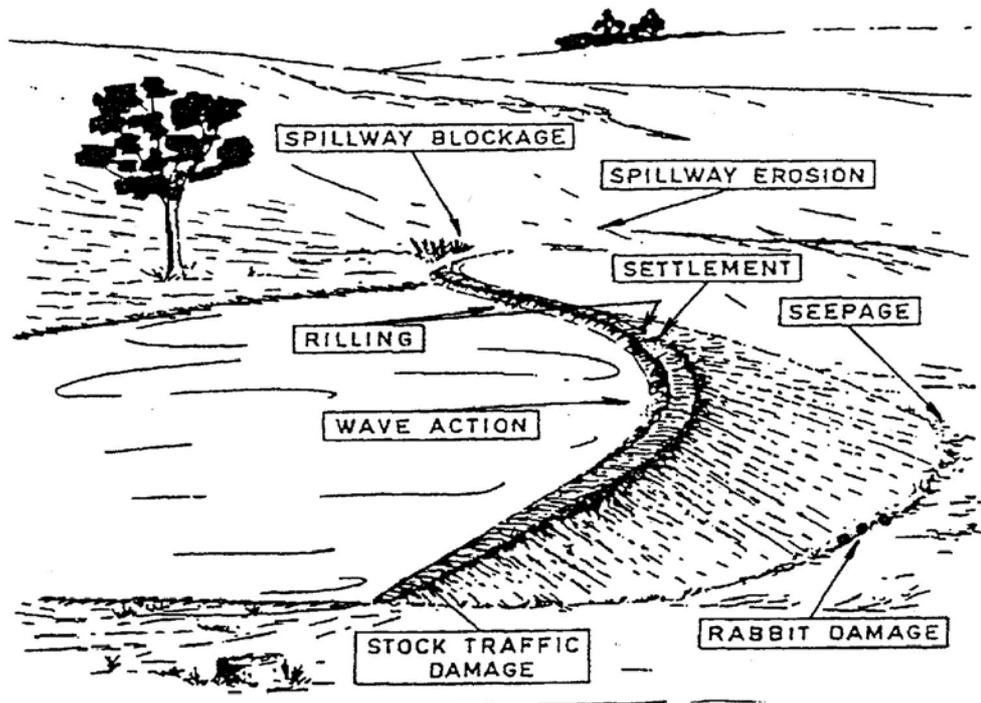


Figure 7.1 – Common Problem Areas

7.5.2 Seepage and Leakage



Seepage - indicated by green patch on dry grass



Leakage - measurable flow of water

Water escaping from the 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 signals or alarms for even greater concern.

It is important that the embankment is well maintained and grass kept relatively short (70 mm is good) 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 should be sought.

7.5.3 Erosion



Embankment rilling and erosion

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

- (a) 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.



Wave action damage and embankment erosion

- (b) 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 the use of windbreaks around the shoreline should be considered.

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.

- (c) 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.

(d) Sinkholes



Sinkhole developing from wheel rutting

Sinkholes are holes or depressions at the surface resulting from internal erosion, which has caused underground cavities into which the surface material eventually subsides. Sinkholes are often a sign of severe and widespread hidden damage, and rectifying this 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 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 run-off rather than leakage from the dam, professional advice should be sought.

(e) 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-establishment of good grass cover is the best remedy.

7.5.4 Stock Damage

Keep stock off the embankment. A fence to exclude stock should be constructed 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' which can lead to serious erosion, the water in the storage can become turbid 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 access to dam embankments constructed from dispersive

clay.

7.5.5 Yabby Damage

If left unchecked yabby holes can lead to leakage through an embankment.

These will need to be dug out and the material re-compacted to reinstate the embankment material. Digging out and backfilling the holes should be done when the water level has dropped below the affected area.

7.5.6 Rabbit and Wombat Damage



Rabbit warrens in embankment

Dig out any burrows and repack with rammed moist clay. If the burrows are extensive the storage should be emptied before they are dug out, or professional advice sought. Maintain effective control of rabbits and the weeds that may harbour them.

Fox holes can also be found on embankments and their eradication and repairs should be treated.

7.5.7 Cracking and Movement



Cracking along downstream shoulder of embankment

(a) Cracks

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

However, 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. 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.

Ideally, large cracks should be filled as soon as possible with compacted clay, or sand mixed with bentonite, but, 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.

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

(b) Embankment Settlement

On large dams, it is usual to have special level markers to monitor embankment settlement. On small dams, embankment settlement can be checked approximately by monitoring the freeboard (the difference between full water level and the top of the bank, measured at the highest point). Hard and fast rules cannot be laid down but, as an indication, it should not normally be less than about one fifth the height of the embankment, but the important point is to examine the records to see if settlement is still occurring or if it has settled down. Checks should also be made to see whether there is any development of transverse cracks in the crest, and if so, professional advice should be sought.

(c) 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. In the short term it may be necessary to drain or pump out the stored water.



Classic surface slip

Photo courtesy of J Whitewood

7.5.8 Defects in Associated Structures

Note:

If a spillway crest is raised as a means of increasing the storage capacity, there is a high risk that the bank may overtop. It is a situation fraught with danger, and should not be undertaken without professional advice.

(a) Spillway Blockage

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

(b) Outlet Pipe Blockage

The cleaning of an outlet pipe is a problem if the gate valve



Uneven spillway cut

Photo courtesy of Southern Rural Water

Note:

The location of water reticulation pipes or other structures within the embankment should be scrupulously avoided, as leakage from the pipes, or around the pipes, can cause problems, or even failure of the dam (see also *Section 5.4*).

7.5.9 Outlets and Valves



What are the chances that this valve will work in an emergency?

Photo Courtesy of Southern Rural Water

has been closed over the winter because trash, fish and siltation 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, as a condition of approval of a dam on a waterway requires the gate valve to be operated so as not to diminish flows during the drier months. It is recommended that regular flushing be carried out to minimise the risk of blockages.

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

All valves used for releasing water from a dam must be properly maintained. It is important to remember that if you have a developing problem with your dam you may need to empty it as quickly as possible. It is therefore important to service/exercise the valve regularly to make sure it is operational at all times. If it starts to get difficult to operate you have a developing problem that requires attention. It is possible to exercise the valve without losing stored water when the spillway is flowing as the water is being passed downstream anyway, but do not wait indefinitely for the spillway to flow first before exercising the valve!

Provision should be made at the outlet pipe point of discharge to reduce the velocity of exiting water. Rock placed on a layer of crushed rock to minimise erosion, or an effective concrete outlet structure should be constructed to dissipate the energy of the discharging flow. The type of protection will be dependent on the size and the pressure head of the water.

Another problem at an outlet valve is the potential for

neglect if not in regular use. Remember that if you have an emergency problem with your dam and need to empty it quickly to save it from total failure you will need this valve to work.

It is recommended that this valve be operated at least four times per year to make sure it is operating properly.

7.5.10 Vegetation

(a) Trees

Self-sown plants, trees or other deep-rooted plants should not be permitted within 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.

Planting trees and shrubs can provide windbreaks, which prevent wave action and, therefore, soil erosion, and also give shelter for wildlife.

If trees are required, they should be planted around the foreshore of the water storage, well away from the dam embankment and spillway. The dominant wind direction needs to be considered. (Refer also to 'Trees at Work - Improving Your Farm Dam' from Greening Australia).

(b) Total Catchment Area Protection

To maintain the required depth and capacity of a dam, it is necessary that inflow be reasonably free from sediment.

Selective plant use can be used to 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 areas. If the catchment area is denuded and eroding, you may need to utilise cultivated areas that are protected by appropriate conservation practices, such as contour tillage, strip-cropping, conservation cropping systems, and other land improvement practices.

(c) 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. However, in all situations the same factors should be considered in deciding what control methods, if any, should be used.

In each case:

- ◆ determine whether there is a problem and, if so, what it is;
- ◆ identify the specific plant causing the problem;
- ◆ find out what control methods are available and which of them could be used;
- ◆ investigate whether these control measures could cause any other problems (eg. toxicity to fish and livestock) and, if so, whether they can be avoided; and
- ◆ decide whether or not all factors considered, control is practical, desirable and worthwhile.

7.6 Modifications



Result of overtopping due to inadequate spillway capacity

Photo courtesy of Melbourne Water

(a) Spillways

Experience has shown that some landowners or lessees try to modify the spillway on a dam to achieve an increase in storage capacity.

This practice is fraught with danger.

If you fill in or obstruct a spillway then the chances of overtopping the dam are greatly increased. Water pressure loading on the dam wall will also increase due to the added height of water and this may cause instability in the bank and embankment slips.

(b) Crest Modification

Even the addition of topsoil to the top of an existing dam has been tried as a means of gaining an increase in storage capacity. This can create problems because it is not easy to

get a good bond between the top of the dam and the new material and topsoil is very permeable. Because of the shape of the dam a simple raising will also result in a narrower crest width making maintenance difficult.

Modifications are best left to an engineer to assess and design a safe structure to meet your needs. Otherwise it may be the most expensive water you ever collected.

8 Dam Failure Emergency Action

8.1 Extreme Events

Section 8 is likely to have less importance for small dams, but for any dam classified as potentially hazardous this section should be given attention regardless of dam size.

Extreme events such as earthquakes, flood or storm activity present a situation where preventative action may be difficult. Whilst there is little that a dam owner can do to prevent them occurring, the risk of dam failure from flood and earthquake can reasonably be expected to be minimised by proper design and construction. A proper dam design looks at the engineering aspects and applies margins of safety that have been developed from industry experience.

Pre planning for an emergency is an important means by which to minimise the impact from dam failure.

Failure of another dam upstream can also impact on your dam. Dam owners carry the responsibility for the safety of their dam under the Water Act. This risk can be minimised by the proper upkeep of the dam. If you are concerned about the condition of any dam, and the matter cannot be resolved locally, you should contact your local regulating/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 what to do in the event that failure of your dam appears imminent.

Owners can play an important role in ensuring the safety of dams by having proper operating procedures, adequate inspection, and maintenance and safety surveillance. However, there should also be a plan of action in case the dam fails or is threatening to do so.

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. It should be reviewed and, if necessary, updated annually. This is especially true for dams with a history of leakage, cracking, settlement, misalignment or erosion from wave action.

Since dam owners may be liable for damages associated with the failure of their dam, 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.

In rural areas telephone or direct contact will usually be used to warn the nearest downstream residents. When telephone conversation is not possible, the person observing the dangerous condition may have to personally warn the nearest downstream residents, campers, etc. The dam owner should therefore keep a listing of the nearest downstream residents and their phone numbers along with the Police, Emergency Services and other emergency numbers.

8.3 How to Deal with a Dam Failure Concern

Immediate action is required on recognition of a threatening condition developing:

1. **If failure is imminent** (eg. water is rising and approaching the top of the embankment, or heavily coloured water is leaking from the embankment or foundation) then you should immediately contact:
 - (a) An engineer, to seek advice
 - (b) Police, SES, local licensing authority and NEMA
 - (c) Your neighbours downstream, to inform them that you have concerns but are working on the problem.
2. If failure appears imminent or is actually in progress (eg. water is spilling over the embankment, or erosion of the embankment, spillway or foundation is occurring). If there is no chance to save the dam, inform the following

at once:

- ◆ Downstream neighbours,
- ◆ Police;
- ◆ State Emergency Services;
- ◆ Local licensing authority; and
- ◆ NEMA.

Advise that you cannot do anything and need help.

3. **Where major flooding is expected or in progress upstream of the dam site** , then inform the following:

- ◆ Downstream neighbours
- ◆ Local licensing authority;
- ◆ Police; and
- ◆ State Emergency Services.

4. **If an upstream dam is about to fail** and you are concerned about your dam, notify the following:

- ◆ Local licensing authority;
- ◆ NEMA;
- ◆ Police; and
- ◆ State Emergency Services.

8.3.1 Emergency Checklist

Addressing 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. A contact list should be prepared and kept accessible and up to date. It might take the form shown in *APPENDIX D*.

APPENDIX D provides a sample of a simple '**Dam Safety Emergency Plan**' that may be useful and can be hung on the wall near the telephone. It provides procedures to follow in the event of certain circumstances occurring and therefore allows response by persons not fully familiar with dam safety procedures.

An emergency action plan is a licence requirement for dams that have a significant or high consequence of failure. Under these circumstances your engineer should prepare a specific

plan for your dam.

Calls should be made first to the police or the local State Emergency Service (SES) who will then warn and if necessary evacuate downstream residents. For smaller dams not requiring 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

There are a number of potential problems that may threaten the safety of a small dam. These can be expensive to remedy. Consequently, it is imperative that dam owners seek advice from an expert when in doubt.

In the event of a problem on a dam, private and government organisations that may be able to provide advice or a service are:

- ◆ DWD;
- ◆ Local licensing authority; and
- ◆ NEMA;

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

Many consulting engineers in general practice will not have an appropriate background in dams and local knowledge is usually the best guide to firms or individuals with good track records in such areas.

9 Decommissioning of Dams

9.1 Removal or Decommissioning of a Dam

Where a dam may have outlived its usefulness or economic life and if you wish to remove or decommission it, you need to obtain a licence.

An owner cannot simply walk away from a dam because it is of no further use or is too costly to manage or rehabilitate. Instead, the dam must be either removed or decommissioned. In either case, it should be made incapable of storing any water either temporarily or permanently. Decommissioning other than by removal is normally done by breaching one or more sections of the dam wall or embankment.

The dam 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 not removed but decommissioned.

Removal or decommissioning of a dam is not without its problems, and thought should be given to the following:

- ◆ 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 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?

Breaching should not be attempted while there is any water in storage unless expert advice is first obtained.

Environmental aspects downstream must also be considered

before a dam is breached. Siltation/sediment transport or erosion caused as a result of decommissioning could become a liability on the dam owner.

It should be noted that 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, professional engineering and environmental advice should be obtained.

9.2 Rehabilitation of Site (After decommissioning)

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. This is because any flow obstruction effect during floods will be an obstacle compared to the natural waterway characteristics.

It would be difficult to defend due diligence where a flood event erodes the remaining dam structure and 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. Care should be taken 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 maintaining protection to safety of persons or property during abandonment works?
- ◆ Is the abandoned dam likely to become a future public hazard?
- ◆ Is there an environmental plan for re-instatement and/or regeneration of the inundated area?

- ◆ Have inundation area and waterway erosion control measures been considered for the interim period until regeneration occurs?
 - ◆ Has consultation with environment authorities been undertaken and are proposed plans acceptable?
 - ◆ Can the dam site and inundated land be disposed of economically?
-

10 Glossary of Terms

TERM	MEANING
Abandonment	Means that 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. Hence this term covers both the “disused dam” and the ‘decommissioned dam’ as appropriate (see later in this glossary).
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.
Appurtenant Works	Includes, but are not limited to, such structures as spillways, either in or beside the dam and its rim; low level outlet works and water conduits such as tunnels, 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 heel to toe.
Beaching	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.
Catchment	The area of land drained by the landform, streams or waterways down to the point at which the dam is located.
Consequences of dam failure	Impact areas downstream as well as upstream of the dam resulting from failure of the dam or its appurtenances. The result of a dam failure in terms of loss of life and damage to property and/or services, as well as economic and environmental damage.
Contractor	For the purpose of this document, a person employed to carry out construction works in accordance with plans and specifications in the construction of a dam.
Crest of Dam	Used to denote 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.
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.
Dam Failure	In terms of structural integrity, the uncontrolled release of the contents of a reservoir through collapse of the dam or some part of it.
Dam owner	Person or legal person, including a company, organisation, corporation or other entity, which either holds a license to operate a dam or retains the legal property title on the dam site, dam and/or reservoir, and which 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.
Dams engineer	A professional engineer who is suitably qualified and recognised by the engineering profession as experienced in the engineering of dams. Competent to undertake some or all of the investigation, design, construction supervision, repair and remedial work, operational, maintenance and abandonment activities associated with dams.
Decommissioned dam	Means 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 present a detrimental affect 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) which has the property of the micro particles breaking apart (or dispersing) 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	In terms of dam operation, any condition which develops naturally or

	unexpectedly, endangers the integrity of the dam and downstream life or property, and requires immediate action.
Emergency planning	Having the capability of responding to a potential or actual dam failure.
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 considered possible and its potential forces are used for the design of dam components. It is usually expressed as Annual Exceedance Probability (AEP), being the chances of it occurring in any one year.
Foundation	The material of the valley 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).
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, could pose a threat to life, property or the environment, if it were to fail.
Height of Dam	The difference in level between the natural surface level, bed of a gully, stream or waterway at the downstream toe of the dam and the crest.
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 Guidelines on Dam Safety Management.
Interim Diversion Limit Methodology	A means for estimating the water available for harvestable catchment run-off and permissible annual volumes.
Maintenance	Actions required to maintain existing works and systems (civil, hydraulic, mechanical and electrical,) in a safe and functional condition.

Minister	Means the Minister administering the Water Act.
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	This is the moisture content of earthen material with suitable clay content at which the best compaction can be easily achieved. (This is the general meaning. In the case of a particular soil, the Optimum Moisture Content is defined by a special standard laboratory test).
Organic Material	Silt or clay containing plant remains. It has low bearing capacity and is compressible when it rots.
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 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	A dam or an artificial lake, pond or basin for storage, regulation and control of water, silt, debris or other liquid or liquid-carried material.
Reservoir Capacity	The total storage capacity of the reservoir or dam up to Full Supply Level (not up to flood level).
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 the toe of the dam. The spillway is principally to discharge flood flows safely past a dam without overtopping the embankment
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.
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	The same meaning as waterway.
Waterway	A term for 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.
Waterway with high ecological values	A wetland or marsh; or a waterway with remnant native vegetation (either in-stream or riparian); or a waterway known to support flora and fauna of conservation significance.

11 References and Suggested Further Reading

Group 1: Non-Technical Reading

- ◆ Lewis B., Farm Dams Planning Construction and Maintenance Landlink CSIRO Publishing 2001.
- ◆ Nelson, K. D., *Design and Construction of Small Earth Dams*, Melbourne, Inkata Press, 2000.

Group 2: Technical Reading

The publications listed below have been used to compile some of the information in this guide, or which are relevant to potentially hazardous dams and to dams equal to or greater than the sizes (height and storage capacity) which are listed in Section 3.2 of this booklet are listed below. It should be noted that they are primarily addressed to engineers with specialist expertise in dam design and construction.

- ◆ Australian National Committee on Large Dams, *Guidelines on Design Floods for Dams*, 1986 reprinted 1990.
- ◆ Australian National Committee on Large Dams, *Guidelines on Selection of Acceptable Flood Capacity of Dams*, March 2000
- ◆ Australian National Committee on Large Dams Inc, *Guidelines on Assessment of the Consequences of Dam Failure*, May 2000.
- ◆ Australian National Committee on Large Dams Inc, *Guidelines on the Environmental Management of Dams*, January 2001.
- ◆ Australian National Committee on Large Dams, *Guidelines on Dam Safety Management*, 2003.
- ◆ Federal Emergency Management Agency (USA), *Dam Safety: An Owner's Guidance Manual*, July 1987.
- ◆ Institution of Engineers, Australia, Australian Rainfall and Run-off, A Guide to Flood Estimation, Canberra, Book 1-1987 and Book 2-1997.
- ◆ Ugandan Guidelines on Dam Safety Management, 2005

APPENDIX A: - CONDUCTING AN INSPECTION

APPENDIX A: CONDUCTING AN INSPECTION

To be able to conduct a thorough inspection of your own dam you may need to consult an experienced engineer who will provide a good insight into what you should be looking for and how to go about it. This would provide a procedure specific to your dam. The following material is provided for your information to assist in understanding inspection requirements.

Preliminaries

(a) Establishment of Reference Pegs

The purpose of an inspection as part of dams safety surveillance is to monitor performance in such a way as to enable early diagnosis of potential problems. As mentioned in the text, this includes such things as noting where cracks or leakage has formed and noting whether there is any deterioration, and how fast or slowly that may be occurring. To enable such monitoring to be reliable, and to facilitate the keeping of records, it is essential that there be both a plan of the dam and a set of reference pegs, relative to which the location of any observation or trouble spot can be pinpointed and recorded.

The degree of sophistication of the plan and of the reference peg system will depend on the size of the dam, its type and its potential hazard category, and advice should be sought on this first. However, as a bare minimum, irrespective of size of dam, there should be established at least one key reference peg (the *primary reference peg*) at one end of the dam. Remember that recording of locations will need to convey the level (height) at each location as well as the distance along the dam length. The key reference peg should be located at one end of the dam. It is preferably to place it at a level close to the dam crest level, but securely in place so that it can be readily found and so that it is unlikely to be knocked out or broken by persons, vehicles, plant or cattle. Ideally a secondary reference peg should be located elsewhere as a backup, preferably at the other end of the dam, with the distance away from the primary peg, and any difference in height being measured and recorded. If the dam crest is not straight, or if there are difficulties about this procedure, professional advice should be sought. With larger dams, or dams classified as potentially hazardous, more sophisticated arrangements may very likely be required, but for small and simple dams it is not essential that the position and level of the reference peg(s) be precisely defined by a land surveyor. Similarly for the latter dams 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 made and the distance of it from the primary reference peg.

APPENDIX A

(b) 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, thus reducing mistakes and avoiding 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 ten-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; and
- ◆ hammer - to test soundness of concrete structures.

(d) Observations to be Recorded

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. The location along the length of the dam should be noted, as well as the height above the toe or distance down from the dam's crest should also be measured and recorded. 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?

APPENDIX A

- does deterioration appear to be rapid or slow? and
- have conditions changed? (note in what way etc).

Note: A sketch plan of the dam is a helpful aid to recording observations.(see *Preliminaries*) It should preferably be approximately to scale and the locations of all observations should be indicated on it.

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; a photograph should also be taken 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 which have occurred since the previous inspection, and that if a situation looks as if it is worsening or otherwise causes concern the owner should not hesitate to get professional help.

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

APPENDIX A

TABLE A1

DAM INSPECTION CHECKLIST

Date:... /... /20..

Owner: **Property** **Dam ID**

Areas of Dam	Items to Address	Observations/Change from Last Inspection
Upstream Slope	<ul style="list-style-type: none"> ◆ Protection ◆ Uniformity ◆ Displacements, bulges, depressions ◆ Vegetation 	
Crest	<ul style="list-style-type: none"> ◆ Cracking ◆ Low spots ◆ Sinkholes ◆ Vegetation 	
Downstream Slope	<ul style="list-style-type: none"> ◆ Signs of instability and non-uniformity ◆ Erosion ◆ Rabbit, wombat or yabby activity ◆ Obscuring growth (trees) ◆ Wetness ◆ Changes in condition ◆ Stock damage 	
Seepage	<ul style="list-style-type: none"> ◆ Location ◆ Extent of area ◆ Characteristics of area (ie. soft, boggy, firm) ◆ Quantity and colour ◆ Transported or deposited material ◆ Spring activity or Boils ◆ Piping and tunnel erosion ◆ Changes in vegetation 	
Outlet	<ul style="list-style-type: none"> ◆ Outlet pipe and valve condition ◆ Operation ◆ Leakage ◆ Downstream erosion ◆ Gate valve operation/condition/leakage 	
Spillway	<ul style="list-style-type: none"> ◆ Condition of crest, chute and floor protection ◆ Spillway obstructions ◆ Erosion or back cutting in spillway 	

APPENDIX A

Inspection Procedures

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

- ◆ the previous diary entries should be reviewed first to note any areas which will require special attention; and
- ◆ if the purpose of the inspection is to re-evaluate suspected defective conditions discovered during the last inspection, any available construction drawings should first be examined 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; and
- ◆ 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.

(e) General Techniques

The inspection is conducted by walking along and over the dam as many times as necessary to see every square metre. From any given spot a person can usually obtain a detailed view for a distance of three to ten metres in each direction, depending on the smoothness of the surface or the type of material on the surface, ie. grass, concrete, rock, brush (*Figure A-1*).



Figure A-1, Sight Distance

APPENDIX A

Successive Passes

To cover extensive surfaces properly, several walks are required (Figure A-2).

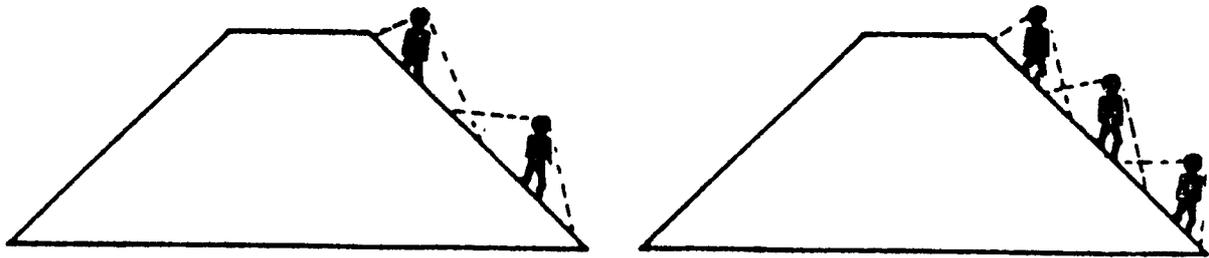


Figure A-2, Successive Passes

Adequate coverage can be achieved using parallel or zigzag paths (Figure A-3).

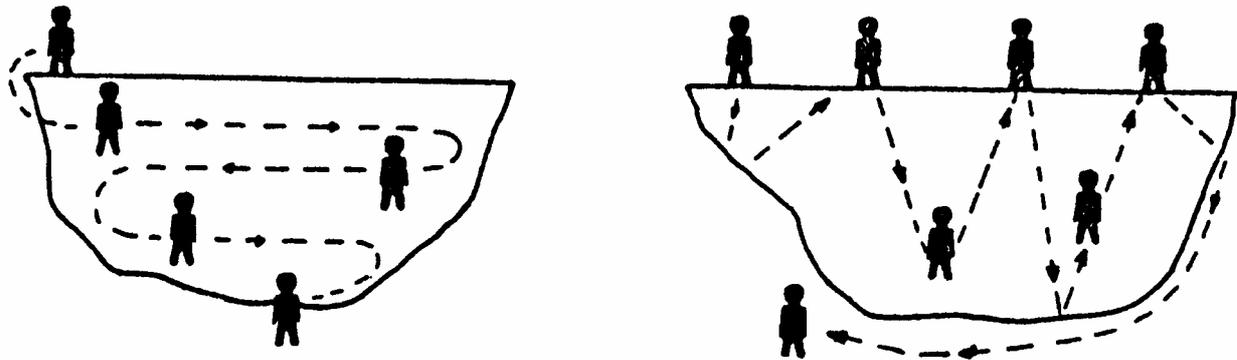


Figure A-3, Parallel Coverage Path

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

Stop and Look

At several points on the slope, you should 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.

APPENDIX A

(f) Particular Techniques

The following is a list of methods that can be used to monitor changes, which will occur over a period of 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.

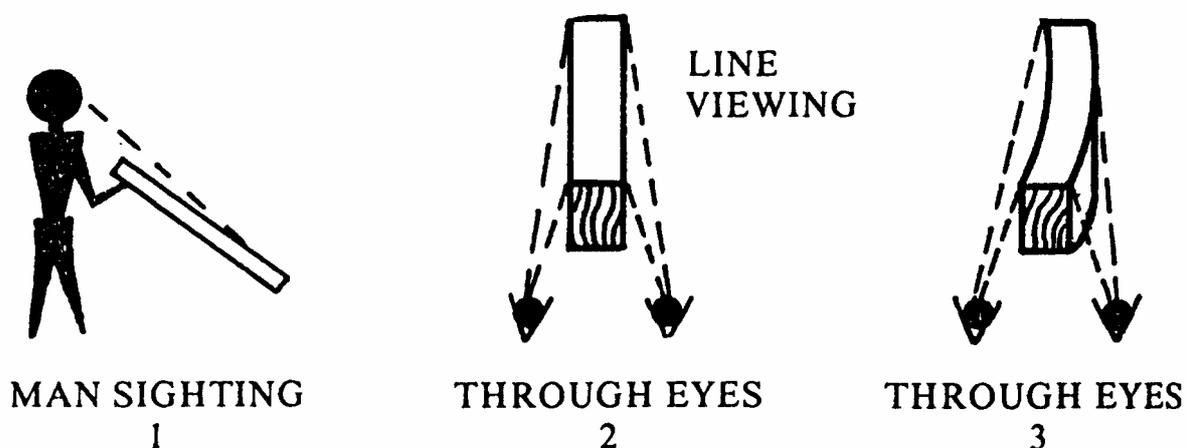


Figure A-4, Sighting Technique

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

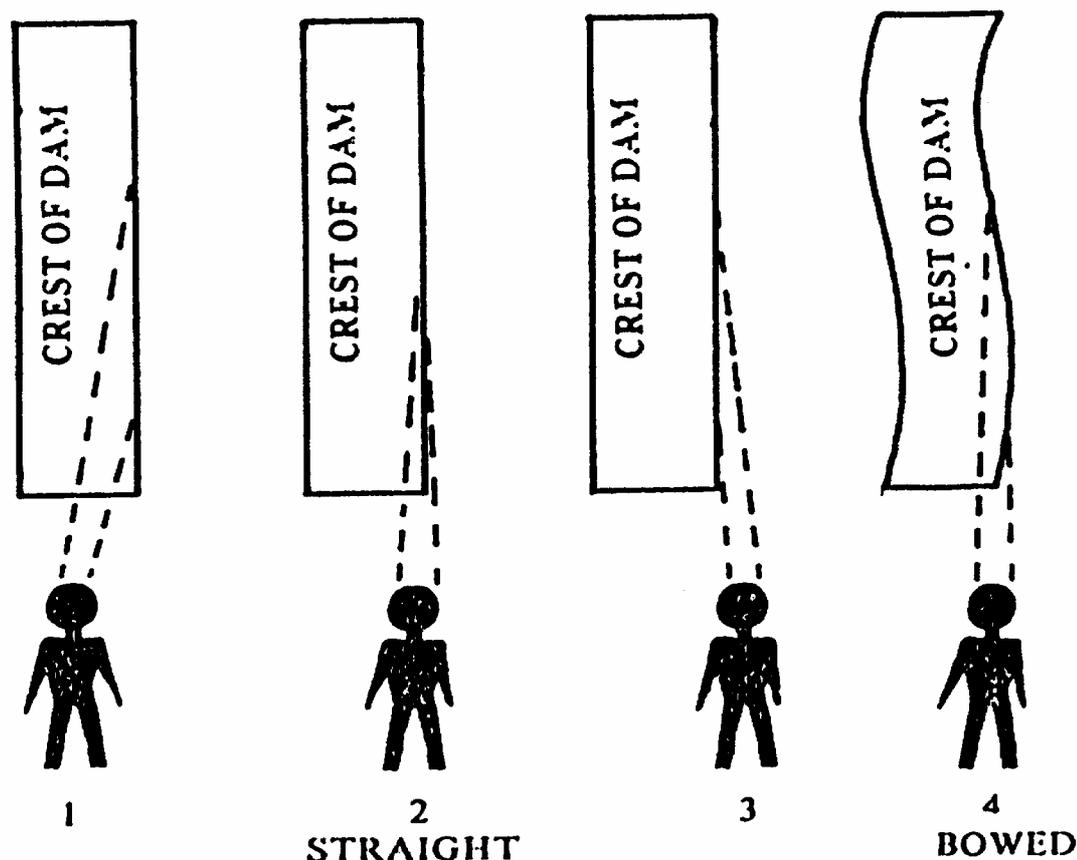


Figure A-5, Sighting along Crest

Probing

The probe (see Glossary of Terms) 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 observed. 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 measuring staff can be permanently set into the storage to 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 five millimetres, and sometimes as much as ten millimetres 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 ten metres. On the other hand, when the dam was finished, the bulldozer operator may not have uniformly graded it, and in such a case the surface of the slope may have an apparent bulge or concavity when in fact no slide is present. A good familiarity with how the slope looked at the end of construction helps identify any slides.

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, whilst those just downhill of the movement would 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.

(g) Evaluation Of Observations

The record of observations taken at periodic inspections is used to develop a mental picture of the dam's performance. Accurate measurements pay off here 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, the observations should be compared with previous records to see if there is any condition, reading, or trend that may indicate a developing problem. The owner can then begin to address any potential problem before it becomes a threat to the dam. When a significant change is detected, any design drawings for the dam should be examined carefully to see if an obvious reason for the change could be found.

If a questionable change of trend is noted, a professional engineer experienced in the field of dam engineering should immediately be engaged 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.

**APPENDIX B: COMMON PROBLEMS - THEIR CAUSES, CONSEQUENCES AND
ACTION REQUIRED**

APPENDIX B: COMMON PROBLEMS - THEIR CAUSES, CONSEQUENCES AND ACTION REQUIRED

Preface

The following information is presented to help the dam owner 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.

A number of the conditions described in the following tables can be corrected by routine and periodic maintenance by the owner. However significant proportion of the conditions which are identified herein threaten the safety and integrity of the dam and require the attention of an experienced professional engineer (see the 'Action Required' column of the following Tables).

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

It should be noted that it is not possible to cover in this appendix all the problems that might arise. Only the more commonly experienced ones are included.

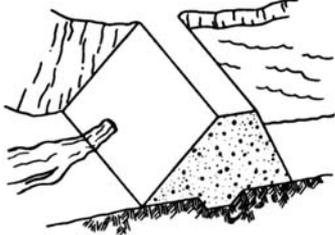
As a general rule, if the owner has any concerns at all he should get help from an experienced professional engineer.

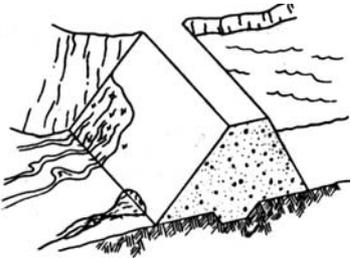
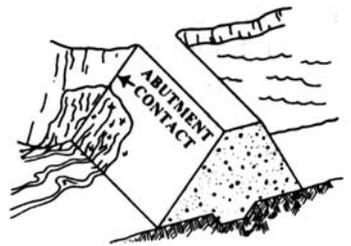
***Note**, as pointed out elsewhere, the term 'experienced professional engineer' or similar in this document means an engineer who is qualified professionally and who is experienced explicitly in dam design and construction for the relevant type of dam. Experience in **construction** only is not considered appropriate. Note that even among professional civil engineers, most practitioners are not experienced in dams, which is a specialist area.*

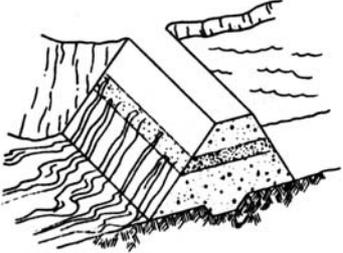
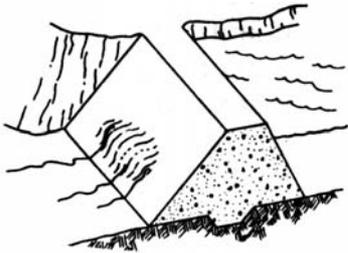
Reference:

Material for this section of the booklet were sourced in the main from the following publication:

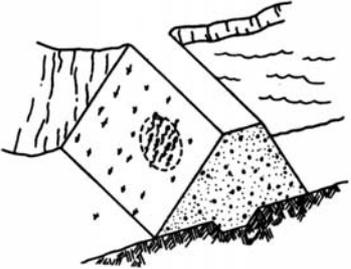
Department of Conservation and Natural Resources: *Your Dam an Asset or a Liability* - 1992

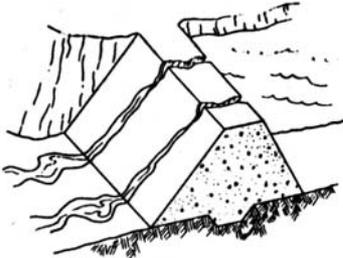
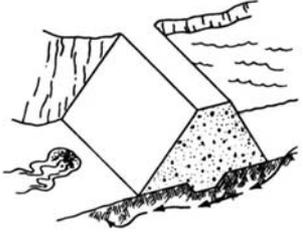
1. Seepage		
Problem	Possible Causes and Potential Harm	Action Required
<p>Seepage water exiting from a point on the embankment</p> 	<p>Causes:</p> <ol style="list-style-type: none"> 1. Water has created an open pathway, channel, (or "pipe") through the dam. The water is eroding and carrying away embankment material. 2. Large amounts of water have accumulated in the downstream slope. Water and embankment materials are exiting at one point. 3. Rabbits, yabbies, rotting tree roots or poor construction have allowed water to create an open pathway or pipe through the embankment. <p>Harm:</p> <ol style="list-style-type: none"> 1. Continued flows can saturate portions of the embankment and lead to slides in the area. 2. Continued flows can further erode embankment materials. This can lead to failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. 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 otherwise. 2. Check whether surface agitation may be causing the muddy water. 3. If quantity of flow is increasing, the water level in the dam should be lowered until the flow stabilises or stops. 4. Search for an opening on upstream side and plug it if possible with clay, but do not get into the water to do so! 5. Prevent rabbit activity. 6. A qualified engineer should immediately inspect the condition and recommend further action to be taken.

Problem	Possible Causes and Potential Harm	Action Required
<p>Large Seepage area producing flow</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. A seepage path has developed directly through the embankment or via the abutment . <p>Harm:</p> <ol style="list-style-type: none"> 1. Increased flows could lead to erosion of embankment material and failure of the dam. 2. Saturation of the embankment can lead to local slides, which could cause failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Stake out the saturated area and monitor wet area for growth or shrinking. 2. Measure any outflows as accurately as possible. 3. Dam water level may need to be lowered if saturated areas increase in size at a fixed storage level or if flow increases. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.
<p>Seepage exiting at abutment contact</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Water flowing through pathways in the abutment. 2. Water flowing through the embankment and out via the abutment 3. Water flowing along the contact surface between the embankment and its abutment. <p>Harm:</p> <ol style="list-style-type: none"> 1. Can lead to erosion of embankment materials and failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Investigate leakage area to determine quantity of flow and extent of saturation. 2. Inspect daily for developing slides. 3. Water level in reservoir may need to be lowered to assure the safety of the embankment. 4. A qualified engineer should inspect the conditions and recommend further actions to be taken.

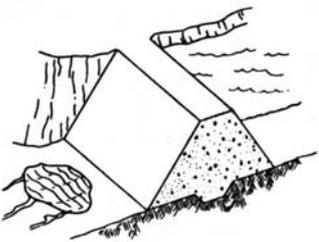
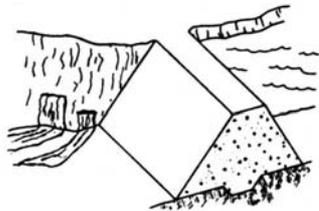
Problem	Possible Causes and Potential Harm	Action Required
<p>Wet area in a horizontal band in the embankment</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Layer of sandy material in original construction. <p>Harm:</p> <ol style="list-style-type: none"> 1. Wetting of areas below the area of excessive seepage can lead to localised instability of the embankment (slides). 2. Excessive flows can lead to accelerated erosion of embankment materials and failure of dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Determine as closely as possible the amount of flow being produced. 2. If flow increases, dam water level should be reduced until flow stabilises or stops. 3. Stake out the exact area involved. 4. Using hand tools, try to identify the material allowing the flow. <p>A qualified engineer should inspect the condition and recommend further actions to be taken.</p>
<p>Bulge in large wet area</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Downstream embankment materials have begun to move. <p>Harm:</p> <ol style="list-style-type: none"> 1. Failure of the embankment due to massive sliding can follow these initial movements. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Compare the observed embankment cross-section with the end of construction condition to see if observed condition may reflect end of construction, or if it represents a subsequent movement. 2. Stake out affected area and accurately measure outflow. 3. A qualified engineer should inspect the condition and recommend further actions to be taken.

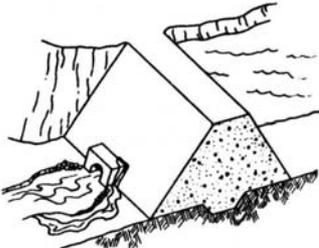
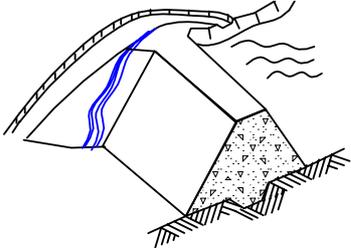
APPENDIX B

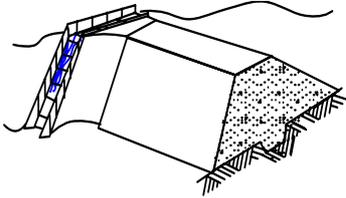
Problem	Possible Causes and Potential Harm	Action Required
<p>Marked change in appearance of vegetation</p> <p><i>Some examples of change:</i></p> <ul style="list-style-type: none"> • More areas of vegetation appear to have grown • A given area appears darker, lighter, larger or wetter • A given area appears to have died 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Embankment materials are providing flow paths. 2. Natural seeding by wind. 3. Change in seed type during initial post-construction seeding. 4. Neglect of dam and lack of proper maintenance procedures. <p>Harm:</p> <ol style="list-style-type: none"> 1. Can indicate a saturated area. 2. 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. 3. Associated root systems develop and penetrate into the dam's cross-section. 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 of Terms). 4. Prevents easy access to all portions of the dam for operation, maintenance and inspection. 5. Provides habitat for rodents 	<p>Action:</p> <ol style="list-style-type: none"> 1. Use probe and shovel to establish if the materials in this area are wetter than in surrounding areas. 2. Remove all detrimental growth from the dam, including removal of trees, bushes, and growth other than grass. Grass should be encouraged on all parts of the dam to prevent erosion by surface run-off. Root systems should also be removed to the maximum practical extent. The resulting voids should be backfilled with competent, well-compacted material. 3. Cutting or spraying, as part of an annual maintenance program should be done to remove further undesirable growth. 4. All cuttings or debris resulting from the vegetation removal should be taken from the dam and properly disposed of outside the reservoir basin. 5. If area shows wetness when surrounding areas do not, a qualified engineer should inspect the condition and recommend further actions to be taken.

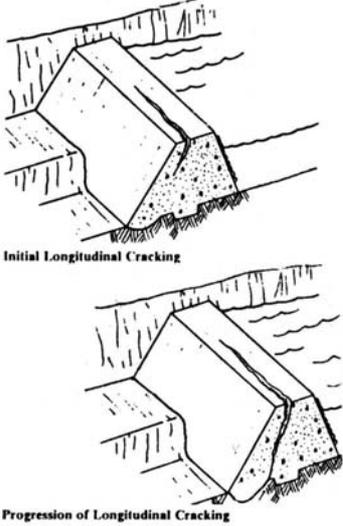
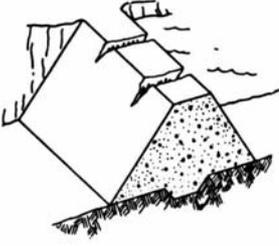
Problem	Possible Causes and Potential Harm	Action Required
<p>Water exiting through transverse cracks on the crest</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Severe drying has caused shrinkage of embankment material. 2. Settlement in the embankment or foundation is causing the transverse cracks. <p>Harm:</p> <ol style="list-style-type: none"> 1. Flow through the crack can cause failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Plug the upstream side of the crack with clay to stop the flow. 2. The water level in the dam should be lowered until it is below the level of the cracks. 3. A qualified engineer should inspect the condition and recommend further actions to be taken.
<p>Seepage water exiting from the foundation (sometimes called a 'boil')</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Some portion of the foundation material is providing a flow path. A sand or gravel layer in the foundation could cause this. <p>Harm:</p> <ol style="list-style-type: none"> 1. Increased flows can lead to erosion of the foundation and failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Examine the boil for transportation of foundation materials. 2. If soil particles are moving downstream, sandbags or earth should be used to create a dyke around the boil. The pressure created by the water level within the dyke may control flow velocities and temporarily prevent further erosion. 3. If erosion is becoming greater, the dam level should be lowered. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.

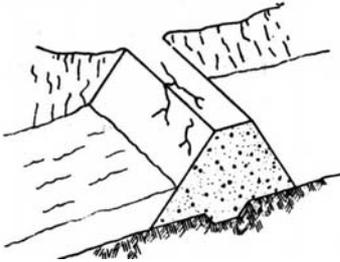
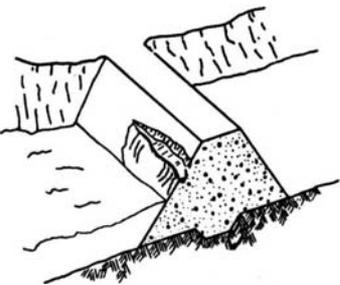
Note: The pattern of cracks (eg., where they are located, how close together they are, whether transverse alone or in conjunction with other cracks etc) requires engineering experience to interpret it. The real cause of cracks may not be apparent to an unqualified observer.

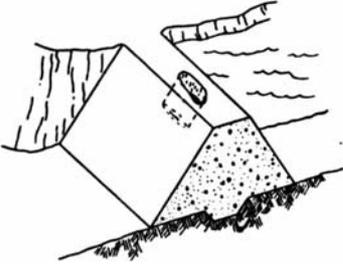
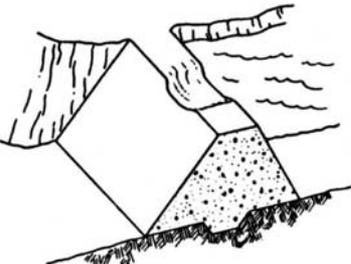
Problem	Possible Causes and Potential Harm	Action Required
<p>Trampoline effect in large soggy area (i.e., area springy or spongy)</p>  <p>The diagram shows a cross-section of a dam. On the left, water is shown flowing over the crest. The embankment on the right is depicted with a porous, spongy texture, indicating water seepage. A small area of the embankment is shown with a trampoline-like effect, where the surface is being pushed up by water pressure from below.</p>	<p>Cause:</p> <ol style="list-style-type: none"> 1. Water moving freely through the embankment or foundation is being controlled or contained by a well-established turf root system. <p>Harm:</p> <ol style="list-style-type: none"> 1. Condition indicates excessive seepage in the area. If the upper layer of soil in the area is eroded or removed, rapid erosion of foundation materials could result in failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Carefully inspect the area for outflow quantity and any transported materials. 2. A qualified engineer should inspect the condition and recommend further actions to be taken
<p>Leakage from abutment beyond the dam</p>  <p>The diagram shows a cross-section of a dam. On the left, water is shown flowing over the crest. The abutment on the right is depicted with a porous, spongy texture, indicating water seepage. A small area of the abutment is shown with a leakage point, where water is flowing out from the side of the dam.</p>	<p>Cause:</p> <ol style="list-style-type: none"> 1. Water moving through cracks and fissures in the abutment materials. <p>Harm:</p> <ol style="list-style-type: none"> 1. Can lead to rapid erosion of abutment and emptying of the dam. 2. Can lead to massive slides near or downstream of the dam. 3. Failure of abutment and loss of control of the dam (in effect a dam failure). 	<p>Action:</p> <ol style="list-style-type: none"> 1. Carefully inspect the area to determine quantity of flow and amount of transported material. 2. A qualified engineer or geologist should inspect the condition and recommend further actions to be taken. 3. May need to block entry on upstream side.

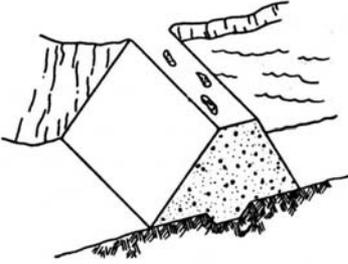
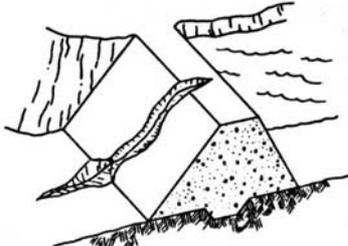
Problem	Possible Causes and Potential Harm	Action Required
<p>Seepage water exiting from a point adjacent to the outlet</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. A break in the outlet pipe. 2. A path for flow has developed along the outside of the outlet pipe. <p>Harm:</p> <ol style="list-style-type: none"> 1. Continued flows can lead to rapid erosion of embankment materials and failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Thoroughly investigate the area by probing to see if the cause can be determined. 2. Determine if leakage water is carrying soil particles. 3. Determine quantity of flow. 4. If flow increases or is carrying embankment materials, dam water level should be lowered until leakage stops. 5. A qualified engineer should inspect the condition and recommend further actions to be taken.
<p>Leakage in or around spillway</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Cracks and joints in geologic formation at spillway are permitting seepage. 2. Gravel or sand layers at spillway are permitting seepage. <p>Harm:</p> <ol style="list-style-type: none"> 1. Could lead to excessive loss of stored water. 2. Could lead to progressive failure if velocities are high enough to cause erosion of natural materials. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Examine exit area to see if type of material can explain leakage. 2. Measure flow quantity and check for erosion of natural materials. 3. If flow rate or amount of eroded materials increases rapidly, dam water level should be lowered until flow stabilises or stops. 4. A qualified engineer should inspect the condition and recommend further actions to be taken. 5. Consider installing upstream valve on outlet pipe.

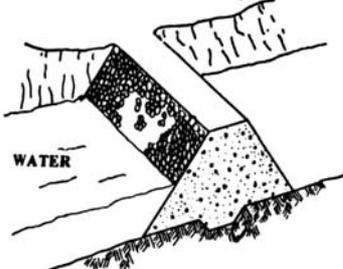
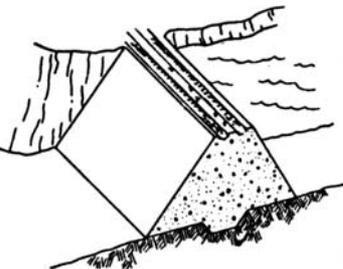
<p>Seepage from crack in concrete or structure construction joint</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Water is collecting behind structure because of insufficient drainage or clogged weep holes. <p>Harm:</p> <ol style="list-style-type: none"> 1. Can cause walls to tip in and fall over. Flows through concrete can lead to rapid deterioration from weathering. 2. If the spillway is located within the embankment, rapid erosion can lead to failure of the dam 3. Excessive flows under the spillway could lead to erosion of foundation material and collapse of portions of the spillway 4. Uncontrolled flows could lead to loss of stored water. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Check area behind wall for ponding of surface water. 2. Immediately measure flow quantity and check flows for transported drain material. 3. If flows are accelerating at a fixed storage level, the reservoir level should be lowered until the flow stabilises or stops. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.
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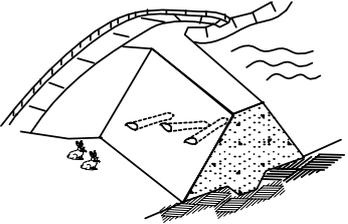
2. Cracking, Deformation and Movement (even if not associated with seepage or leakage of water)		
Problem	Possible Causes and Potential Harm	Action Required
<p>Longitudinal Cracking</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Drying and shrinkage of surface material. 2. Downstream movement or settlement of embankment. <p>Harm:</p> <ol style="list-style-type: none"> 1. Can be an early warning of a potential slide. 2. Shrinkage cracks allow water to enter the embankment and further weaken the embankment. 3. Settlement or slide indicating loss of strength in embankment can lead to failure. 	<p>Action:</p> <ol style="list-style-type: none"> 1. If cracks are from drying, dress area with well-compacted material to keep surface water out and natural moisture in. 2. If cracks are extensive, or growing in length, width or number, a qualified engineer should inspect the condition and recommended further actions to be taken.
<p>Transverse Cracking</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Drying and shrinkage of surface material is most common cause. 2. Differential settlement of the embankment also leads to transverse cracking (eg. centre settles more than abutment). <p>Harm:</p> <ol style="list-style-type: none"> 1. Shrinkage cracks allow water to enter the embankment and weaken it and may lead to failure. 2. Settlement cracks can lead to seepage of reservoir water through the dam causing erosion and failure. 	<p>Action:</p> <ol style="list-style-type: none"> 1. If necessary plug upstream end of crack to prevent flows from the reservoir. 2. Clean up cracks and backfill with compacted material 3. If cracks are extensive, or are growing in length, width or number, a qualified engineer should inspect the dam and recommend further actions to be taken

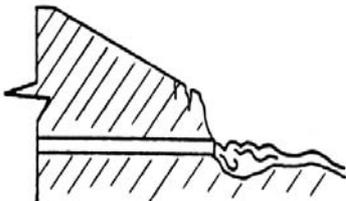
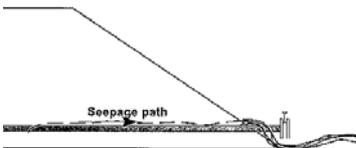
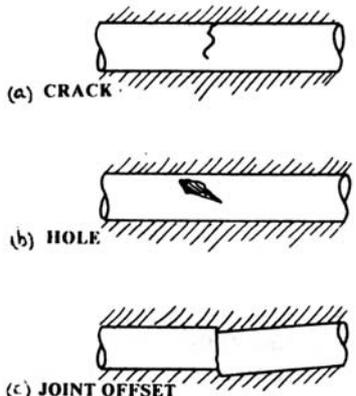
Problem	Possible Causes and Potential Harm	Action Required
<p>Cracks due to drying (random pattern)</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. The soil loses its moisture and shrinks, causing cracks. 2. Note: -Usually seen on crest and downstream slope. <p>Harm:</p> <ol style="list-style-type: none"> 1. Heavy rains can fill up cracks soften the soil and cause small portions of embankment to move along internal slip surfaces. 2. Provides points of entrance for surface run-off, leading to deterioration of the crest. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Monitor cracks for increases in width, depth, or length. 2. On crest, seal surface cracks with a tight impervious material. 3. Routinely grade crest to provide proper drainage and fill cracks. 4. Cover crest with non-plastic (not clay) material to prevent large moisture content variation with respect to time. 5. A qualified engineer should inspect the condition and recommend further actions to be taken.
<p>Slide, Slump or Slip</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Lack of or loss of strength of embankment material. 2. Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation. 3. Earth or rocks move down the slope along a slippage surface because they were on too steep a slope or the foundation moves. <p>Harm:</p> <ol style="list-style-type: none"> 1. A slide can reduce the dam's seepage path. This can accelerate the rate of seepage and lead to loss of material. 2. A series of slides can lead to obstruction of the outlet or failure of the dam. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Evaluate extent of the slide. Monitor slide. 2. Draw the dam water level down if safety of dam is threatened. 3. A qualified engineer should inspect the conditions and recommend further actions to be taken.

Problem	Possible Causes and Potential Harm	Action Required
<p>Sinkhole in Crest</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Internal erosion or piping of embankment material by seepage. 2. Breakdown of dispersive clays within embankment by seepage waters or rain. 3. Hole in outlet conduit is causing erosion of embankment material. 4. Rodent activity. <p>Harm:</p> <ol style="list-style-type: none"> 1. A void within the dam embankment could cause localised caving, sloughing, instability, or reduced embankment cross section. 2. Entry point for surface water, loss of soil leading to instability of embankment failure. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Carefully inspect and record location and physical characteristics (depth, width, length) of sinkhole. 2. A qualified Engineer should determine cause of sinkhole and supervise all steps necessary to reduce threat to dam and correct condition. 3. Excavate sinkhole, slope-sides of excavation, and backfill hole with competent material using proper construction techniques. An engineer should supervise this.
<p>Low Area or Dip in Crest</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Excessive settlement in the embankment or foundation directly beneath the low area in the crest. 2. Internal erosion of embankment material. 3. Foundation spreading toward upstream and/or downstream direction. 4. Foundation wind erosion of crest area. 5. Improper final grading following construction. <p>Harm:</p> <ol style="list-style-type: none"> 1. Reduces freeboard available to pass flood flows safely through spillway and increases risk of dam overtopping and failure 	<p>Action:</p> <ol style="list-style-type: none"> 1. Determine exact amount, location, and extent of settlement in crest. 2. A qualified engineer should determine cause of flow area and supervise all steps necessary to reduce possible threat to the dam and correct condition. 3. Re-establish uniform crest elevation over crest length by placing fill in low area using proper construction techniques. Engineer should supervise this. 4. Establish markers across crest of dam and monitor on a routine basis to detect possible future settlement.

Problem	Possible Causes and Potential Harm	Action Required
<p>Puddling on Crest - Poor Drainage</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Poor grading and improper drainage of crest. 2. Localised consolidation soft spots or settlement on crest allows puddles to develop. <p>Harm:</p> <ol style="list-style-type: none"> 1. Causes localised saturation of the crest and loss of soil strength. 2. Inhibits access to all portions of the dam and crest. 3. Becomes progressively worse if not corrected 	<p>Action:</p> <ol style="list-style-type: none"> 1. Drain standing water from puddles. 2. Regrade and re-compact crest to restore integrity and provide proper drainage toward upstream slope. 3. Provide gravel or road-base material to accommodate traffic. 4. Perform periodic maintenance and regrading to prevent reformation of low areas.
<p>Erosion Gully on Crest and Downstream Slope</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Heavy rainfall. 2. Poor grading and improper drainage of crest. Improper drainage causes surface run-off to collect and drain off crest at low point in upstream or down-stream shoulder. 3. Inadequate spillway capacity which has caused dam to overtop. <p>Harm:</p> <ol style="list-style-type: none"> 1. Can reduce available freeboard. 2. Reduces cross-sectional area of dam. 3. If allowed to continue, can lead to severe deterioration of downstream slope and shorter internal drainage path. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Protect eroded areas with rock or clay. 2. Regrade crest to provide proper drainage of surface run-off. 3. If gully was caused from overtopping, provide adequate spillway, which meets current design standards. This should be done by an engineer. 4. Re-establish protective cover.

3. Miscellaneous		
Problem	Possible Causes and Potential Harm	Action Required
<p>Broken Down or Lost Rock Beaching</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Poor quality beaching has deteriorated. Wave action has displaced beaching. Round and similar-sized rocks have rolled downhill. 2. Similar-sized rocks allow waves to pass between them and erode small gravel particles and soil. <p>Harm:</p> <ol style="list-style-type: none"> 1. 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. 2. Causes over-steepness of upstream slope increasing instability and resulting in reduced crest width. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Re-establish effective slope protection. Place bedding material. 2. Engineer required for design of gradation and size of rock for bedding and beaching. 3. A qualified engineer should inspect the dam and recommend further actions to be taken.
<p>Ruts along Crest</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Heavy vehicle traffic without adequate or proper maintenance or proper crest surfacing. <p>Harm:</p> <ol style="list-style-type: none"> 1. Inhibits easy access to all parts of crest. 2. 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. 3. Loss of soil strength in embankment. 4. Vehicles can get stuck 	<p>Action</p> <ol style="list-style-type: none"> 1. Drain standing water from ruts. 2. Regrade and re-compact crest to and provide proper drainage toward upstream slope. 3. Provide gravel or road-base material to accommodate traffic. 4. Perform periodic maintenance and regrading to prevent reformation of low areas.

Problem	Possible Causes and Potential Harm	Action Required
<p>Livestock Traffic</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Excessive travel by livestock especially harmful to slope when wet. <p>Harm:</p> <ol style="list-style-type: none"> 1. Creates areas bare of erosion protection grass cover. 2. Causes erosion channels. Allows water to stand. Area susceptible to drying cracks. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Fence livestock outside embankment area. 2. Repair erosion gully. 3. Recover with grass for protection.
<p>Rodent, Rabbit or Wombat Activity</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Over-abundance of animal pests. 2. Favourable habitat or burrowing conditions at dam. <p>Harm:</p> <ol style="list-style-type: none"> 1. Burrows can substantially reduce leakage path, leading to piping failure. 	<p>Action:</p> <ol style="list-style-type: none"> 1. Control pests to prevent additional damage. 2. Provided the diagnosis is correct, determine the extent of burrowing and backfill with compacted clay, working from upstream to downstream as far as possible. If there is any doubt at all as to the cause of these burrows, seek professional advice before any remedial action.
<p>Obscuring Vegetation and trees</p> 	<p>Cause:</p> <ol style="list-style-type: none"> 1. Natural vegetation (self-sown). <p>Harm:</p> <ol style="list-style-type: none"> 1. Large tree can die. Roots can then create seepage paths 2. Bushes can obscure visual inspection 3. Provides habitat for rodents 4. Trees can fall, creating holes in crest or side slopes 	<p>Action:</p> <ol style="list-style-type: none"> 1. Remove large deep rooted trees and shrubs on or near embankment 2. Properly backfill void left by tree stump 3. Control all other vegetation on the embankment that obscures visual inspection

4. Outlet Works and Concrete Structures		
Problem	Possible Causes and Potential Harm	Action Required
<p>Outlet Releases Eroding Toe of Dam</p> 	<p>Cause:</p> <ol style="list-style-type: none"> Outlet pipe too short. Lack of energy-dissipating pool or structure at downstream end of conduit. <p>Harm:</p> <ol style="list-style-type: none"> Erosion of toe over-steepens downstream slope, causing progressive sloughing. Eroded material causes environmental damage 	<p>Action:</p> <ol style="list-style-type: none"> Extend pipe beyond toe (use a pipe of same size and material, and form watertight connection to existing conduit). Protect embankment with riprap over suitable bedding.
<p>Piping Along Outlet</p>  <p>Note: Do not allow anyone to enter the water to try and block the outlet when water is flowing.</p>	<p>Cause:</p> <ol style="list-style-type: none"> Fracture or joint failure in outlet pipe. Seepage along outside of pipe (poor construction). <p>Harm:</p> <ol style="list-style-type: none"> Will get progressively worse and cause embankment failure Can be difficult to stop once it progresses beyond a seep. 	<p>Action</p> <ol style="list-style-type: none"> 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. A qualified engineer should inspect the dam and recommend further actions to be taken.
<p>Outlet Pipe Damage</p> <p>(these can be difficult to diagnose because of occurring internally within the embankment)</p> 	<p>Cause:</p> <ol style="list-style-type: none"> Settlement; impact. Rust (steel pipe) pitting. Settlement or poor construction practice. <p>Harm:</p> <ol style="list-style-type: none"> Excessive seepage, possible internal erosion. Provides passageway for water to exit or enter the pipe, resulting in erosion of internal materials of the dam and possibly dam failure. 	<p>Action:</p> <ol style="list-style-type: none"> 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. Install upstream valve to isolate pipeline and enable inspections

APPENDIX C: STANDARD DESIGN GUIDE

APPENDIX C

APPENDIX C: STANDARD DESIGN GUIDE FOR SMALL DAMS**Application**

These guidelines are meant for dams not exceeding 3 metres in height and 20 megalitre in capacity, and for which the consequences of failure are reliably assessed as low (ie. in the 'low hazard' category). Note that these size limits are less than those set out in *Section 3.2* of this booklet.

Warning

These guidelines are given in good faith only as an outline in principle as to how a safe and durable dam may be designed. They are not intended as a manual giving explicit instructions which may be applied to any given dam, to do so requires professional appraisal of the dam site, proposed materials and construction procedures, as well as any relevant features of the site-specific hydrology, meteorology, operation of the dam and any other relevant matters. As stated elsewhere in this booklet, a dam must be matched to its site for assuring performance, and the relevant expertises to do that adequately, even for small dams, are typically outside the expertises of dam owners. The state of Victoria and the authors of these guidelines do not accept any responsibility for application of these guidelines, in whole or in part, to any particular dam, and owners are warned that professional advice from a suitably qualified and experienced engineer is required for that purpose.

General

It is beyond the scope of this booklet to cover all aspects of the design of larger or complicated dam sites. So if there is any doubt about the circumstances or the nature of the materials or site on which the dam is to be constructed you will need to seek professional advice from a qualified and experienced dam engineer.

Generally the dam design and construction can be broken up into the following four areas:

- ◆ foundations;
- ◆ embankment;
- ◆ spillway; and
- ◆ outlet works.

The following is an outline of 'good practice' criteria in designing and constructing such a dam.

Foundation

The first step is to strip the total foundation area, on which the dam is to be placed, of all topsoil and organic material.

APPENDIX C

Stockpile topsoil separate from other materials so that it can be spread on the finished surface of the dam and spillway chute to encourage grass re-growth and provide protection from erosion.

All soft material and pockets of sand or other permeable material should also be removed from the foundation and replaced with sound compacted material.

If on stripping the topsoil from the foundation the surface has voids and cracks, advice should be sought.

Foundations must be stable and not excessively steep. On steep sided abutments against which the dam is to be placed do not leave vertical or overhanging material. Cut back preferably to a slope of 1H to 1V but do not have any surface steeper than 0.5H to 1V.

The core trench located under the centre of the dam should have cut slopes of 1H to 1V and have a base width of 3 metres.

The depth of the core trench should be a minimum of 0.5m into impervious material. Impervious material is that which watertight. If this becomes excessively deep then further advice should be sought.

If foundations are making water then seek advice from a suitably qualified engineer.

Embankment

Slopes

Where the foundations are stable, the embankment should have an upstream slope of 3H to 1V and a downstream slope of 2.5H to 1V or flatter. Steeper batter slopes are only suitable for certain types of materials and should not be used except on the advice from a suitably qualified engineer.

If the embankment is to be constructed on a gully with a steep sloping floor consideration would need to be given to flattening the above mentioned batters to provide stability.

Materials

Peat, highly organic soils, organic clays, silts, sandy silt or sand are not suitable materials for constructing embankments. Similarly materials with high gravel or sand content, or which are excessively wet or dry, are also not suitable. The different types of soils at the site should be investigated prior to engaging an earth-works contractor to ensure sufficient suitable soil is available.

If the materials available to construct the embankment vary in quality, then less permeable material (higher clay content) should be used towards the upstream face.

APPENDIX C

Material suitable for embankment construction needs to contain 30 per cent of clay and silt size particles (passing 75 micron sieve). Clay is material passing a 2 micron sieve and should comprise 20 per cent of the content. Where this is not available then advice should be sought. (Note that the content of soils in the above context is often deceptive to the untrained eye, and the content of clay (for example) cannot be reliably determined without carrying out standardised tests in a soil-testing laboratory.

Dispersive clay is material which on contact with water may be drawn (disperse) into suspension in the 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. This problem can result in the clay being washed out of the embankment, leading to failure of the dam, often during first filling. Dispersive clays are discussed elsewhere in this booklet, and it should be stated again that **dams constructed with these materials are at a higher probability of failure** unless they are carefully constructed. Measures to combat dispersive clays include lime or gypsum treatment of the soil, carefully controlled compaction, and possibly the use of filters (the latter feature usually for larger dams). Professional engineering advice should be sought where dispersive clays are encountered.

Placement and Compaction of Materials

Prior to placement of embankment material, its moisture content should be adjusted so that it can be properly compacted. The moisture content is achieved when the material can be readily moulded in the hand without crumbling, but without being soft. Adjustment may require addition of water by spraying, or removal of water by drying (loosen to allow sun and wind to dry soil). The material should be mixed to achieve uniform moisture content before placement on the embankment.

Embankment materials should be placed in layers no thicker than 150 mm when compacted. These layers should not be allowed to dry out prior to the next layers being placed above them.

An additional amount of 5 per cent of the embankment height should be allowed over and above the freeboard to allow for settlement (consolidation) of the fill material after initial construction.

A self propelled or towed tamping foot roller should be used to compact the embankment material. Adequate compaction is generally achieved when the tamping feet “walk out” of the fill without further disturbing the compacted layer.

Relying on track rolling with a dozer for compaction of the materials is not suitable for most types of materials and proper compaction equipment should be used, notwithstanding common practice to the contrary. Track rolling for dispersive materials is not acceptable

APPENDIX C

under any circumstances, and for these materials very careful control of moisture content is also required.

Embankment Crest Width

The embankment crest width should be suitable for vehicle traffic (minimum 3.5m) to cope with emergency maintenance should it be needed. Day to day vehicle access on the crest should be avoided, unless the surface has been capped with gravel, as wheels ruts can pool water and accelerate deterioration of the dam.

A 150 mm capping layer of well-graded gravel on the crest of the dam provides a trafficable surface and protects against drying out of the soil, helping to prevent cracking of the embankment material.

Erosion Protection

Erosion protection of the embankment can be achieved by spreading topsoil and sowing grass over the upstream and downstream slopes of the dam. If gravel is available it can be used to provide erosion protection for the water-face slope of the embankment.

Spillways

General

Spillways are an essential part of the dam construction. Without a spillway, dams will overtop and fail when high inflows occur. Dams are at greatest risk when full.

The spillway crest level must be set such that there is adequate allowance for flood overflow to occur without the dam overtopping, and to cope with any wind induced waves that can also overtop the dam.

The nature of the discharge channel from the spillway crest should be both sized and protected against erosion occurring.

Location

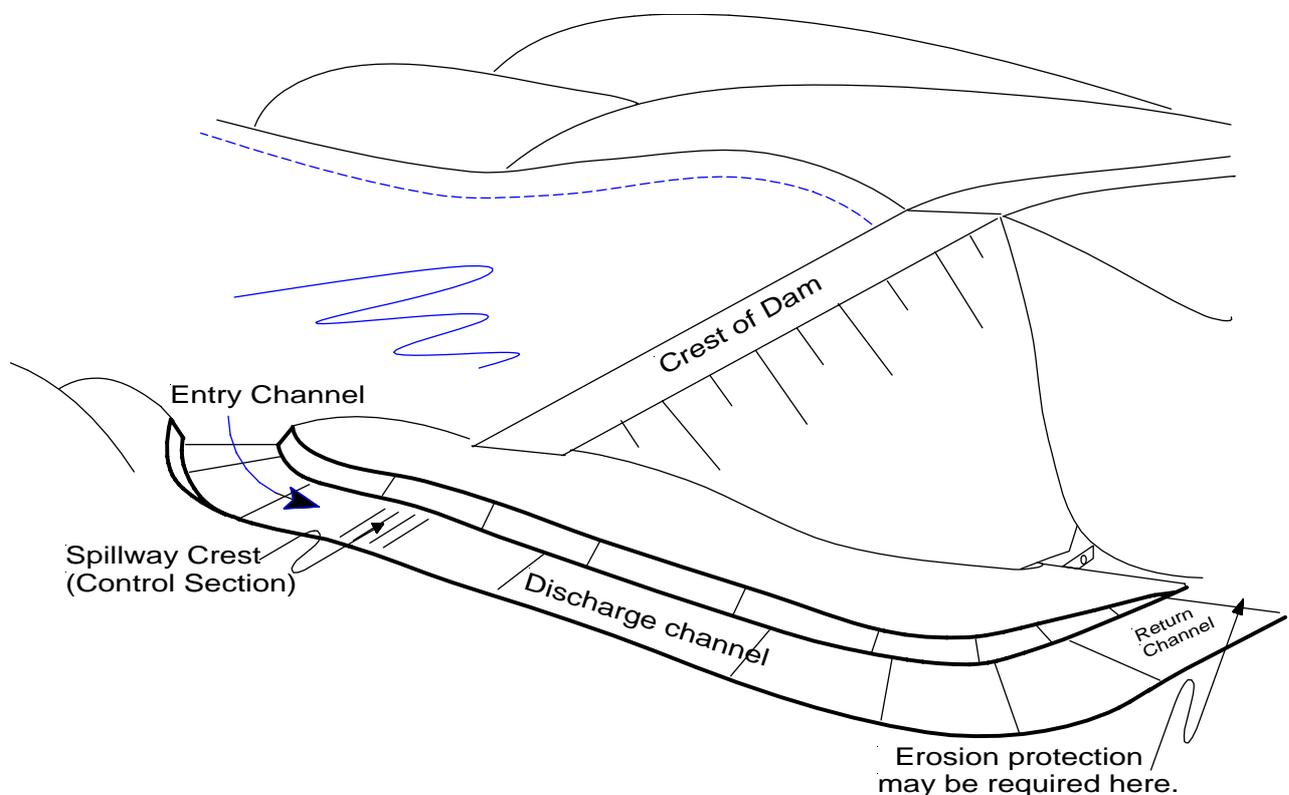
Spillways must be located in the natural abutment material and not in the embankment (refer *Figure C- 1*). Where an earthen spillway is provided, some protection against erosion will be needed. In stable soils well-established grass cover 100-200 mm long will provide good protection without obstructing flow. In more erodible soils additional protection is likely to be needed such as graded rock or beaching. The spillway cut should be flat to make sure the flow is evenly distributed across the width of the channel. Do not allow traffic (vehicles or cattle) across or along the spillway channel, as any rutting will create a starting point for erosion.

APPENDIX C

Spillways must be located such that water discharging from them is directed away from the embankment or the embankment interface with the hillside. If this is not done., the discharge water may cause erosion of the embankment and ultimately failure of the dam.

Ideally, a spillway should have a control section across its width, constructed of concrete with its surface at the overflow level, but extending at the sides about 0.3 m above the overflow level. Installation needs some care if this is to prevent erosion lowering the overflow level, which is its main purpose.

FIGURE C- 1



Freeboard

Freeboard is also an important protection and is defined as the vertical distance between the full storage (spillway crest) level and the embankment crest. The amount of freeboard required depends on the storage size, expected wave heights and the desired spillway capacity. For situations covered here the freeboard should not be less than 1.0-m.

Size of Spillway

The size of the spillway is determined from the likely rainfall intensity for the area, catchment characteristics and the nature of the spillway being used. When sizing a spillway you need to consider all factors that will affect the speed of rainfall run-off into the dam. For example

APPENDIX C

timbered areas will not normally be as fast as grass areas however rocky catchments generally have the fastest run-off rate.

For the purpose of assisting owners of small dams two standard spillway size options have been provided on the following pages. These are related to catchment sizes and must be used within the limitations identified.

These standard sizes should only be applied if the dam:

- ◆ does not exceed 3 metres in height;
- ◆ holds **20ML** (20,000 cubic metres) or less at full capacity;
- ◆ will have **negligible impact** on any other person, property or the environment if it fails;
- ◆ has a spillway discharge channel slope of less than 15%; and
- ◆ is not located in the very high rainfall areas

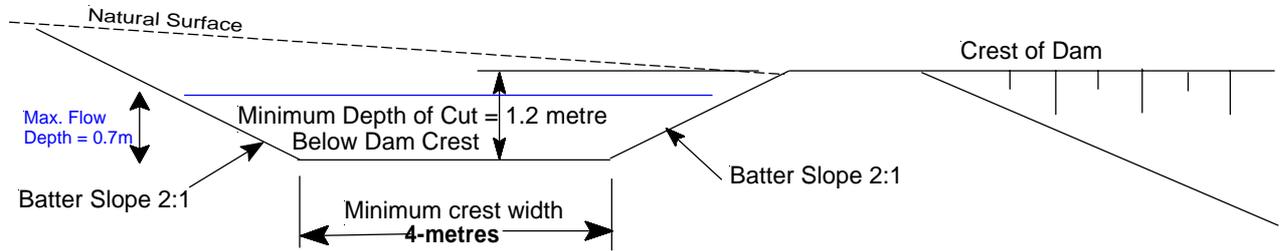
Engineering advice should be sought for dams (even if less than 3m in height or 20 ML in capacity) as follows:

- ◆ in the high rainfall areas mentioned above;
- ◆ where the dam has a catchment larger than 50 Hectares; and
- ◆ where a different form of spillway is used.

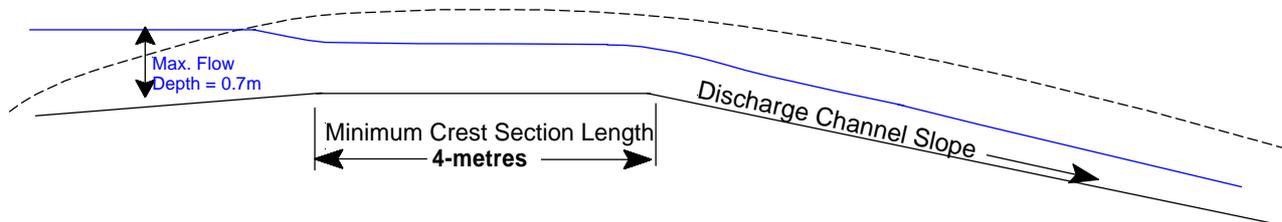
Remember: *The consequences of dam failure must be negligible to be able to apply the spillway sizes presented below. Where this is not the case then seek advice from a dams engineer.*

For dams that have a catchment area of 25-hectares or less the following size may be used:

FIGURE C- 2



CROSS-SECTION OF SPILLWAY CREST



LONGITUDINAL SECTION THROUGH SPILLWAY CREST

Where a long entry channel is required this channel width must not be less than the width the spillway crest and the level must not be higher than the crest section.

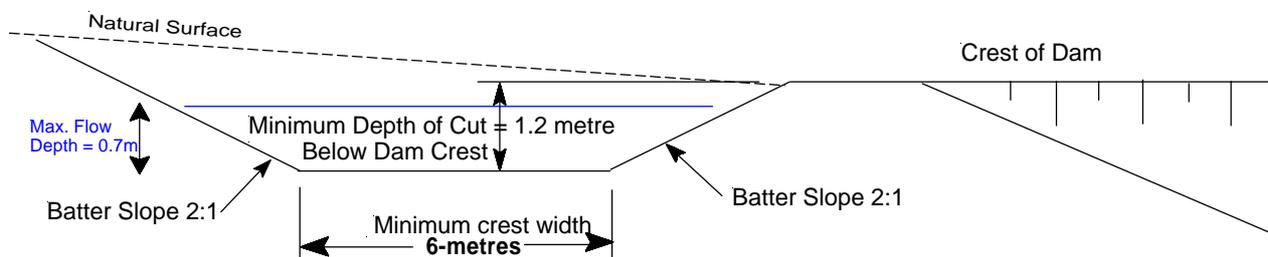
The width of the discharge channel must be sized to suit the gradient. This is required to make sure the water flow will not be too fast or restricted. *Table C-1* below provides the discharge channel width required for the slope of your channel

Table C-1 for Up to 25-Hectare Catchment

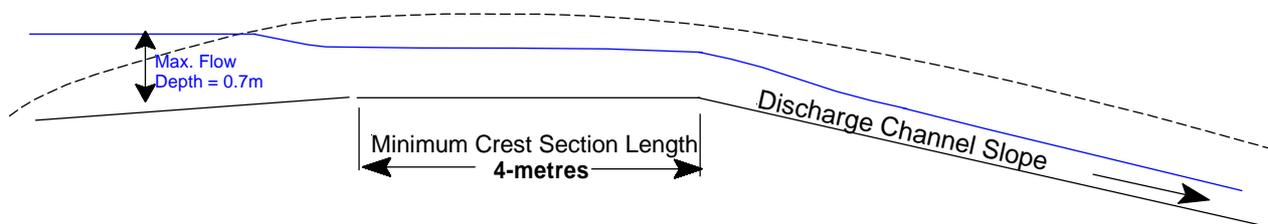
Discharge Channel Slope (% vertical to horizontal, or fall in m. per 100m)								
3%	4%	5%	6%	7%	8%	9%	10%	15%
Discharge Channel Width in metres								
4	4	5	6	7	7	7	10	13

For dams that have a catchment greater than 25-hectares and less than 50-hectares, the following size may be used:

FIGURE C- 3



CROSS-SECTION OF SPILLWAY CREST



LONGITUDINAL SECTION THROUGH SPILLWAY CREST

Where a long entry channel is required this channel width must not be less than the width the spillway crest and the level must not be higher than the crest section.

The width of the discharge channel must be sized to suit the gradient. This is required to make sure the water flow will not be too fast or restricted. *Table C-2* below provides the discharge channel width required for the slope of your channel

Table C-2 for over 25 up to 50-Hectare Catchment

Discharge Channel Slope (%)									
3%	4%	5%	6%	7%	8%	9%	10%	15%	
Discharge Channel Width in metres									
6	8	9	11	13	14	15	17	22	

In some cases there may be some potential for trimming of the spillway size if an experienced dams engineer is engaged to consider all the factors relating to your specific dam site.

APPENDIX C

Outlet Pipe

General

Outlets should be constructed in undisturbed ground in the foundation. The outlet pipe may be a welded steel (preferred), polyethylene or ductile iron pipe below the embankment to discharge the stored water for supply or environmental flow purposes. The type of pipe selected should be able to take the embankment and water pressures. Taking into account a minimum service life of around 50 years, some wall thickness allowance for corrosion should be made for steel and ductile iron pipes. PVC pipe is not considered suitable due to its potential for cracking.

Many failures occur along the outlet pipe due to lack of compaction around the pipe particularly under the lower third of the laid pipe. The outlet pipe should be concrete encased because it is very difficult to get suitable soil compaction around a pipe. The trench for the outlet pipe should have vertical sides up to the top of the pipe then battered 1H to 1 V side slopes to allow good compaction of backfill. (Note that this requires careful attention to detail: seek advice)

Installation

The pipe should be laid in the trench supported at intervals off the floor of the trench (75 mm high concrete blocks) to ensure that concrete can flow under the pipe to fully encapsulate it. Prior to pouring the concrete the pipe should be filled with water to test for leaks. When the outlet pipe is being encased, care should be taken that it is not only supported from the floor of the trench but that it is also held down at intervals to stop it floating in the fresh concrete. Filling the pipe with water will help in this regard.

Size of Pipe

The minimum size should be 200 mm to protect against blockage. This size of pipe is also useful should you need to lower the level of the water if an embankment problem develops. The diameter of the outlet pipe should also be large enough to provide adequate supply and environmental flows. Pipe manufacturers have strength and flow chart information readily available.

Other Pipe Details

At the upstream end the pipe should be kept at least 600-mm off the floor of the dam and extend some 1.5 m into the water to reduce the chances of silt or debris blockages and to make cleaning easier. The outlet pipe should continue at least 1 m past the downstream toe of the embankment and discharge from the outlet pipe should be designed so that erosion of the discharge area does not occur.

APPENDIX C

Cut- Off Collars

Anti seepage concrete cut off collars should be constructed at intervals along the encased pipe. These collars inhibit seepage along the outside of the pipe. They comprise 150 mm minimum thickness of reinforced concrete extending at least 1 metre into undisturbed ground on the sides and under the pipe and also extend 1 metre above the pipe into the embankment fill.

Outlet Valves

The ideal valve arrangement is to have both an upstream and a downstream valve. This enables the downstream valve to be maintained without draining the storage and provides added protection to the embankment in case of problems with the outlet conduit. The upstream valve should be capable of being operated from the embankment crest (inclined stem from the valve along the upstream face of the embankment or a 'floating arm' intake).

Remember NEVER enter the water if the downstream valve is open or if there is uncontrolled leakage from the storage.

The downstream gate valve on the outlet is to control discharges from the storage. Remember that the outlet conduit is not a substitute for a spillway to pass flood flows. This is the role of the spillway or overflow pipe.

Reservoir Rim

Look for pervious layers that may allow leakage and/or cause piping erosion to occur.

Where these conditions are found to exist get expert help. It may be necessary to provide a 300-mm minimum thickness of clay lining to all or parts of the storage basin area to ensure it is watertight. There will always be a maintenance concern with clay lining if the clay is permanently submerged and allowed to dry out and crack. Another problem is heavy stock such as cattle that may wade in the water and penetrate the layer with their hooves.

Operation

There is a sense in which 'operation' is usually considered something different from design. However, if certain things to do with operation are not carried out, they can negate the effectiveness of the design and render the dam not fit for its purpose. For this reason, the designer should incorporate in the instructions to the owner, warnings about the importance of the following things (at least) in ensuring satisfactory performance:

- ◆ No cattle should be allowed on the embankment or spillway channel.
- ◆ No trees or heavy vegetation should be allowed on the embankment or in the spillway channel.
- ◆ Always regularly clear any blockages or accumulation of debris from the spillway channel.

APPENDIX C

- ◆ Regularly test the operation of the outlet valves (see also under Operation elsewhere in this booklet).
- ◆ Inspect and carry out dam safety surveillance regularly (see Appendix A and Section 6 of this booklet).

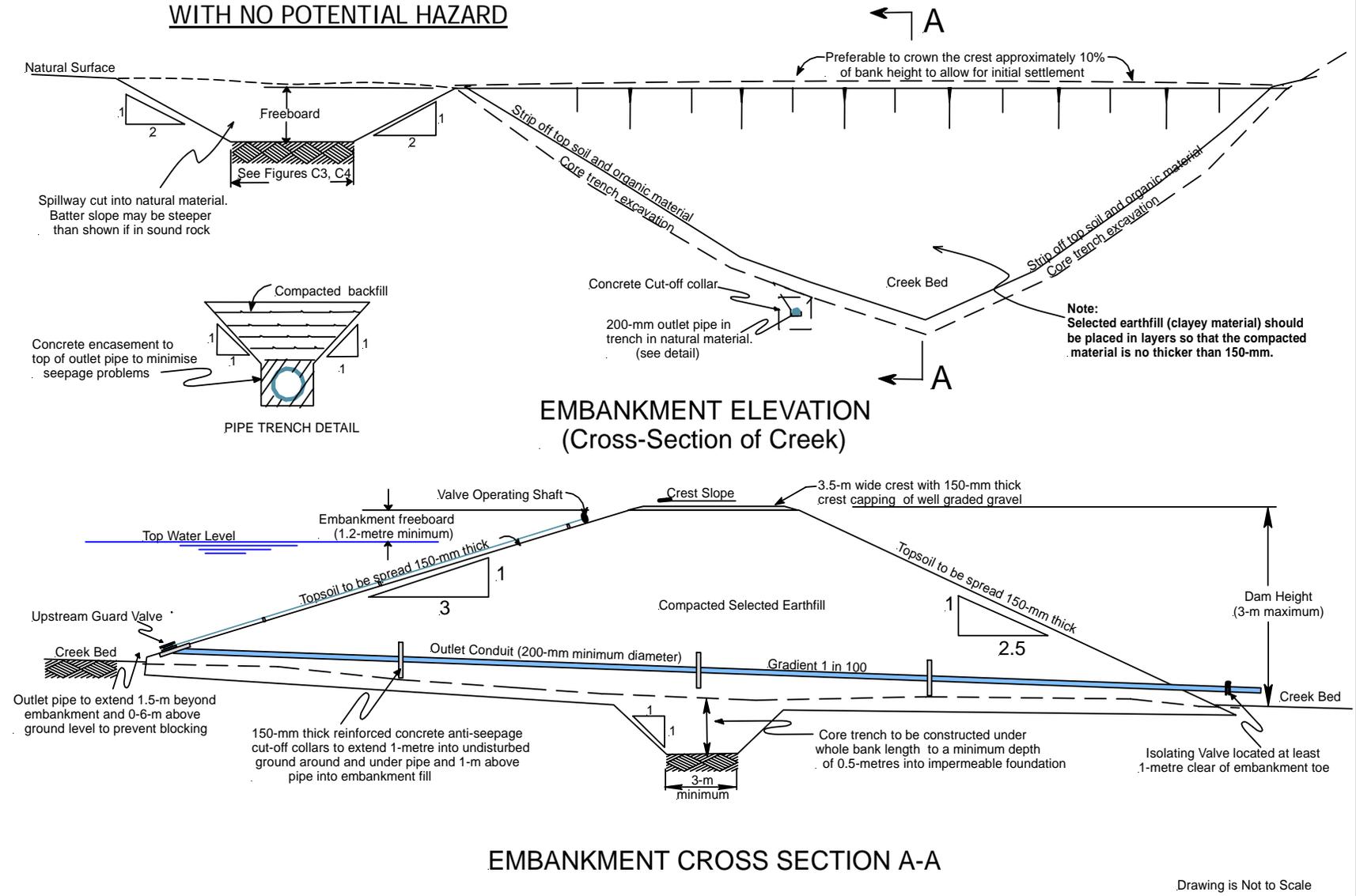
References:

- ◆ The Institution of Engineers Australia "Australian Rainfall and Run-off (ARR) – A Guide to Flood Estimation, Book 1-1997 & Book 2-1987.
- ◆ Lewis B – Farm Dams Planning, Construction and Maintenance, CSIRO Publishing, Melbourne 2001

APPENDIX C

FIGURE C-1: DESIGN GUIDE FOR FARM DAM NOT EXCEEDING 3-METRES IN HEIGHT OR 20ML CAPACITY

WITH NO POTENTIAL HAZARD



APPENDIX D: DAM SAFETY EMERGENCY PLAN