

Levee Management Guidelines

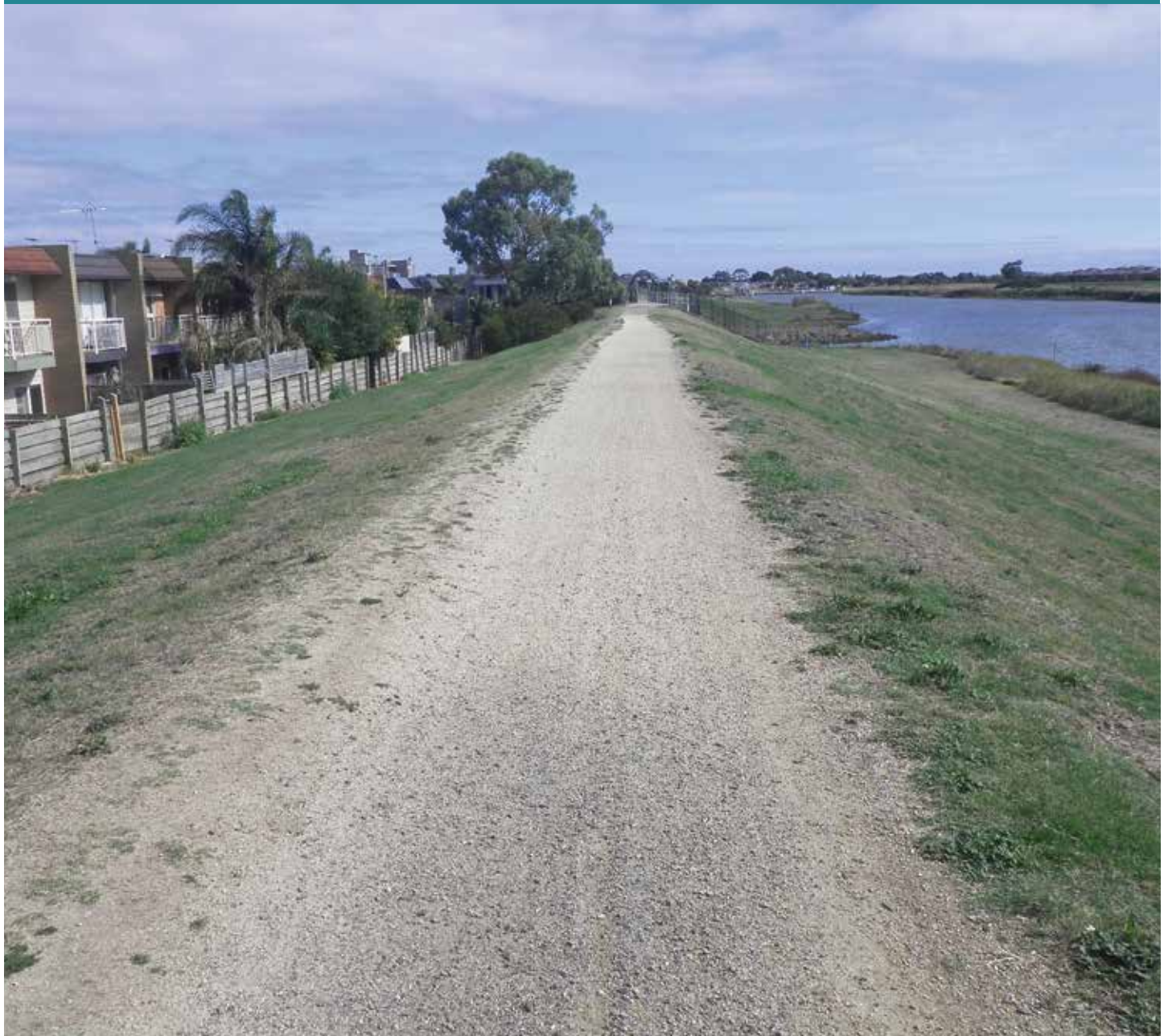


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Levee Management Guidelines



Table of Contents

1 Introduction	6
2 Principles of levee management	7
2.1 Essential principles	7
2.2 Asset management of levees	8
Principles of asset management	9
2.3 Additional considerations	10
3 Levee categories and hazard classification	11
3.1 Levee categories	11
3.2 Levee hazard classification	12
4 Types of levees	13
4.1 Permanent levees	13
4.2 Temporary and demountable levees	16
5 Levee design (for permanent levees)	18
5.1 Location	18
5.2 Design considerations	19
5.3 Access requirements	22
5.4 Involvement with other services/works	24
5.5 Drainage	24
5.6 Approvals	24
6 Levee construction	25
6.1 Standard of construction	25
6.2 Specifications for earthworks	25
6.3 Involvement with other services/works	25
6.4 'As constructed' survey	28
7 Developing a levee management system	29
7.1 Levee specific considerations	29
7.2 Connected assets	32
7.3 Protected assets	32
7.4 Varying the approach to suit the level of risk	32
7.5 Periodic third party inspections	32
8 Levee upgrade and renewal	33
8.1 Post flood repairs or refurbishment	33
8.2 Increasing the level of service or life expectancy	33
9 Levee decommissioning	34
10 Community engagement	35
10.1 Community consultation	35
10.2 Community education	35
11 References	36

Appendices	37
Appendix A – House protection levee design and construction considerations	39
Typical cross sections	39
Clearing and stripping	40
Foundation preparation	40
Materials	41
Placing and compaction	41
Trimming and finishing	41
Maintenance	41
Appendix B – Components of an earthworks specification	43
Standards	43
Site preparation: clearing and grubbing	44
Stripping of topsoil	44
Excavation	44
Foundation treatment	44
Materials	44
Construction	45
Compaction requirements	45
Compaction tests	46
Levee cap	46
Construction tolerances	47
'As-constructed' survey	47
Appendix C – Underground and aerial crossings	49
Pipelines through or under embankment levees	49
Drilled pipelines	50
Aerial crossings	51
Appendix D – Template for a Levee Management Manual	57
Example table of contents	58
Introduction	59
Asset description	60
Inspection and maintenance program	62
Management for operational readiness	63
Levee inspection and follow-up tasks after a flood event	65
Budgeting	65
Appendix E – Potential modes of levee failure	67
Overtopping	68
Seepage	69
Cracking, deformation and movements (even if not associated with seepage or leakage of water)	72
Miscellaneous	80
Glossary	84

1 Introduction

Levees are an important part of Victoria's flood management infrastructure and can be highly effective in containing flood waters. However, without proper planning and management, including maintenance, they can become ineffective or even add to flood risk and hamper flood response and recovery.

It is important for communities and individuals to develop a total plan to manage their levees, covering issues such as where the levees are located, their design, and how they will be managed.

The Department of Environment, Land, Water and Planning (DELWP) developed these Guidelines in response to several recommendations of the Parliament of Victoria Environment and Natural Resources Committee (ENRC) Inquiry into Flood Mitigation Infrastructure in Victoria final report (August 2012).

The Guidelines have been prepared primarily for levee owners/managers. They provide high-level guidance for the whole-of-life-cycle management of various types of levees, such as permanent earthen embankments, concrete walls, and demountable and temporary structures. They cover important aspects of levee design, construction, maintenance, renewal or decommissioning.

The Guidelines also describe the main elements of what owners/managers need to do to manage a levee before, during and after a flood to demonstrate due diligence and to be able to provide critical information about a levee to emergency services during floods.

Each section provides information about issues that need to be considered in important areas of levee management. Where more technical detail is warranted (e.g. house protection levees, earthworks specifications, underground and aerial crossings, levee management manuals, potential modes of failure), an appendix has also been prepared.

The Guidelines were prepared in consultation with a number of practitioners and managers in this field, and represent their views on practices used in the field and matters that should be considered when dealing with levees. The Guidelines are not intended to provide solutions to all levee management problems. They should not be used as a substitute for sound engineering consideration of all the relevant issues and variables of a particular project. The services of suitably qualified engineers should be used, especially during the design and construction phases of a levee, and sound asset management principles should be applied throughout the life of the asset.

The Guidelines are freely available to all stakeholders. It is hoped that public levee managers, such as councils, will make landowners constructing new levees on their property, where appropriate and with the necessary approvals, aware of the Guidelines' principles and specifications and encourage their whole-of- life-cycle management.

'Levee Management Guidelines' supersedes 'Levee design, construction and maintenance', issued by DSE in 2002.

2 Principles of levee management

An effective levee is appropriately located and is designed and constructed according to accepted standards, with a carefully prepared foundation, core and capping to withstand flooding of a specific magnitude.

A levee is usually constructed close to a watercourse (river or creek) to reduce the risk to property from flood waters by confining the watercourse to its channel and preventing it spilling over into the floodplain.

A floodplain, by definition, is subject to regular natural flooding. Its function is to temporarily store and convey floodwaters that cannot be carried by the watercourse channel. Levees stop this natural flow.

Full confinement of floods by levees will not always be possible or desirable. During extreme floods, water levels may overtop any levee and even the best-quality levees could breach and fail. For example, a levee designed and built to exclude a 1-in-100-year flood may be overtopped by a larger flood. Levee systems provide protection from the more frequent smaller floods.

The goal of managing levee assets is to ensure their ongoing successful performance up to their design standard. A levee manager must expect that the capability of a levee will be exceeded at some stage, and develop and exercise contingency plans to deal with this residual risk. This includes being able to provide critical information about the levees to emergency management authorities as and when required.

2.1 Essential principles

- A levee reduces flood risk, but does not eliminate it.
- A levee protects property, not lives (although lives may be at risk if a levee fails and contingency plans haven't been implemented).
- A levee is an expensive structure that needs to be appropriately managed. A levee cannot be relied on to provide flood protection if it has not been diligently maintained and if people are not trained and available to manage it during floods.
- A levee is built to protect assets that exist at the time, but the presence of a levee will usually encourage further development behind it. The levee management plan and local Municipal Flood Emergency Plan (MFEP) need to be regularly reviewed to ensure that additional risk due to new development is considered. The higher the risk, the higher the degree of sophistication required for the flood protection system.
- A levee should have minimal impact on the property or livelihood of others. Any adverse impacts should be considered and mitigated as far as practicable.
- A levee should have minimal impact on the flood storage and conveyance capacity of the floodplain on which it is built.
- A levee should have minimal impact on the environment.
- Reference to the location and management of a levee should be included in the relevant MFEP.

If other structures, such as roads, railways and irrigation channel embankments, perform a flood protection function, their design, construction, operation and decommissioning should be considered as part of a flood protection system. It is unlikely that such structures would have been designed with such a function in mind and they may need to be upgraded. Alternatively, any limitations will need to be taken into account in the MFEP. Such structures need to be addressed on an individual basis.

Urban levees protect relatively small areas and are likely to have only a small impact on floodplain storage and flow conveyance. The potential changes to water levels and flows upstream and downstream may be minor. Rural levees, however, tend to protect large areas, which can cause significant differences to upstream and downstream water levels and flows. To minimise this, rural levees should provide a lower level of protection.

Levees are only one flood risk mitigation measure. Others include planning controls, building controls, flood warning, education and awareness. It is advisable to use more than one flood mitigation measure at all locations.

2.2 Asset management of levees

If properly constructed, managed and maintained, many levees will effectively have an indefinite life span and eventually become permanent fixtures in the landscape. Their disposal or decommissioning is not usually required.

A lot of information is generated over the long asset life of a levee, so it is important that a comprehensive asset management system is set up as early as possible, i.e. while the levee is being built, so that the owner/manager can ensure that copies of all design and construction documentation are kept, appropriately filed, and referenced in operation and maintenance documentation.

Levees are usually required to be managed in conjunction with other assets, some of which relate to flood protection. For example, pumps, pump pits and drainage pipes are required to remove standing water from inside a levee. Vehicle crossings and other pipelines (e.g. for water, gas, commerce) are required to provide access and services to both sides of a levee when there is no flooding. These ancillary assets need to be regularly inspected and maintained to ensure the levee will work effectively during a flood.

The primary function of a levee system is flood protection, and all other uses of a levee or levee reserve need to be managed to ensure this is never compromised. This is achieved by either ensuring the use is compatible (e.g. well maintained walking or cycle paths) or, if it is a competing use, such as access crossings (e.g. roads, pipes) or farming (e.g. stock crossing or grazing), by ensuring that the activity is limited and regulated as much as practically possible.

Principles of asset management

The life cycle of an asset can be split into four key phases:

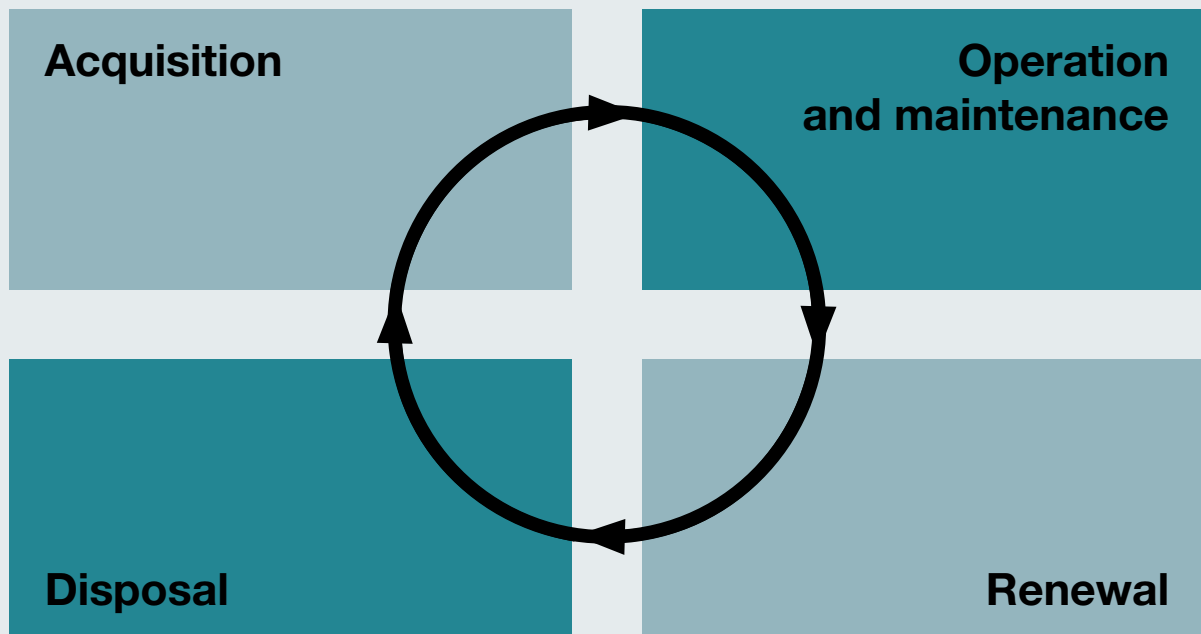
Acquisition: Functions include the identification of a need, assessing the service level requirements and available options, specification of the design requirements, definition of the procurement and management requirements (process to buy or build, capital costs, operation and maintenance requirements and costs, identification and recording of the asset in owner organisation's systems, etc).

Operation and maintenance: Functions include use of the asset according to its design, planned and unplanned maintenance, maintenance of asset records, and periodic evaluation of asset condition.

Renewal: Functions include the periodic replacement of assets or asset components to return the service potential or the life of the asset to that which it had originally

Disposal: Functions include the method of retirement, demolition or disposal, including transfer for alternative use.

Figure 1: Asset management life cycle (DPCD 2004, p.17)



The goal of asset management is to meet a required level of service in the most cost effective way - through the creation or acquisition, operation and maintenance, renewal and disposal of assets - to provide for present and future communities. The life cycle approach takes into account the total cost of an asset throughout its life. A better service, not a better asset, is a key indication of successful asset management (DPCD 2004, p.5).

Due diligence in financial planning and reporting are just as important as the planning and management of the physical asset in order to achieve the targeted level of service and functionality for the least cost over the life of the asset.

To improve asset management systems in Australia, the Institute of Public Works Engineering Australia (IPWEA) is promoting the application of the ISO 55000 Asset Management Standards, which were released in January 2014.

2.3 Additional considerations

Currently, there is no Australian Standard for assessing the risks associated with levee systems, or for the design and construction of levees. The information provided in these Guidelines is based on current good practices.

The Australian National Committee on Large Dams (ANCOLD) has produced a number of guideline documents relating to dam engineering and management that are considered to have some relevance to levee management. These include:

- Guidelines on the Consequence Categories for Dams (ANCOLD, 2012)
- Guidelines on Dam Safety Management (ANCOLD, 2003)
- Guidelines on Dam Safety Risk Assessment (ANCOLD, 2003).

The most authoritative reference for embankment dam engineering in Australia is 'Geotechnical Engineering of Dams' (Fell et al, 2005). Many of the topics covered in this reference are applicable to levee design and construction.

In many ways, levees and flood-retarding basins have common features. Both retain water for only short periods following heavy rainfall or flood events and the failure of both types of structure can result in 'dambreak' flood rises far in excess of natural flood rises.

A number of industry representatives support adopting the relevant provisions of the Guideline on Retarding Basins being prepared by ANCOLD and due for release in 2015 or later. This may influence the management of levees in the future.

Melbourne Water has produced its own draft Guidelines for the Assessment of Flood Retarding Basins (MWC 2012), which is currently being reviewed externally. The guidelines aim to formalise Melbourne Water's requirements for the general design, construction, operation and maintenance of retarding basins. These guidelines provide guidance on a number of aspects related to retarding basins that may be relevant to levee engineering and management.

The United States Department of the Interior Bureau of Reclamation (USBR), the US Army Corp of Engineers (USACE), the US Federal Emergency Management Agency (FEMA) and the US Department of Homeland Security (USDHS) have produced a number of publications applicable to flood levee engineering and management. The publications listed below are available free of charge via the internet:

- Retaining and Floodwalls (USACE, 1989)
- Design and Construction of Levees (USACE, 2000)
- Technical Manual: Conduits through Embankment Dams (FEMA, 2005)
- Levee Owners' Manual for Non-Federal Flood Control Works (USACE, 2006)
- Filters for Embankment Dams (FEMA, 2011)
- Emergency Preparedness Guidelines for Levees – A Guide for Owners and Operators (USDHS, 2012)
- Best Practices in Dam and Levee Safety Risk Analysis (USACE, 2012).

The UK-based body, the Construction Industry Research and Information Association (CIRIA), in association with the USACE and a number of European governments and organisations, has recently published the 'International Levee Handbook' (CIRIA, 2013). This publication is also available free of charge via the internet and provides an excellent summary of current international practice.

References for these documents are provided in Section 11.

All guidelines, manuals, etc, have certain limitations when applied to specific circumstances and situations. Levee owners and managers are advised to consult with suitably qualified and experienced engineers and practitioners throughout the design, construction and maintenance phases of levee management.

3 Levee categories and hazard classification

Levees may be arbitrarily divided into various categories. Across Victoria, about 4,000 km of permanent levees have been identified; they have been divided into two main categories, public and private, and then into two further sub-categories, urban and rural. These are described in this Section 3.1.

The level of management of a levee system should be based on the associated consequences of failure. Higher standards of protection are normally required for urban areas than for rural areas, because even though the geographical area may be much smaller, the potential for loss of human life and property damage in urban areas is usually larger. Levees protecting urban areas tend to have more stringent design and management requirements than levees protecting rural areas.

The US Federal Emergency Management Agency (FEMA) has developed a hazard classification system for dams that is clear and succinct and has been modified for adoption by DELWP. It involves the classification of levees in terms of three hazard potential levels, Low, Significant and High, as described in Section 3.2.

Although most rural levees would be classified as Low or Significant hazard potential, with a smaller number of mainly urban levees classified as High hazard potential, some urban levees will have Significant or even Low hazard potential and some rural levees will be High hazard potential structures. All levees should be assessed on an individual basis.

The hazard potential classification provides a useful basis for applying the appropriate design, construction and management standards to a levee.

It is recommended that only suitably qualified and experienced levee or dam engineers be engaged to design and assess all but Low hazard potential levees.

3.1 Levee categories

3.1.1 Public

Public levees are those that are funded by government - federal, state or local - or a combination of the three. Ownership or responsibility for these levees may be clear, as in the case of schemes managed by municipalities, or somewhat blurred, such as where schemes were funded or constructed by governments in the past but ownership or responsibility for maintenance was not clearly established or has been eroded over time.

Public levees are constructed to protect assets that are important from a broader or strategic point of view, such as urban areas, large areas of rural (particularly highly productive) land, or critical infrastructure public assets.

Urban: Public urban levees are owned and/or managed by local councils or Melbourne Water. The vast majority have been constructed to a relevant standard under Government-funded schemes and are expected to be maintained as such. Most offer an adequate level of protection (up to 1% annual exceedance probability [AEP] flood) to public and private assets in medium to high-density urban areas.

Rural: Public rural levees have been constructed under various government programs, mostly in the first half of the 20th century. These have generally been built to a lesser standard and offer a lower level of protection than urban levees.

3.1.2 Private

Private levees are privately funded and constructed. The vast majority are in rural areas. Private landholders are responsible for maintaining their private levees.

Urban: Private urban levees are constructed and/or erected by individual landowners to protect their home or business.

Rural: Private rural levees have been privately funded and constructed by an individual seeking to protect his/her property or a group of individuals seeking to protect a number of properties. They have mostly been constructed in the absence of formal approval processes, without proper design, using poor construction techniques and are consequently of low quality.

3.2 Levee hazard classification

Levees can be classified in terms of three hazard potential levels, Low, Significant and High, depending on the consequences of failure of the levee as defined in Table 1.

Table 1: Levee hazard classification

Hazard potential classification	Damage and loss
Low	Rural areas with reasonably small flood extents, also affecting an individual house
Significant	Rural areas with reasonably large flood extents affecting high value agriculture, assets and houses
High	Urban areas

Hazard classification is based on the *consequences* of failure, not the *likelihood* of failure. A levee in very poor condition with a high probability of failure could have a Low Hazard Potential Classification, while a levee in excellent condition with a low probability of failure could have a High Hazard Potential Classification.

The potential for loss of life has not been considered in the hazard classification as levees in Victoria are designed and built to protect structural assets, not lives.

The 'Guidelines on the Consequence Categories for Dams' (ANCOLD, 2012) may provide guidance on assessing the hazard potential classification for levees.

4 Types of levees

There are two main types of levee systems: permanent and temporary.

4.1 Permanent levees

A permanent levee system requires minimal operational activity to provide protection during a flood, provided it has been managed to ensure its level of service is consistently maintained. It is technically the most reliable protection system as it is always in place to offer flood protection up to its design standard.

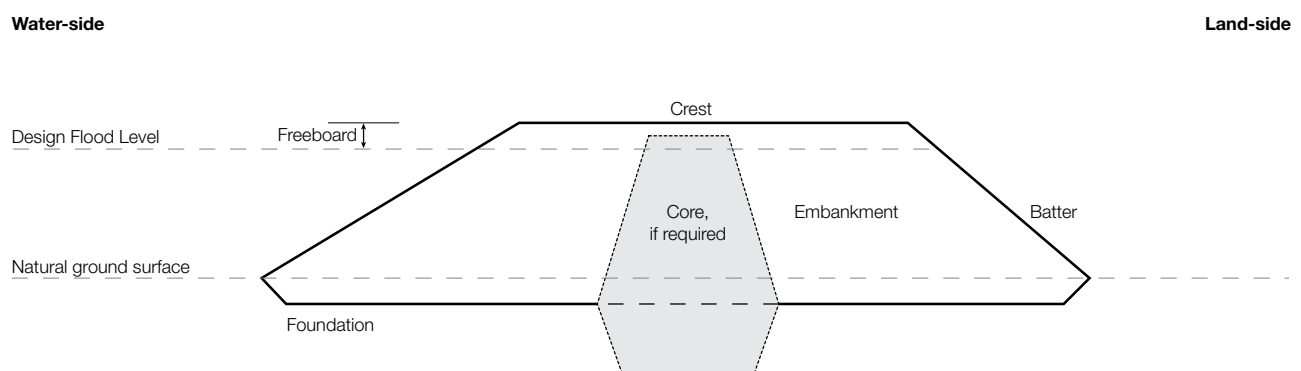
Permanent levees are most commonly earthen embankments, but may take other forms, such as free-standing concrete walls or retaining wall systems also known as floodwalls.

A properly designed permanent levee is appropriately located, constructed according to accepted standards on a carefully prepared base, has a foundation, core and capping designed specifically to withstand flooding of a specific magnitude. Components of a typical levee bank are shown in Figure 2. Parts of levees may also be constructed from rock, concrete and other materials.

A levee that has been constructed to accepted standards will provide long-term security, with lower maintenance costs and less possibility of failure in the future than a levee not constructed to accepted standards. It is critical that maintenance and management be both regular and on-going.

Location and costs generally dictate the type of levee chosen for a particular situation. Where the location is not suited to a conventional earthen bank, as may be the case in and around urban areas, there may be opportunities to use other options, such as crib walls, concrete retaining walls and roadways, or a combination of these.

Figure 2: Components of a typical permanent earthen levee bank (simplified)



4.1.1 Earthen embankments

The most common levee is the conventional earthen bank that may be constructed with a clay core or cut-off, depending on the underlying foundation material. If properly constructed and maintained, earthen levees effectively have an indefinite life span.



4.1.2 Crib walls

A full or part crib wall is a useful alternative where there is limited room. A full crib wall consists of two near vertical walls with a compacted clay core; a part crib wall has a conventional batter on one side, a crest and a crib wall on the other side, which may adjoin a road or other asset. These alternatives, as with conventional levees, provide an opportunity to incorporate a walking or bike track. It is not common to use crib walls on the water face of a levee, however, if this is proposed, it is necessary to lay a geotextile fabric behind the crib to avoid scouring out of the compacted clay from behind the crib wall.



4.1.3 Concrete retaining walls

Concrete retaining walls or floodwalls provide a useful alternative levee, particularly in and around town areas where sites are restrictive. Where the wall is mainly required to provide freeboard rather than to withstand a significant depth of water, a concrete block wall may be adequate. Depending on the height required, the wall may be free-standing or backed up by earth fill.

Floodwalls need to have a properly designed base to provide stability (including uplift, overturning and sliding) and avoid foundation piping erosion. The maximum hydraulic gradient (depth of water retained by a levee divided by its base width) under a 2 m high earthen embankment levee would typically be less than 20%, the hydraulic gradient under a 2 m high floodwall could be in excess of 80%. This increases the risk of piping failure of the floodwall levee foundation.

The main disadvantage of this type of levee is that, unlike the earthen levee, it is not easy to temporarily raise it if necessary. Earthen levees can be raised using sandbags or earth, but this is difficult with narrow concrete walls.

A concrete retaining wall provides a consistent crest height and is not usually subject to subsidence, which would reduce available freeboard.



4.1.4 Roadways

Where no alternative location is available, a useful option to consider is raising an existing roadway. This provides an excellent levee with no access problems and the 'crest' is maintained as part of normal road maintenance arrangements. If the roadway is, or can be, sealed, this is an advantage because the levee/road moisture level is then maintained. Access during times of flood events is not an issue in this option.



4.1.5 House protection levees

House protection levees are earthen embankments built to encircle and protect individual buildings and curtilages (the enclosed area of land adjacent to a building or dwelling) on floodplains, such as farmers' homes and sheds. They generally protect areas of less than 1,000 m² and are generally less than 1.5 m high, although their size and height will vary depending on local conditions and requirements.

As house protection levees completely encircle the area protected, they could require an opening for vehicle access that needs to be closed if a flood is imminent. Each house protection levee owner should have a plan and readily available materials or devices to close the opening. Pumps should also be set up with sumps to remove any rainwater or leakage from within the levee.

The property owner constructing a house protection levee will need to consult with, and seek approval from, the relevant authorities (local government, catchment management authority) before working with a consulting engineer to design the structure and identify suitable construction materials.

As house protection levees are usually in rural areas, there may be some room for compromise in the method of construction, particularly in the area of compaction. With this approach, the potential lowering of standard with associated small increase in risk may be acceptable when offset against the cost savings in comparison to the possible damage. Further information on design and construction considerations is provided in Appendix A.



4.2 Temporary and demountable levees

A **temporary** levee system is a removable flood protection system that is wholly installed shortly before or during a flood, and removed completely when floodwaters have receded. Temporary levees are quickly constructed using temporary materials or items, such as sandbags, plastic sheeting, water bladders, metal sheets and compacted earthen embankments. They can be used in any location. They do not offer the same level of protection as a permanent levee system.

Temporary materials or items are also sometimes used to supplement existing permanent levees by extending them vertically and/or horizontally. However, as a rule, permanent levees are not designed to be supplemented by additional temporary structures. A temporary levee should only be employed when a flood occurs, and should be removed when it has passed.

A **demountable** levee system is a moveable system that is either fully pre-installed and requires operation during a flood or requires part-installation into pre-installed guides or sockets within a pre-constructed foundation. They are usually proprietary products that have been adapted to suit a specific location.

Before opting to use a demountable system, it is important to consider the flood travel time and potential event duration, i.e. will there be enough time to install the system after the flood warning has been received but before the flood arrives and will the system be able to withstand the forces of the floodwaters for the duration of the event (e.g. if longer than a week)?

Temporary or demountable systems should only be used where a permanent system is not viable. They should not be relied on to replace permanent systems. They can be useful when a flood occurs, but have their limitations.

The prepared foundation is critical to the effectiveness of a demountable levee system. As with floodwalls, the hydraulic gradient under the structure could be high. They would typically require a concrete slab foundation and approach slab.

The construction of temporary levees may cause new problems. As they alter the natural or modelled flow of water, adding additional levees to a system makes it more difficult to predict where floodwaters may travel, their potential impacts and, consequently, how emergency services should react.



4.2.1 Sandbags

Sandbags provide the most common temporary levee system. They are regularly used to reduce the impact of low-level flooding on private homes. Sandbags will not stop the water completely, but can reduce the amount of water entering a home or area if placed correctly in appropriate strategic locations.

Sandbags are also regularly used to top-up low points or to increase the freeboard on earthen levees. However, incorrect or excessive use of sandbags on a levee increases the risk of levee failure.

More detailed advice on the use of sandbags (where to place sandbags, how to fill and lay sandbags, what to do with them after the flood has passed) is available on the VICSES website.

4.2.2 Temporary earthen banks

These may only be constructed at the direction of the Incident Controller during a flood event. They should be removed as soon as practicable after the event has ended.

4.2.3 Proprietary products

Non-permanent forms of barrier for flood protection can provide much-needed flexibility and increased opportunities for effective management of a wide range of floods. New temporary and demountable systems have been developed, each with its own features, particular standard and quality. Guidance should be sought from the manufacturer or supplier regarding the potential advantages and disadvantages for a particular application before opting to rely on a proprietary product. The manufacturer's instructions should be observed for installation, operation and storage.

5 Levee design (for permanent levees)

These Guidelines assume the proponent has sufficient information to make an informed decision to construct a levee, and that a decision will be taken only after relevant studies, community consultation and conceptual designs have been completed, irrespective of the type of levee project to be undertaken, e.g. new, rehabilitation, upgrade.

Typically, the conceptual design will include the design flood level, design flood profile, a concept alignment, provisional freeboard, provisional levee types and conceptual cost estimates that include all significant cost items. Major levee projects could typically take 3-5 years to develop a plan and 2-10 years to implement.

It is important that all the issues raised in these Guidelines are considered and allowed for before constructing a levee. The final design will be contingent on local circumstances and engineering advice.

If the proponent lacks the appropriate expertise, they should use the services of a specialist consulting engineer. For Significant and High hazard classification levees (see Section 3) a recognised levee or dam engineer should be engaged.

5.1 Location

Levees are long-term assets and their location requires designers to consider future plans for an area as well as existing conditions. Relocation of an existing levee to accommodate development is expensive and can generally be avoided by more careful planning for future growth and development possibilities.

Location of urban levees is generally dictated by existing development and land use. Drainage facilities are also major factors affecting levee location.

In many cases, decisions have to be made as to whether a levee is to be located on a river frontage or private land, and how far back from the river the levee should be located.

There are some important aspects of levee location that should be considered when designers are assessing their options. The location must provide an adequate waterway area to accommodate the design flood and not create adverse conditions that would worsen the impact of the flood. To achieve this, most levees will need to be located an appropriate distance from the river frontage. This approach should be adopted as a principle where possible, as the levee would then be on the land that it is built to protect and would minimise the impacts on the natural flood storage and conveyance functions of the floodplain. In addition, locating levees on river frontages may have an impact on native vegetation and require trees to be removed.

If there are other assets in the area, such as roads or channel banks, they can be incorporated into the design, where appropriate, as part of the levee.

Where drains are involved, it may be possible to locate the levee so that it provides for some drain flow retardation or diversion during a flood, and reduced pumping costs.

Careful siting of levees can reduce the flooding of productive land on the land-side by allowing the best drainage arrangements to be maintained and may provide other opportunities to mitigate the impacts of flooding.

5.2 Design considerations

The following design elements should be considered for all levees. They will need to be modified to take into account other features, such as associated works (e.g. drainage and pumping), involvement with services or other works, and access requirements.

The discussion in the following sub-sections is targeted at Significant and High hazard classification levees. The potential consequences of a Low hazard classification levee failing are smaller and usually limited to the owner's property, so these levees are usually designed to a lower standard.

5.2.1 Level of protection

The general level of protection used in levee design for urban areas in Victoria is against a 1% annual exceedance probability (AEP) or the 100 year return period flood. However, different levels of protection may be offered, depending on the circumstances (e.g. to a defined gauge height, or flood of record).

The levee, whether earthen bank, crib wall or concrete wall, should be high enough to provide the required protection level, plus an additional freeboard allowance.

A risk assessment should be carried out on all levee proposals. There may be instances where the level of protection may be varied. Where a level of protection less than 1% AEP is chosen, careful consideration must be given to setting floor levels and '*land liable to flooding*' boundaries.

The level of protection for rural areas tends to vary, but generally should be around the 10% to 5% AEP (10-20 year return period) flood. A rural levee designed to a higher level of protection will confine larger floods, which will have an increased cumulative effect further downstream, which is not desirable. It would be more equitable to have private house protection levees providing a higher level of protection to small areas containing high-value assets rather than a levee providing a lower level of protection over a large area.

5.2.2 Freeboard

Freeboard is an additional height allowance used in the design of levees to cover variables inherent in that design. The variables covered by the freeboard allowance include the difficulty in precise flow estimation and water profile modelling due to an insufficient historical record and also wave action. Freeboard may also assist in short-term protection against bank consolidation (settlement and erosion), but design crest levels should be maintained through regular maintenance.

General engineering practice is to provide a minimum freeboard allowance in urban areas of 600 mm.

Freeboard may be increased or decreased depending on local knowledge and conditions. For example, it may be increased where flood levels cannot be predicted with confidence, but decreased in wide flat floodplains, where the height difference between a minor and major flood event is quite small.

Varying the freeboard allowance over the length of a levee (e.g. lowering freeboard where a section of road is part of the levee system) can create different overtopping levels and problems when design floods are exceeded. It is suggested that uniform crest levels and freeboard allowances be adopted for each system, except where a spillway is incorporated into the system.

5.2.3 Cross section

Apart from variations necessary to take account of differing foundation conditions, general dimensions of levees can be varied to suit the site conditions. Crest width can be varied to cater for access requirements; batters can be flattened to allow for mowing; and sections of crib or concrete walls can be used where space is limited due to roads, trees or other physical features.

The form for a particular levee may vary due to the location of the levee, soil type, access arrangements, construction methods, maintenance arrangements and a range of similar considerations.

Under normal conditions, the maximum batter slopes used would be 2.5 (H):1 (V) for the water face and 2 (H):1 (V) for the outside face. These may have to be flattened, depending on the geotechnical properties of the material to be used in the levee and in its foundation.

The use of a core and/or cutoff arrangement in an earthen bank depends on the geotechnical properties of the foundation material, as well as the material available for use in the levee construction. Where geotechnical investigations indicate the presence of sand lenses in the levee foundation, it will be necessary to use a core

trench to provide a suitable cut-off arrangement for the levee. Where there is a limited availability of good quality clay, it may be necessary to use a core, or zoned cross-section, in which the material in the central zone is selected clay. If the clay is dispersive, it may need to be treated with gypsum or lime, and placed as specified in the engineer's design. The material in the outer zone can then be more permeable material from the borrow pit.

If recommended by an experienced levee engineer, geofabrics may also be used to minimise the loss of fine materials in embankments and foundations where earthfill materials are low quality.

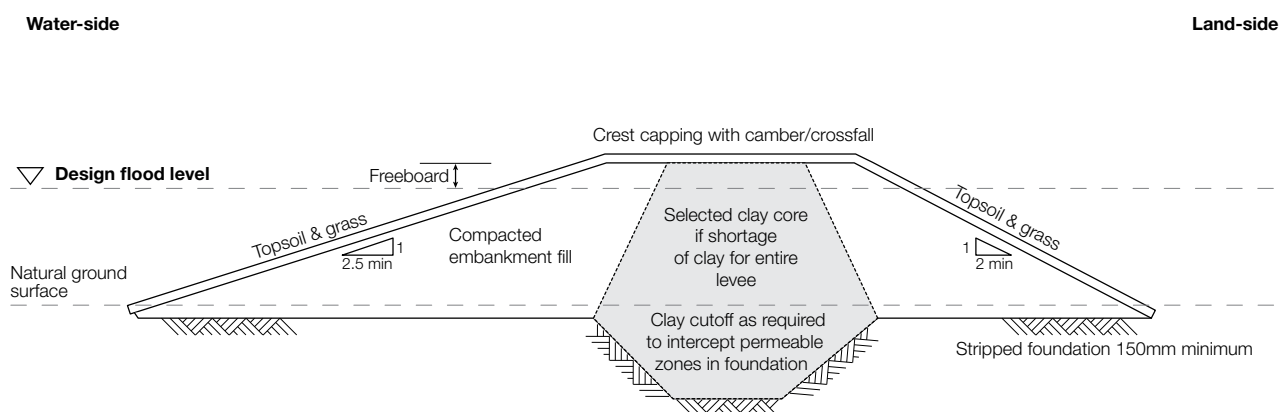
Where only sandy or silty, less-clayey soils are available, an option is to construct a suitable levee from the more permeable material by using a wider crest, and/or flatter batter slopes and, consequently, a much wider structure.

Where access is to be provided along the crest rather than the back of a bank, a wider crest will be required to accommodate the track.

A bank of the minimum cross section for a particular soil type that can reasonably be constructed will most likely cover all of the stability requirements of a levee. However, when access, construction methods and costs are considered, the size of the constructed bank will most likely significantly exceed the minimum requirement. Generally, the larger the levee footprint is, the greater its stability and the lower its likelihood of failure.

The cross section of a typical levee bank is provided in Figure 3.

Figure 3: Components of a typical permanent earthen levee bank



5.2.4 Topsoil stripping

The correct stripping of topsoil from the levee site is critical to ensure the necessary bonding of the bank with the underlying material. Stripping should be carried out down to a firm inorganic soil. Where topsoil is shallow, a minimum stripping depth of 150 mm should be adopted to ensure all surface roots and vegetation are removed.

5.2.5 Foundation

If the foundations contain sand lenses, gravels or other permeable materials at shallow depths (less than the height of the levee), a clay core cut-off trench to a firm cohesive clay soil foundation should be provided. The base width of the cut-off trench is typically dictated by the construction equipment used for placing and compacting the clay backfill, usually about 3 m. The sides of the core trench should be battered at about 1 (H): 1 (V). Where a core trench is not required, due to the absence of shallow permeable soils, the foundation must be scarified and re-compacted to remove all cracks, fissures and other discontinuities in the upper foundation.

5.2.6 Crest treatment

The integrity of an earthen levee is maintained largely by ensuring that the compacted bank remains at or near its optimum moisture content. Under most conditions, this requires that the crest of the levee be protected against drying out or cracking by the provision of a crest capping layer.

The type of crest capping is governed by access requirements.

In the case of un-trafficked levees, this could involve a 150 mm thick, low-plasticity local topsoil with a good grass cover. The grass varieties should be selected to suit local conditions, require low maintenance, minimise fire hazard and provide a thick, erosion-resistant cover with a strong binding capacity root system.

Where access by vehicles is required for inspection or flood response, a 100-150 mm thick Class 3 crushed rock or similar capping should be provided.

In the case of a levee doubling as a trafficked urban area (such as road or cycle path), the crest should be sealed with an asphalt or concrete capping.

The crest capping on a levee should be in addition to the levee freeboard allowance.

Levee crests should be constructed with a 3% cross fall or camber, to shed heavy rainfall. This will help prevent the pooling of water and associated deterioration of the crest surface.

5.2.7 Batter treatment

Batter treatments aim to protect the batter from drying out and cracking. Providing a protective layer over the compacted clay bank will also help stabilise the batters by preventing erosion and scouring by rainfall runoff.

Batters can be protected by topsoiling and grassing as for the crest capping described in Section 5.2.6. Where it is necessary to mow the batters to maintain the general appearance of an area, the mown grass will act as mulch, which helps maintain bank moisture and stabilising of batters.

A good cover of suitable grass will provide a greater resistance to river flow velocities and wave action on the water-side batter.

Trees should not be planted on or near batters. They can increase the likelihood of the levee failing because of potential leakage paths formed by tree roots and the loss of bank when such trees are uprooted during strong winds. Trees should be limited to where the drip line of the mature trees is beyond the toe of the embankment

Trees should also not be planted in areas where they could restrict access for maintenance and emergency management activities.

The ability of a levee to withstand erosion due to overtopping by floods in excess of the design flood is greatly increased if the land-side batter is well protected by a good cover of suitable grass.

In some cases, the water-side batter of a levee may be subjected to river flow velocities parallel to the levee that could erode the bank. In such cases, rock armouring or similar protection may be needed.

5.2.8 Spillway

The purpose of a spillway is to provide one or more specified low points in the levee that will overtop before other sections do. If a flood exceeds a levee's design level, without a spillway the levee may overtop or fail at multiple points and cause scour erosion at those points.

A spillway is specifically designed to withstand the scour and erosion forces of overtopping. It is also located in an area that would suffer less damage than if the levee failed elsewhere.

Spillways are most useful if the levee has a low standard of protection and may be subject to relatively frequent overtopping.

5.2.9 Development setback

A development setback is the buffer distance from the toe of the levee on the protected side where no development is permitted. The purpose is to allow adequate access and space to undertake inspection, maintenance and upgrade works as required as well as to have access to manage the levee during a flood event.

General engineering practice is to provide a minimum setback allowance of 5-10 m in urban areas, and 20-50 m in rural areas.

5.3 Access requirements

Access requirements for a levee system must be given serious consideration during the initial planning phase of a project. This should consider access along each side of the levee, along the crest, as well as between one side and the other. Access along the base of the levee should generally be at least 3 m wide.

Appropriate questions should be asked early in the planning process. For example, what area of land is required for the levee reserve to ensure all required activities can be undertaken? Under what circumstances (if any) should fencing across the levee be allowed? This fencing could hamper emergency management activities.

The method adopted to provide access will affect the construction process as well as maintenance procedures, hence capital and recurrent expenditure. Points to be considered include the following.

5.3.1 Public access

Public access may be incorporated into the design if there is a demand for it. However, it cannot always be achieved. Safety issues and access for everyday management purposes and for emergency services during a flood event should not be compromised.

5.3.2 Vehicular access

Vehicular access requires that the crest be wide enough to safely accommodate a vehicle. It must have appropriate signage and must have suitable on/off ramps to provide safe access and egress.

A 3.0-3.5 m wide levee crest is needed to safely accommodate a vehicle. The crest width is also linked to the construction method and has cost implications. This is dealt with further in Section 6 – Levee Construction.

The additional crest treatment required to adequately carry regular traffic will result in a higher level of maintenance, including pothole repairs, grading and the occasional re-capping to maintain crest level. Generally, it would be preferable to deny access to public vehicles.

If vehicular access is to be permitted, access at the base of the levee on the land-side should be considered. This does not affect the integrity of the levee and also allows access during flood events, when the crest may not be available due to sandbagging or other activities. Access behind levees also has lower maintenance requirements than crest access, and its suitability and safety are not governed by the width of the crest, but by the needs of vehicles.

5.3.3 Pedestrian and bicycle access

Pedestrian access does not require major treatment nor create maintenance demands on the crest. However, if bicycle access is envisaged, additional maintenance will be necessary. If the levee site is close to an urban area or school, and is likely to attract significant use, the design should consider the safety of cyclists, as well as other users of the access track.



5.3.4 Maintenance access

The main consideration for maintenance access is where to provide access and egress points from the formal road network, and their frequency, to minimise use of the bank by maintenance vehicles.

Irregular use of the crest for access by maintenance vehicles is not likely to create any problems, even if the crest has only a sown topsoil surface.

5.3.5 Access inside the levee for patrol or combat operations during a flood event

Access requirements for patrol or action during a flood event are similar to maintenance requirements and should be considered in a similar way. One of the main considerations is the proximity of the road network and where to provide the most efficient access points.

Access should be provided at the rear of the bank where this is a viable option. This would keep the levee free from all but maintenance traffic, reduce deterioration and allow access to all parts of the bank during a flood event, without using the crest that could be in use for sandbagging operations.

The decisions relating to access will have a significant impact on the final levee design. They will affect aspects such as the size and appearance of the bank, public access to the area and future maintenance requirements and costs.

For example, if the public is not to be permitted access to the levee, the levee can be built to a minimum width, topped with soil and grassed. This would be sufficient to carry maintenance or combat traffic, as required. In these circumstances, removable barriers or gates would have to be installed to prevent public access.

5.3.6 Access for boats

It is important to provide for safe access for boats across a levee during a flood for emergency services operations, as well as potentially for community members seeking supplies and assistance.

Emergency services require a properly constructed ramp to provide boat access to the water for response operations during floods. This is to ensure ease and safety of operations and also to prevent damage to the levee from boats docking at inappropriate locations.

To ensure adequate access is provided, the number and location of boat access facilities should be determined in conjunction with emergency services authorities. Storage requirements for boats, vehicles and related equipment adjacent to the access areas should also be considered on both sides of the levee.

The degree of boat access across a levee for community members may be controversial, but should be considered. Optimally, community members should not be encouraged to enter floodwaters. However, in reality it may ease the burden on emergency services if community members living on properties isolated by a flood are able to access a town in their own boats after the flood peak has passed. This would require a landing facility to be constructed on the water-side of the levee, as well as adequate supply storage facilities on the inside of the levee. The docking and loading of boats at these locations should be strictly regulated for safety reasons and to ensure the levee is not damaged.

Boat access facilities should be designed to accommodate the water levels, traffic and loads that may be anticipated during smaller flood events when the levee is operational, as well as up to the levee's design standard.

5.4 Involvement with other services/works

Levees will inevitably come into contact with some or all of the usual services provided by various authorities to the community. These services may be aerial, surface or below surface, and each must be treated in a specific way to avoid problems during construction, maintenance operations or flood events.

The main types of unrelated services that levee managers will encounter are pipelines and cables, which need to cross the levee by either open cut or drilling. Aerial lines also need to be considered. Pipelines under or through the embankment are one of the most common causes of failure of embankment dams. This is also likely to apply to levees under flood conditions.

Any works carried out on the levee to accommodate the unrelated service must not weaken the levee, and it is important to ensure that these works are covered by an appropriate maintenance period, with an appropriate financial guarantee, to ensure any defects can be repaired promptly.

Authorities or persons wanting to construct works through or under a levee must obtain prior written approval from the levee manager. The works should be designed by an experienced levee/dam engineer and appropriate design drawings, specifications and method statement supplied. The works must be carried out in accordance with the approved design and be overseen by a suitably qualified supervisor.

Section 6.3 deals with services and their involvement with levees in greater detail.

5.5 Drainage

Levees, by their nature, will nearly always interfere with natural drainage lines within the area they are designed to protect. Generally, levee designs should incorporate access for the drainage outfalls through the levees. The drainage design should make allowances for any potential future development.

Structures incorporating gates or valves located in the levee can prevent floodwater backing up drainage lines during flood events. The choice of structure will depend on the conditions under which it is to operate.

Screw-operated doors or gated valves have the advantage of being able to be securely closed or used partly closed if needed.

Flap valves are self-operating and convenient. They are located on the water-side of a levee but are prone to blockage and may stick open during flooding. Flap valves need to be checked regularly to ensure they operate properly. Ideally, a flap valve should be provided with an isolating valve so that the drainage lines can be closed off if it fails to seal during a flood.

Where it is necessary for drainage flows to be pumped during a flood event, a temporary pump must be located at the outfall. There is a range of options to incorporate this feature. The most basic is to locate the outfall gate or valve in the central wall of a double celled pit, enabling short suction and delivery lines, to pump water from one side of the central wall, to the other. The top of the pit is constructed at crest level.

It is recommended that an area behind the levee be set aside for temporary storage should the pumps fail or their capacity be exceeded.

5.6 Approvals

A number of approvals are required during the levee design and construction process. The proponent needs to consult with the appropriate authorities to ensure all requisite approvals have been received.

6 Levee construction

6.1 Standard of construction

There is currently no Australian standard for the construction of levees. However, experience has shown that it is important that the following issues are considered before deciding on construction methods and procedures.

6.1.1 Varying the approach to suit the project

There is a distinct difference in the way asset managers treat works in the field, depending on their size and complexity. The construction or refurbishing of a major High or Significant hazard classification urban levee requires the preparation of a specific contract, which allows for all of the necessary controls and supervision. The construction or refurbishing of a Low hazard classification rural levee also requires controls and supervision, but to a lesser standard.

Specifications for large works should take an outcome-based approach. Where, for example, a certain standard of compaction and moisture content is required in the constructed bank, the test procedure and acceptance criteria should be specified. How this is to be achieved should also be specified, e.g. the type of compaction equipment to be used. Test results, even on major, well-engineered projects only cover a fraction of the material placed. Specification of the broad construction procedure attempts to ensure that the test results are representative of the bulk of the material. The use of inappropriate construction equipment could also result in construction flaws not readily detected in test results. This is why it is always specified that smooth drum rollers should not be used on cohesive fill. Particular attention should be paid to the specification for embankments with clay cores.

A more prescriptive approach may be more appropriate for smaller, Low hazard classification levees; the method of compaction or the number of passes of a certain size roller could be specified, not the testing procedure and acceptance criteria.

This type of approach can be applied to a whole range of works carried out on levees.

6.2 Specifications for earthworks

It is not possible to produce a set of specifications that will cover all designs, conditions and soil types likely to be encountered in the construction of earthen levees. Appendix B provides an indication of the main components that should be included in specifications for levee works, to ensure that the main areas of concern are covered.

Responsibility for the specifications for any engineering structure falls on the designer. The designer will take the site-specific conditions into account, including the results of geotechnical investigations and test results to both produce the design and draw up the specifications on which the design is based.

6.3 Involvement with other services/works

As mentioned previously, levee managers come into contact with the services of other authorities or individuals when they need to cross the line of the levee.

Services/works associated with levees, although not playing a part in flood protection, can lead to potential weaknesses or future operational problems. These works need to be managed carefully to ensure that they do not create problems by interfering with flood response operations, maintenance activities or affect the integrity of the levee.

6.3.1 Fencing

Longitudinal fencing

Longitudinal fencing is used to control access to levees and will usually be found on one side of levees on river frontages and both sides where levees are on private land.

Much of the fencing along existing levees is there because the fences existed before the levee was constructed. Maintenance of these fences is important to prevent damage to the levee by stock and unauthorised vehicles gaining access to the levee.

The type of fencing should be in keeping with that generally used in the area and should take into account the stocking of adjacent properties.

Placing new longitudinal fencing along the crest of a levee should be avoided, as the potentially large number of posts placed into a levee may compromise its integrity and would require unnecessary additional maintenance.

Cross fencing

Where property boundaries or roads cross levees, appropriately constructed cross fences should be used. These cross fences should incorporate a lockable gate, boom or other barrier, which will allow access for maintenance and emergencies, but prevent unauthorised access.

Where access to the levee is not being prevented satisfactorily by cross fences at road crossings and property boundaries, it may be necessary to construct intermediate cross fences or other barriers. Any barrier or additional cross fence will have to have a gate or be removable, to permit access for maintenance or during a flood event.



6.3.2 Access crossings

The number of services crossing a levee should be limited as much as possible.

Vehicle crossings

Vehicle crossings are a necessary feature of levees and provide access to land and other sites on both sides of levees, other than in periods of flooding. Other installations may themselves be protected by levees and attached to the main levee using a common bank through which access is needed.

For public roads and access track crossings, designers must refer to the appropriate road design standards and manuals.



Stock crossings

As many levees are in peri-urban or rural areas, they may bisect areas that have been historically used for stock grazing. Unless other arrangements can be agreed on, farmers may insist on their rights to continue grazing their stock on both sides of a levee. In such instances, specific stock crossing points should be defined and fenced to limit the section of the levee that is impacted by stock.

Stock crossings will require frequent maintenance. Similar management principles to those for vehicle crossings should be applied.



6.3.3 Underground and aerial crossings

Most pipeline crossings are installed by open cut through or under a levee or by directional drilling methods under a levee. Wherever possible, pipes installed through a levee should be within the freeboard zone above the design flood level. Drilling is commonly used for installation of cables and smaller pipes under a levee, where the pipe or cable is either laid in a sleeve pipe or pulled through an oversized hole.

Overhead lines, although not affecting the integrity of the levees, have the potential to create hazards and interfere with maintenance and future works. As covered in Section 5.4, prior written approval by the levee manager must be obtained for any new service crossings of a levee.

Further guidance on how to manage these works is provided in Appendix C.

6.4 'As constructed' survey

An experienced surveyor should undertake a detailed survey of all completed works to confirm that the constructed levee conforms to design. The survey should include the following:

a) Longitudinal Section

- Levee crest elevations at a maximum interval of 50 m, taken at the levee centreline.
- A longitudinal section of the levee crest centreline along the survey traverse shall be produced at a scale of 1:1000 (horizontal) and 1:50 (vertical), or as otherwise agreed.

b) Cross Sections

- Cross sections of the levee at maximum 100 m intervals (urban areas) from natural surface 10 m beyond the water-side and land-side toes of the embankment. Intervals may be greater for rural areas.
- Cross sections should include all changes of slope and the water-side and land-side edges of the crest as well as the crest centreline.
- Generally, a minimum of two cross sections between each angle are required, with the exception of very short reaches of levee (i.e. less than 100 m long), when only one cross section is required.
- All survey information is to be related to existing property boundary fences.
- Cross sections are to be produced at a scale of 1:100 (horizontal) and 1:100 (vertical), or as otherwise agreed. Points of significance should be shown on the cross sections (e.g. fences).

c) Location and extent of:

- Service crossings
- Drainage pipes and pump stations
- Access points
- Spillways
- Any other structures.

7 Developing a levee management system

A key element of levee ownership/management is the development and application of a locality-specific levee management system (LMS).

Levee owners/managers should start to develop their LMS while the levee is being designed. The LMS should be populated and updated during the construction phase in order to provide comprehensive guidance on all aspects of how the levee should be managed as soon as it is commissioned. The system should be 'live' and updated regularly when information that affects the condition or criticality of the levee becomes available. The system should also be 'controlled' in that amendments should only be made in accordance with due process.

Some organisations may choose to establish their LMS as a suite of digitally connected databases that can be accessed on-line or printed out if required. Others may choose to develop a hard copy system with a main manual, appendices and reports (strategic, operational, financial).

A local municipality that is already using a digitally based asset management system for other assets, such as roads, buildings, parks, etc, could use this system to manage its urban levees. A group of landowners managing a rural levee or a single landowner managing a house protection levee may find it more appropriate to develop and maintain a hard copy levee management manual. Appendix D provides a template that could be used as a basis for developing a levee management manual.

The LMS is a critical tool that provides technical information and guidance to help ensure that a levee is effectively maintained throughout its life cycle and to ensure that its operational capability and potential risks are understood. The LMS should define the levels of service being provided by the levee and document operation and maintenance procedures. It should also include or reference relevant design documentation and as-built drawings for the levee and provide links to the most recent report or advice on the levee condition to ensure that these are available when needed. If used in this manner, the LMS can enable tracking of modifications, improvements, and monitoring of problems or deficiencies, that is readily retrievable at short notice in the lead up to a flood event.

7.1 Levee specific considerations

A permanent levee that has been constructed to accepted standards will provide long-term security, provided that management and maintenance are both regular and ongoing. While an earthen embankment may have an almost indefinite lifespan, if appropriately maintained, associated works, such as pumps, fencing, cross overs, demountable sections, will need to be replaced at varying times.

The owner/manager of a levee has the responsibility to ensure their asset is fit for purpose over a very long time span, is well maintained, and that information on the levee and its operation is readily available as required. The owner/manager should also maintain a risk register documenting all the risks associated with the assets, a plan for any upgrades, and a contingency plan should matters not eventuate as planned.

When a flood is imminent there will usually be insufficient time to undertake repairs, remedial works or strengthening if there are problems with the levee. Additionally, information about the levee may be needed urgently by the emergency services for critical decision-making to respond to the flood.

A levee is like a chain and it only takes one weak link for it to fail and for the benefits it provides to be partially or fully negated.

The level of management of a levee system should be appropriate for its hazard classification. Higher standards of protection are normally required for urban areas than for rural areas because, even though the geographical area may be much smaller, the potential for loss of human life and property damage in urban areas is usually larger. Levees protecting urban areas tend to have more stringent design and management requirements than levees protecting rural areas due to their higher risk profiles and levels of service.

7.1.1 Description of the flood protection system

The description of the flood protection system should cover at least:

- elements and components of the system, including a map showing their location
- asset technical information, including references to design and construction documentation
- the level of protection the levee is providing and key risks to the asset owner/manager should the levee system fail.

7.1.2 Strategic inspection and maintenance tasks

The strategic inspection and maintenance tasks to address the key risks that should be undertaken on an infrequent but regular basis (about every 5-10 years) over the life of the asset, using the services of independent qualified and experienced experts where required should cover at least:

- a survey of the levee crest and key features to identify any changes from the as-built drawings or previous survey results
- a detailed visual audit of the system to identify areas that could compromise the level of service of the levee if not addressed
- any other assessment deemed necessary as a result of the above assessments;
- a review of the asset management system to ensure that all requirements are achievable (documentation is accessible, staff are informed and trained, funding is available, etc.)
- a work plan developed and implemented to rectify any identified shortcomings.

7.1.3 Operational inspection and maintenance tasks

There are no day-to-day activities required on levee systems except during flood events. Depending on the levee element or component, inspections, maintenance works and defect rectification should be scheduled once or several times per year based on the risk profile of the asset or in response to unsolicited reports.

Regular inspections and maintenance work should ensure that all components of the levee system are in working order and that there are no fences, gates, trees and building encroachments that would prevent emergency vehicle access on or alongside the levee or compromise levee operation and safety.

The LMS should contain check lists to be used when inspecting the assets and undertaking maintenance works. Sometimes, it may be sufficient to simply record that an activity occurred (e.g. mowing of batters, removal of saplings during inspection). At other times, details of locations, resources, work procedures and work quantities, may be required (e.g. in response to rabbit burrowing, cracking, slumping, testing of pumps).

The description of operational inspection and maintenance tasks to be undertaken by the owner/manager's staff once or several times per year over the life of the asset should cover at least:

- Regular maintenance for each defined component of the levee system (e.g. mowing of batters, removal of weeds and debris, cleaning and checking operational readiness of connected assets, such as pumps, drainage systems, drop logs, gates, valves).
- A general visual inspection of the system once a year (at least) by an experienced levee/dam engineer for all High and Significant hazard classification levees. The inspection of Low hazard classification levees would be the responsibility of the owner. Appendix E provides guidance on the visual identification and management of potential problems.
- Follow-up on issues identified by the general visual inspection (e.g. removal of trees and saplings, removal of rabbit burrows, repair of rilling and other weather erosion, repair of fencing, improved management of stock access, etc).
- Reporting of the above activities into the LMS.

7.1.4 Record-keeping system

The record-keeping system for the assets should be checked at least once a year to ensure that all defined documentation has been correctly filed so that it can be quickly accessed if an emergency situation arises. This is also important to ensure that, even with staff turnover, the knowledge built up over a number of years is not lost.

7.1.5 Levee management during a flood event

The primary purpose of a levee system is to protect a defined community or property from being inundated during a flood. All the maintenance tasks during drier years will be to no avail if procedures are not in place, if additional items and materials are not ready to go, and if staff have not been trained to manage the levee and connected assets throughout a flood event. Planning of these activities requires significant effort and cooperation between the levee owner/manager, the municipality and the emergency services agencies.

The development of such a plan requires careful consideration of the lead time available for individual locations to obtain or set up various resources or items of equipment. This time can vary from a few hours to a few days.

Information on the location of levee systems, their owners/managers and their management systems, should also be included in the relevant municipality's Municipal Flood Emergency Plan.

This part of the LMS should cover how the levee should be managed just before, during and following a high water or flood event. It should strongly emphasise that levees are meant to protect property, not lives. It should provide enough guidance to cover at least the following issues.

Prior to the arrival of floodwaters

- Visual inspection of the levee to ensure it is operational and to identify any potential weaknesses or operational constraints.
- Placement and testing of pumps, drop bars and other temporary barriers, etc.; instructions regarding the timing or other triggers for operating pumps, closing gates, etc.
- Adequate personnel and other resources available to cover levee system management tasks before and during the flood.
- The systems in place to capture, document and exchange information between the levee manager and emergency response agencies as required.
- Preparation for any additional actions listed in contingency plans.

The information that may be required include details of historic floods, the levels they reached at various locations, details of the areas at risk if a levee breach occurs, and the steps to be taken, requirements for the distribution of sand and sandbags, etc.

During the flood event

Visual inspections should be scheduled at least daily. As the flood approaches the Design Flood Event level, inspections should be scheduled more frequently (provided the area is deemed safe to inspect) and responses put into action within a few hours if there is a danger of breach or overtopping.

If the design level of the levee is expected to be exceeded, the only response available is to inform those who will or may be affected to prepare or evacuate in accordance with the pre-planned evacuation plan. Other interventions, such as adding rows of sandbags to increase the height of a levee, may be employed to gain extra time to evacuate.

After the flood event

Even if the levee was not breached or overtopped, a thorough visual inspection should be scheduled as soon as practicable. Depending on resource availability, a comprehensive inspection may not be possible until clean up and recovery is well under way. In this case, a two-step approach should be taken, using a RAM (rapid assessment methodology) approach to schedule any interventions that are needed immediately and indicate the timing within which the comprehensive inspection should be undertaken.

7.2 Connected assets

Other in situ connected assets specifically associated with flood protection, such as pumps, pump pits, associated piping and valve flaps, drop bars, etc., are components of the flood protection levee asset and should be covered in the LMS.

If a levee serves a dual purpose, such as being a road or cycle pathway as well as a levee, it may be subject to two sets of asset management systems that should be cross-referenced. However, it should always be ensured that the primary purpose of the asset is flood protection.

Involvements with other services, such as pipeline and cable crossings over or under the levee, are not considered part of a levee asset, and should be managed under a separate asset management category. However, the LMS should contain references to all connected assets, including the details of each asset owner, so they can be contacted as needed for regular maintenance or emergency management requirements.

7.3 Protected assets

Information on the assets (infrastructure, properties, etc.) and people at risk behind the levee should also be available to levee managers and emergency service managers. Physical addresses and contact details should be updated regularly.

7.4 Varying the approach to suit the level of risk

Inspection and maintenance requirements are more detailed and frequent for levees with a higher level of protection and a higher hazard classification than for those with a lower hazard classification.

Rural levees of a Low level of protection may not to be inspected for a number of years, or may not have a strategic assessment undertaken unless commissioned by a regional or state authority. If this is the case, levee failure may be expected during a flood.

7.5 Periodic third party inspections

Periodic third party inspections of public levees should be undertaken by a levee/dam engineer to ensure that those responsible for their management are able to demonstrate that the works are always capable of meeting their original objectives.

8 Levee upgrade and renewal

8.1 Post flood repairs or refurbishment

Even if a levee was not breached or overtopped, a thorough visual inspection should be scheduled as soon as practicable after a flood event, and a work plan developed and implemented to rectify any short-comings identified.

Some tasks may be able to be completed as part of the operational inspection and maintenance program; others may be able to be delayed and included in the strategic inspection and maintenance program.

If a levee was seriously compromised or breached during the flood event, a post-flood emergency works project needs to be initiated.

8.2 Increasing the level of service or life expectancy

There are a number of potential reasons for increasing the level of protection or life expectancy of a levee:

- excessive 'wear and tear' due to environmental factors (e.g. drought) or human factors (e.g. encroachments by adjoining landowners, stock crossing, vehicle traffic)
- a flood having eroded or otherwise compromised the levee
- available new data/information indicates that the defined level of protection was not as high as previously understood
- changes in land use planning resulting in pressures for increased development behind the levee
- a decision has been taken that a section of the levee should be moved.

Regardless of the reason, a complete design review needs to be undertaken to ensure that the upgraded levee is fit for purpose, and that it is physically and hydraulically capable of providing the new level of protection.

Most levee upgrades require the crest and batter of the existing levee to be stripped to ensure a sufficient bond between the old and new works, and hence also an increase in the size of the levee footprint.

9 Levee decommissioning

Permanent levees are rarely decommissioned. If they are no longer required for flood protection, they are usually simply left to slowly erode.

If a redundant levee poses a risk, it should be formally decommissioned. Even then, the decommissioned levee is rarely totally removed from the landscape. It is more common for large gaps to be made in the levee so that, in future, flood waters would flow largely unrestricted through the gaps and spread out over the floodplain.

A formal process, including approvals by the relevant authorities, should be undertaken.

10 Community engagement

Community members play an important role in the design and ongoing management of a levee. Without the involvement of local landholders, both those who may be affected by the levee and the wider community, a levee may not meet the community's expectations.

10.1 Community consultation

During the design phase, the community should be consulted about the need, purpose, location and aesthetics of a levee. Engaging with the affected community at this stage enhances their understanding and therefore their support for the levee once it is constructed.

10.2 Community education

In addition to managing flood protection assets, response agencies have a number of important activities that affect a community's ability to be self-sustaining during a significant flood. These include flood monitoring, warnings, road monitoring/closures, public information, asset protection, livestock management, evacuation, relief, etc.

The success of these activities relies heavily on communities being aware of the nature of the emergency and having a plan to manage the situation. This requires individual community members to have a minimum set of skills necessary to protect their own safety and that of their family. To improve the way individual communities respond during a flood event, it is necessary to raise their awareness about the risk, and what they can do to help protect their own safety.

Development of a strategy or program that will do this should consider:

- distributing and explaining the municipality's agreed approach to flood mitigation and flood response management
- preparing inundation maps and making them available to the public
- preparing evacuation plans for caravan parks and other low-lying areas
- pre-preparing templates for media releases, bulletins, etc
- providing information in alternative format or languages other than English (LOTE)
- providing training in media interview techniques for people in selected positions
- supporting agency training
- providing revision/training in sandbag laying techniques
- developing inter-agency liaison arrangements
- disseminating handbooks and awareness material
- addressing community groups and schools
- arranging pre-flood briefings
- arranging pre-flood public meetings.

Many of the areas are covered in the various Municipal Emergency Management Plans and Sub-Plans that have been developed across Victoria. These plans should include all the appropriate criteria used in the design of levees, together with any plans, levels and other information considered useful in an emergency.

11 References

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Appendix A – House protection levee design and construction considerations

House protection levees are typically small, Low hazard classification levees designed to protect individual rural houses, or high-value buildings or equipment. They are typically constructed by the owner or a local earthmoving contractor.

This appendix provides basic technical information about typical cross sections (including vertical (V) to horizontal (H) dimension ratios), site preparation, construction and finishing.

The owner will still need to consult with, and seek approval from, the relevant authorities (local government, catchment management authority) before working with a consulting engineer to design the structure and identify a nearby source for suitable construction materials.

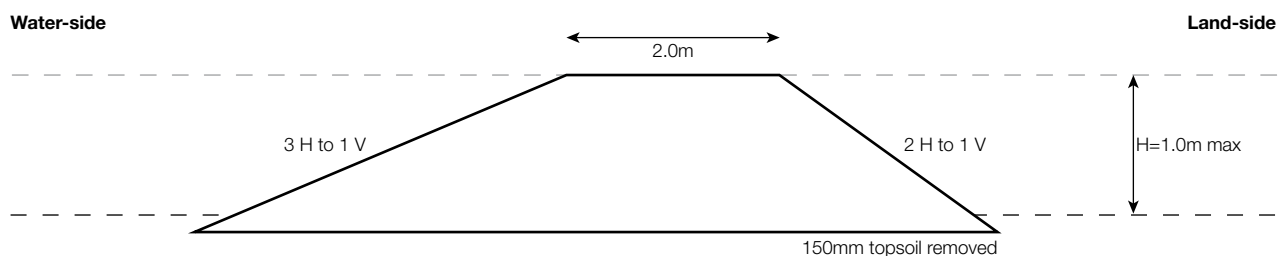
The owner should develop and maintain a suitable management manual following construction. Elements of Appendix D are applicable. It is also recommended that local government references the location of house protection levees in their Municipal Emergency Management Plan.

Typical cross sections

The following three typical cross section forms have been used for house protection levees in Victoria.

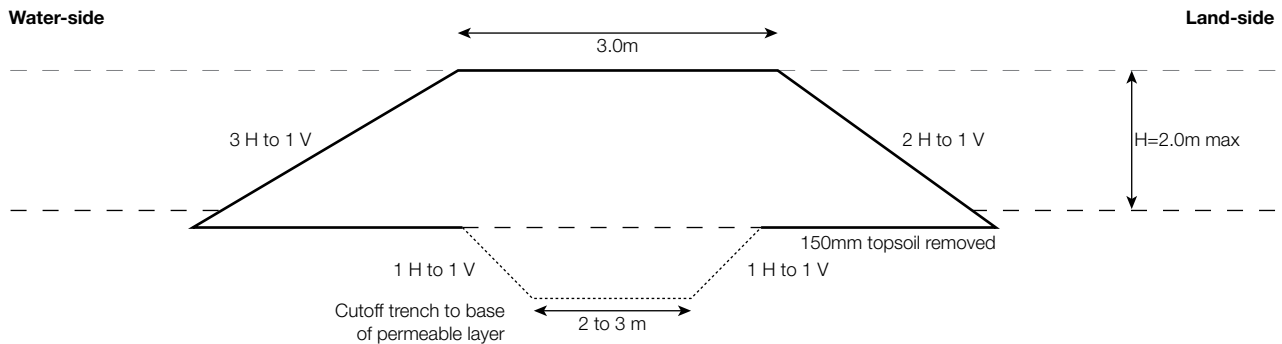
Type 1: Standard Bank – a standard cross section with no cut-off trench

- The bank has a homogenous clayey earthfill and requires a suitable clayey soil foundation.
- There is no cut-off trench.
- The crest is cambered to prevent ponding of water on the crest.
- The stripped topsoil is graded back over the levee at completion of the bulk earthworks.
- A good grass cover should be established and maintained.



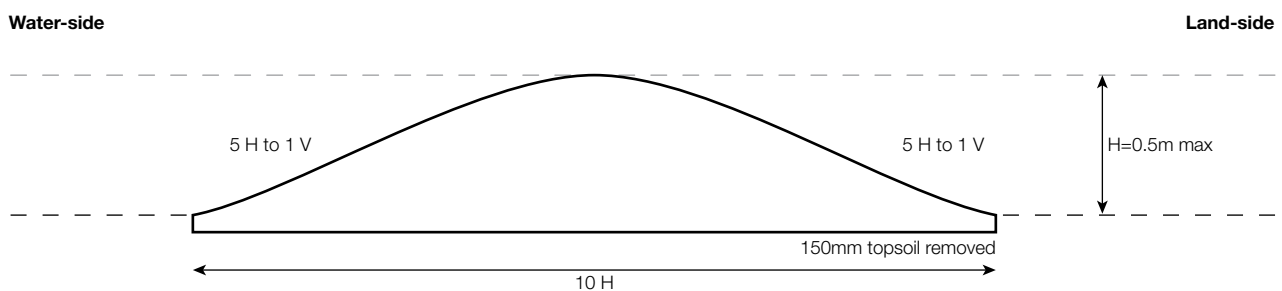
Type 2: High Bank – a standard cross section with cut-off trench

- The bank has a homogenous clayey earthfill.
- A cut-off trench is provided if permeable soil foundation is present.
- The crest is cambered to prevent ponding of water on the crest.
- The topsoil is graded back over the levee at completion of the bulk earthworks.
- A good grass cover should be established and maintained.



Type 3: Garden Bank – a rounded bank suitable for hand or ride on mower

- The bank has a homogenous clayey earthfill.
- The stripped topsoil is graded back over the levee at completion of the bulk earthworks.
- A good grass cover should be established and maintained.



Clearing and stripping

The footprint of the levee should be stripped of all surface vegetation, stumps and roots. The top 150 mm of topsoil should be stripped and stockpiled for spreading over the levee bank on completion of the bulk earthworks.

Foundation preparation

Any soft or saturated ground in the foundation should be removed and backfilled with compacted earthfill as for the embankment (see below).

If a Type 2 bank is to be constructed, excavate the cut-off trench to the required depth and dimensions.

Compact the foundation surface as for the embankment (see below).

Materials

The earthfill material to be used for the levee should consist of fine grained inorganic cohesive soils, free of rocks, organic material and other deleterious material. The clay content of the soil should be sufficient to ensure that when the appropriate amount of water is added, the soil can be moulded by hand.

A suitable borrow pit should be remote from the levee so as to not create an excavation that would provide a short circuit for water to flow under the levee in a permeable layer. It should be as far from the levee as practicable, at least 20 times the levee height.

If necessary, the material in the borrow pit should be irrigated to condition it to optimum moisture content (OMC) as defined in Appendix B. When a soil is at OMC, it should be possible to mould it into a ball with one's fingers. When squeezed, the ball should deform plastically before breaking up.

Placing and compaction

The earthfill should be placed and evenly spread in layers not exceeding 150 mm thick running along the levee and repeated until the full width of the levee is covered. The layer should then be compacted. Ideally, compaction should be undertaken with 4-6 passes of a vibrating 'padfoot' roller of drum mass exceeding 5 t. If a smooth drum roller or rubber-tyred vehicle is used, the surface of the compacted layer should be scarified to a depth of 50 mm to ensure a good bond with the subsequent layer.

The degree of compaction required is 95% of standard maximum dry density as defined in Appendix B.

A simple field test for adequate compaction is that when thumb pressure is applied with moderate effort, the surface of the layer should not indent by more than a few millimetres.

Trimming and finishing

After compaction of the final layer, the embankment should be trimmed to line and level. The crest of the levee should be trimmed to provide a 3% camber to facilitate drainage of rainwater off the crest.

The batters and crest should then be topsoiled and grassed.

Maintenance

The owner should ensure that a good grass cover is established and maintained to mitigate the formation of cracks in the levee and enhance the ability of the levee to accommodate any overtopping by flood waters.

Appendix B – Components of an earthworks specification

The Earthworks Specification forms part of the Contract Documents for construction projects. The Contract Documents typically include:

- The General Conditions of Contract: AS 2124 is recommended unless the owner (Principal) is a large organisation that may have its own General Conditions of Contract. AS 4904 or 4905 could be used for minor construction projects.
- Any Special Conditions of Contract: These are normally covered by Annexure Parts A and B in AS 2124, AS 4904 or AS 4905.
- The drawings detailing the works to be constructed.
- The specifications that provide additional detail on the requirements for the works to be constructed. In minor projects it may be possible to include all the specifications on the drawings. Typically, an embankment levee project would include an Earthworks specification but it may also need a number of other specifications including concrete, pipeline, roadworks, valves, pumps, etc, depending on the ancillary works included in the contract.
- Other documents, if required, such as geotechnical investigation reports, flood hydrology reports, etc.
- The signed Tender from the successful tenderer.
- The signed letter of acceptance from the Client.

It is not possible or desirable to provide generic guidance to cover all possible variations in sites and materials likely to be encountered for the earthworks component of a levee specification. The Specification and the Drawings represent the design of the works to be constructed. Only the designer is fully aware of the conditions on which the design is based so it is essential that they are satisfied that the specifications fully cover the design intent.

However, there are many components of a specification that are generally applicable to most Low hazard classification, homogeneous or clay core embankment levees on a soil foundation and these are presented below. Levees requiring filter protection and those founded on rock are not covered.

Sample wording for Specification clauses is shown in italics.

Standards

To avoid potential confusion, a caveat such as the following should be included in the General section: *Wherever a Standard Specification or Code is specified herein, it shall mean the latest edition and/or amendment of that Specification or Code at the date of calling of tenders for this Contract.*

The following Australian Standards are applicable to most embankment levee earthworks specifications:

AS 1726: Geotechnical site investigations

AS 1289: Method of testing soils for engineering properties. The following test procedures are of particular relevance:

- 1289.3.8.1 - Soil classification tests – Dispersion - Determination of Emerson class number of a soil
- 1289.5.1.1 - Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using standard compactive effort
- 1289.5.8.1 - Soil compaction and density tests - Determination of field density and field moisture content of a soil using a nuclear surface moisture-density gauge - Direct transmission mode.

Site preparation: clearing and grubbing

Clearing is the removal and disposal of trees and surface vegetation, rubbish, obstructions, disused structures, etc. Grubbing is the removal and disposal of stumps, large roots and other obstructions to a depth of not less than 500 mm. Clearing and grubbing are generally performed concurrently to prepare the site for topsoil stripping and bulk excavation. Since clearing and grubbing are the first work items, they are usually critical to the project schedule. This section should cover:

- area to be cleared
- method of trimming
- depth of grubbing
- backfilling of grubbed holes
- methods of disposal of materials from the operations.

Stripping of topsoil

Topsoil shall be stripped to a depth of 150 mm minimum. Stripped topsoil shall be stockpiled and used for topsoiling the levee when the bulk earthworks are completed.

Excavation

Any organic or spongy material remaining after stripping of the topsoil shall be removed to spoil.

Where a cut-off trench has been specified to intercept permeable layers in the foundation, it is to be excavated to the lines and levels shown on the drawings or as approved on site by a levee/dam engineer responsible for the design or his/her authorised representative.

Foundation treatment

The levee foundation shall be prepared by scarifying to a minimum depth of 150 mm, moisture conditioning to bring it to the required moisture content and compacting to the specified density for compacted fill.

Materials

The suitability of material to be used for construction of the levee banks shall be determined by geotechnical testing and the Superintendent's approval. The Contractor shall be responsible for the procurement of sufficient material to complete the work under the Contract.

Care should be taken in the location of borrow pits for material for the levee. If too close to the levee on the water-side, it is possible for the borrow pit excavation to expose a permeable layer that extends under the levee foundation, possibly resulting in a piping failure of the levee under flood conditions. Similarly, if on the land-side of the levee, the borrow pit excavation could remove an existing natural clay blanket over a permeable layer that extends under the levee to the river.

Earthfill material to be used for the levee shall consist of fine grained inorganic soils, free of rocks, organic material and other deleterious material.

The earthfill should ideally have a Plasticity Index (PI) of more than 10% and a grading with at least 25% finer than 0.075 mm and at least 75% finer than 4.75 mm. The maximum particle size should be less than 75 mm.

If there is insufficient material meeting the above requirements, the levee should include a clay core of material meeting these requirements with the shoulders constructed from available materials with at least 15% finer than 0.075 mm.

The Unified Soil Classification System (USCS) is a method for classifying soils to give a general indication of the engineering properties including mechanical strength, hydraulic conductivity (permeability) and tendency to shrink on drying and therefore suitability for the compacted channel banks and for the sections of clay lining. *The Unified Soil Classification System in accordance with AS 1726 shall be used in the determination of a suitable soil in conjunction with requirements in this Specification.*

Earthfill material meeting the requirements for the levee core is expected to have a USCS classification of CL or CH, although material with a MH and SC could meet the requirements if the clay fraction is high enough.

Ideally, dispersive soils having an Emerson Class of 3 or less should not be used. However, if non-dispersive soils are not available, dispersive soils can be used if appropriate measures are adopted in the construction. Such measures include tight control on compaction to a higher dry density, a higher compaction moisture and possibly the inclusion of filters to control piping erosion. Dispersive soils can also be treated with lime or gypsum (typically 2-3% by weight) to reduce the dispersiveness.

Construction

The levee banks shall be constructed to the lines, levels, grades and cross sections shown on the drawings and within the tolerances specified below.

Immediately preceding placement of suitable earthfill material on a previously compacted surface:

- *the earthfill material shall be moisture tested and brought to the specified moisture content as necessary*
- *if the previously compacted surface has been damaged by drying out and cracking or become over wet due to rainfall or suffered any other damage, the surface layer shall be scarified, moisture conditioned and compacted as specified.*

The Contractor's operations in handling, spreading and compacting earthfill material on the levee shall result in an acceptable distribution and gradation of the material throughout the bank, free of lenses, streaks, laminations, layers of material differing substantially from the surrounding material in the bank, or other discontinuity ensuring the density is uniform throughout each compacted layer.

Earthfill layers throughout the levee banks shall be spread such that the final compacted layer thickness is not greater than 150 mm

Compaction requirements

The levee banks shall be constructed to achieve a minimum dry density ratio of 95% standard compaction as determined by AS 1289 - Determination of the dry density/moisture content relation of a soil using standard compaction effort.

If dispersive soils are incorporated in the embankment, the required minimum dry density shall be 98% standard compaction.

The compaction moisture content shall be as follows:

- *Clay core: between optimum moisture content (OMC) and OMC+ 2%*
- *Embankment either side of clay core: between OMC -2% and OMC + 2%*
- *Dispersive soils: between OMC and OMC + 3%*

If the required density and moisture content are not achieved, the compacted material shall be reworked to meet the density and moisture content requirements. If the density and moisture content requirements again cannot be achieved, the failed layer shall be removed at the Superintendent's direction for either moisture conditioning in a borrow area before reuse or stockpiled if still considered unsuitable.

If there is excessive moisture in the borrow clays, the Contractor shall undertake such works as necessary including ripping, working, spreading and aerating the clay to ensure a reduction in the moisture content to within the specified moisture tolerance. The conditioning shall be performed in a manner to ensure uniform moisture content throughout the clays before borrowing takes place. All drying back operations shall be performed within the borrow area or in an area designated by the Superintendent.

Compaction of the earthfill shall be performed with a vibratory padfoot roller with a minimum drum static mass of five tonnes. In confined spaces or near pipes and other structures where large plant cannot be used, hand-operated mechanical tampers shall be employed.

If the surface of a previously placed and compacted lift has been left for some time and has dried out or wetted up, the affected surface zone shall be excavated to expose compacted earthfill beneath that has a moisture content within the specified tolerance.

If the contractor elects to stop placing of fill for an extended period or rainfall is expected, completed layers of the levee shall be sealed by rolling with rubber-tired equipment or smooth drum roller and sprinkled with water if necessary. Where a smooth drum roller has been used, the surface of the sealed layer shall be thoroughly scarified to ensure the following layer of earthfill is keyed in to the previous layer to prevent laminations at the layer interfaces. Trafficking of the scarified surface shall only be permitted by equipment used to place the following layer, unless approved by the Superintendent. All regions where laminations occur, either between or within layers, shall be reworked to remove all laminations.

Compaction tests

The Contractor shall arrange for and meet all costs associated with sampling and testing to show compliance with the specified compaction requirements. The geotechnical work shall be undertaken by a NATA registered laboratory, and shall include such tests to ensure conformance with the drawings and specifications.

The Contract price shall include allowances for possible time delays while samples are being collected and tested. No additional payment will be made for any completed work requiring removal and/or repair as deemed by the results of any tests.

Testing shall be performed on the basis of at least one test per 500 cubic metres of compacted earthfill or as directed by the Superintendent.

The samples for testing for conformity with the compaction requirements of this specification shall be from random locations, as determined by the independent geotechnical sub-contractor or at the Superintendent's direction. The sampling locations shall provide a representative and distributed sampling of each section of the embankment. The location of each sample, running distance and level (relative to the embankment) shall be recorded and submitted with the test results.

Acceptable work is defined as when 90% of the test results achieve the minimum dry density ratio specified based on standard compaction to AS 1289.

Notwithstanding the above, where test results show dry density ratios more than 2% below the specified density, the Contractor shall carry out such reworking to the filling as needed to achieve the specified values and the zone shall be retested.

If the quality of materials is in doubt at any time, the Superintendent may order tests to be carried out by the Contractor at his own expense. Where the results of such tests comply with this Specification, the cost will be borne by the Principal. The cost of any tests that fail to comply with the Specification shall be at the Contractor's expense.

All test results in the same form as that presented to the Contractor by the NATA registered testing laboratory shall be submitted to the Superintendent within 24 hours of receipt.

Levee cap

A levee may be capped with either topsoil or Class 3 or 4 crushed rock.

Areas to be capped with topsoil shall be finished 100 mm below finished surface level and topsoil placed and firmed with a light roller so that the finished surface conforms to that specified. Suitable topsoil, specified by the Superintendent shall be placed on the batters to a uniform depth of 100 mm and areas, when finished, shall present smooth surfaces, free of stones and lumps of soil gradually blending into adjoining ground and left ready for grassing. Topsoil shall not be placed until the Superintendent has checked the lines and levels of the embankment and approved the bank.

Areas to be capped with crushed rock shall be finished 100 mm below finished surface level and capped with not less than 100 mm thick of 20 mm class 3 or 4 crushed rock. The crushed rock shall be evenly spread in a moist condition and compacted with a smooth drum roller to leave a surface that is uniformly tight and free of loose uncompacted material, segregated or 'bony' material or soft, overwet areas and free of roller indentations.

Construction tolerances

Earthworks shall be finished to reasonably smooth surfaces that conform to the lines, grades and cross-sections shown on the drawings or directed by the Superintendent. Tolerance limits are as follows:

Crest Levels:

- Minimum Level: Design Level*
- Maximum Average Level: Design Level + 100 mm*
- Variation from Average Level: +/- 50 mm*

Batters: No steeper than specified

Crest Width: + 200 mm – 0 mm

Topsoil Thickness: + 25 mm – 0 mm

Base Width: + 500 mm – 0 mm

'As-constructed' survey

A detailed survey of all completed works should be undertaken by an experienced surveyor to confirm that the constructed levee conforms to design, and should include the following:

a) Longitudinal Section

- Levee crest elevations at a maximum interval of 50 m, taken at the levee centreline.
- A longitudinal section of the levee crest centreline along the survey traverse shall be produced at a scale of 1:1000 (horizontal) and 1:50 (vertical), or as otherwise agreed.

b) Cross Sections

- Cross sections of the levee at maximum 100 m intervals extending from natural surface 10 m beyond the water-side and land-side toes of the embankment.
- Cross sections should include all changes of slope and include the water-side and land-side edges of the crest as well as the crest centreline.
- Generally, a minimum of two cross sections between each angle are required, with the exception of very short reaches of levee (i.e. less than 100 m in length), when only one cross section is required.
- All survey information is to be related to existing property boundary fences and any known permanent survey marks in close proximity.
- Cross sections are to be produced at a scale of 1:100 (horizontal) and 1:100 (vertical), or as otherwise agreed. Points of significance should be shown on the cross sections (e.g. fences).

c) Features

Location and extent of the following:

- service crossings
- drainage pipes and pump stations
- access points
- spillways
- any other structures.

Appendix C – Underground and aerial crossings

Pipeline crossings through or under an embankment levee introduce a potential weakness in the levee for a number of failure mechanisms:

1. The pipeline can create a preferential seepage path through the levee around the contact between the pipe and adjacent fill, especially beneath the obvert of the pipe where compaction and a good seal is difficult to achieve. This could lead to seepage and internal erosion.
2. Water pipelines can leak and result in internal erosion. Typical causes of pipe leakage include corrosion of the pipe wall, structural failure of the pipe due to external loading resulting from differential settlement and separation of pipe joints due to consolidation of the overlying earthfill and/or settlement of the foundation.
3. Pipelines can also cause zones of low vertical stress in an embankment that may result in internal erosion. This can occur in two ways. The first way is that settlement of the earthfill immediately above a rigid pipe projecting above the levee foundation can result in a disproportionate load being carried by the crown of the pipe thus 'holding up' the bank above the sides of the pipe. This 'hold up' results in zones of low vertical stress adjacent to the pipe. The second way is where the pipe is laid in a deep trench through or under a levee bank, settlement can result in the weight of the overlying embankment being transferred to the trench sides in an arching action resulting in a zone of low vertical stress immediately above the pipe. These zones of low vertical stress can be areas where seepage can initiate which can lead to piping erosion.
4. Vertical sides of concrete encasement of pipelines can result in an area of low horizontal stress along the sides of the concrete encasement, creating a preferential seepage path that could lead to internal erosion.

It is therefore desirable that service crossings of levees be avoided or kept to a minimum.

The sections below provide guidance on issues that should be considered for underground and/or aerial crossings

Pipelines through or under embankment levees

Wherever possible, service crossings should be located where the height of the levee is as small as possible and ideally on a rock foundation.

For pressurised pipes, current practice is to locate service crossings within the flood freeboard as an inverted siphon, to minimise the potential hydraulic gradient across the levee. If necessary to provide sufficient cover, the crest of the levee can be raised locally, with the crest ramping up on either side of the crossing to maintain access along the crest, as shown in Figure C-1.

The pipes could be above ground level on the water-side and land-side batters or buried to facilitate maintenance of the batters. The pipes may have to be anchored to withstand uplift forces during a flood.

All pressurised pipes should have welded or flanged joints to minimise the risk of a joint failure due to settlement or corrosion. The release of water from a pressure pipeline could cause hydraulic fracture, internal erosion and piping failure.

Where it is not possible to locate crossings within the freeboard zone of a levee, as is the case for a gravity drain under a levee, the following design features should be adopted for the installation of a new pipeline under an existing levee with a soil foundation:

- The trench, excavated for the pipeline, should be battered back at a 1:1 slope or flatter and fully compacted when backfilled.
- The pipe should ideally be fully encased as shown in Figure C-2. The sides of the concrete encasement should not be steeper than 1(H): 8(V).

- Steel and plastic pipes should have welded or flanged joints. Concrete pipes should have rubber ring joints.
- The pipes should be suited to the maximum expected internal pressure and external loads.
- The pipes should have suitable long-term corrosion protection.
- The width of the trench should provide a minimum space of 600 mm at the base of the concrete cradle/encasement to facilitate good compaction. The sides of the trench should be battered to flatter than 1(H): 1(V).
- A filter diaphragm should be installed for high hazard potential levees (see section 3.2) but may be omitted for lower hazard potential levees. It is up to the designer to assess the need for a filter diaphragm. Where required it should be installed at a distance land-side of the levee centreline equal to the height of the levee above the pipe foundation as shown on Figure C-2. The filter material should be a free-draining, cohesionless sand with a grading to meet the filter criteria for the selected clay material as per Fell et al, 2005. This is typically a coarse, washed sand with less than 3% passing a 0.075 mm sieve.
- Water-side of the filter diaphragm (or equivalent distance if diaphragm omitted), the pipe should be backfilled with selected clay material compacted to 98% of maximum dry density at a moisture content of between optimum moisture content (OMC) and OMC +2% (Figure C-2).
- Land-side of the filter diaphragm the pipe should be backfilled with the same filter material.
- At the land-side toe, a suitable arrangement should be provided to drain the filter.

Where a new levee is to be constructed over an existing pipeline, all existing granular material around the pipe including all backfill and foundation sand/gravel, needs to be removed prior to encasement of the pipe and the trench reinstated as described above. Alternatively, in some instances, the pipe may be relocated over the levee

Note: Concrete cut-off collars around conduits through embankment levees should not be provided.

Prior to the mid-1980s, it was customary to provide such cut-off collars around conduits through embankment dams. Investigations of many failures of embankment dams provided with such collars found that they collars may have contributed to the failures rather than prevented them. The presence of cut-off collars was considered to have increased the propensity for differential settlement and impeded proper compaction around the conduit. This increased the potential for cracking to occur, creating seepage paths and leading to internal erosion and piping failure. Filter diaphragms were found to be most effective in intercepting and sealing off the flow through a crack (FEMA, 2005).

Drilled pipelines

In the case of a directionally drilled hole under a levee, the principal concern is to avoid drilling into the levee or the cut-off of the levee. It is also necessary to prevent water getting into the small annular space left around the pipe, after it is pulled through the drilled hole. See Figure C-3.

A further concern with directional drilling is the potential to cause hydraulic fracturing of the foundation that could result in internal erosion and piping failure.

To achieve this, the following suggested procedures should be adopted where appropriate:

- Trenching should not be undertaken within a distance of twice the height of the levee or 3 m of either toe, whichever is the greater.
- Depth of pipe should be based on 1.2 m of cover, below natural surface, at the start of the drilling. If the levee is keyed into the foundation material, the top of the pipe should be at least 1 m below the bed level of the cut-off, to avoid interfering with the integrity of the cut-off.
- The diameter of the drilled hole should be kept to the minimum that will allow the service pipe to be pulled through.
- Should an annular space be left around a pipe, the space should be filled by pressure grouting, using a 10:1 sand:cement grout mix. This is extremely difficult to monitor and care should be taken to ensure grouting pressures do not cause hydraulic fracture of surrounding foundation/embankment materials.

- For levees up to 1 m high, the ends of the pipe outside the drill hole should be supported 150 mm above the bed of trench. The first 2 m of trench on either side of the levee should then be filled to within 150 mm of natural surface with a compacted 10:1 sand cement mixture.
- Final backfilling of the plug is to be completed using topsoil.
- For levees greater than 1 m high, a 300 mm thick concrete cut-off wall should be built at the end of the drill hole to within 150 mm of natural surface.
- Where cut-off walls are used, care must be taken to properly support the pipe (particularly if reinforced concrete), to avoid cracking the pipe. In these situations, it is good practice to have a rubber ring joint, adjacent to the wall.
- A good bond must be achieved between the cut-off wall and the pipe. With concrete pipes, this can be achieved by scabbling the pipe surface; for steel pipes, by welding on a cut-off flange; and for PVC, poly or black brute type pipes, by using a puddle flange or other water stop arrangement. In all cases, cut-off walls should be centrally reinforced with mesh and with hooped bars around the pipe.

Note: For power cables crossing under levees, additional requirements that must be included in the granting of any permission for a crossing are:

- Cables must in all cases be enclosed in a heavy-duty rigid PVC conduit to AS 2053. The conduit must have a minimum cover of 1 m within 10 m of each toe of the levee.
- Concrete slabs constructed to AS 3000, must be used to protect cables. These slabs are to be laid 150 mm above the cable.
- Plastic warning tape must be laid 300 mm above the cable along the entire underground length of the cable.
- Warning signs must be located on either side of the levee indicating the presence of a cable.

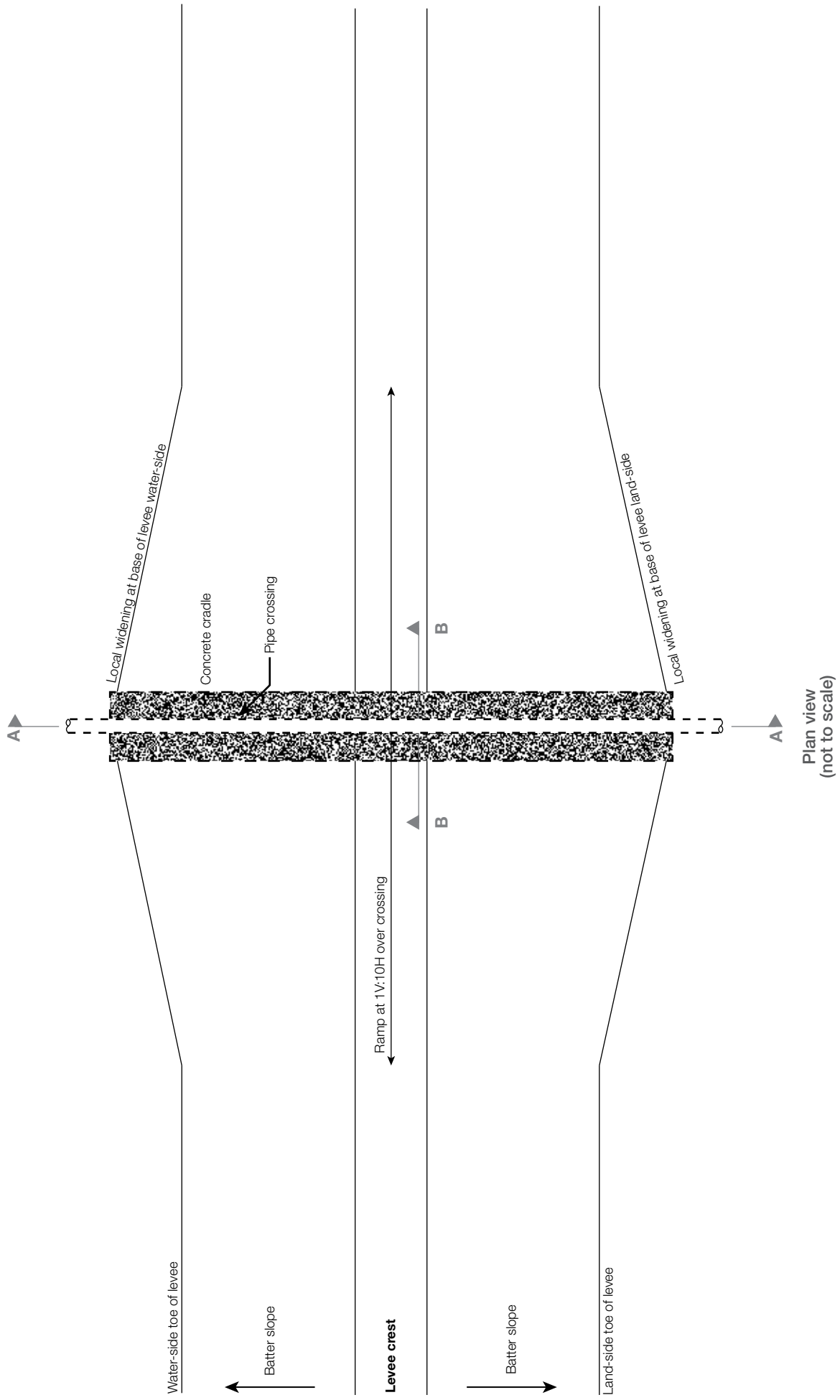
Aerial crossings

These crossings are generally required by power or telephone authorities or private works associated with these services. They are usually not a major issue, however, consideration must be given to any negative impacts that these works may have on the management of the levee.

Matters that should be considered are:

- Clearance above the crest level of the levee must be sufficient to allow the safe passage of plant and vehicles required for maintenance or emergency works on the levee.
- Supporting poles must be set back sufficiently, say 10 m, so as not to interfere with future access or other works requirements outside either toe of the levee.
- Necessary warning signs should be displayed at each aerial crossing advising of the danger, as well as the contact authority, for further information on the crossing.

Figure C-1
Pipe crossing through levee crest



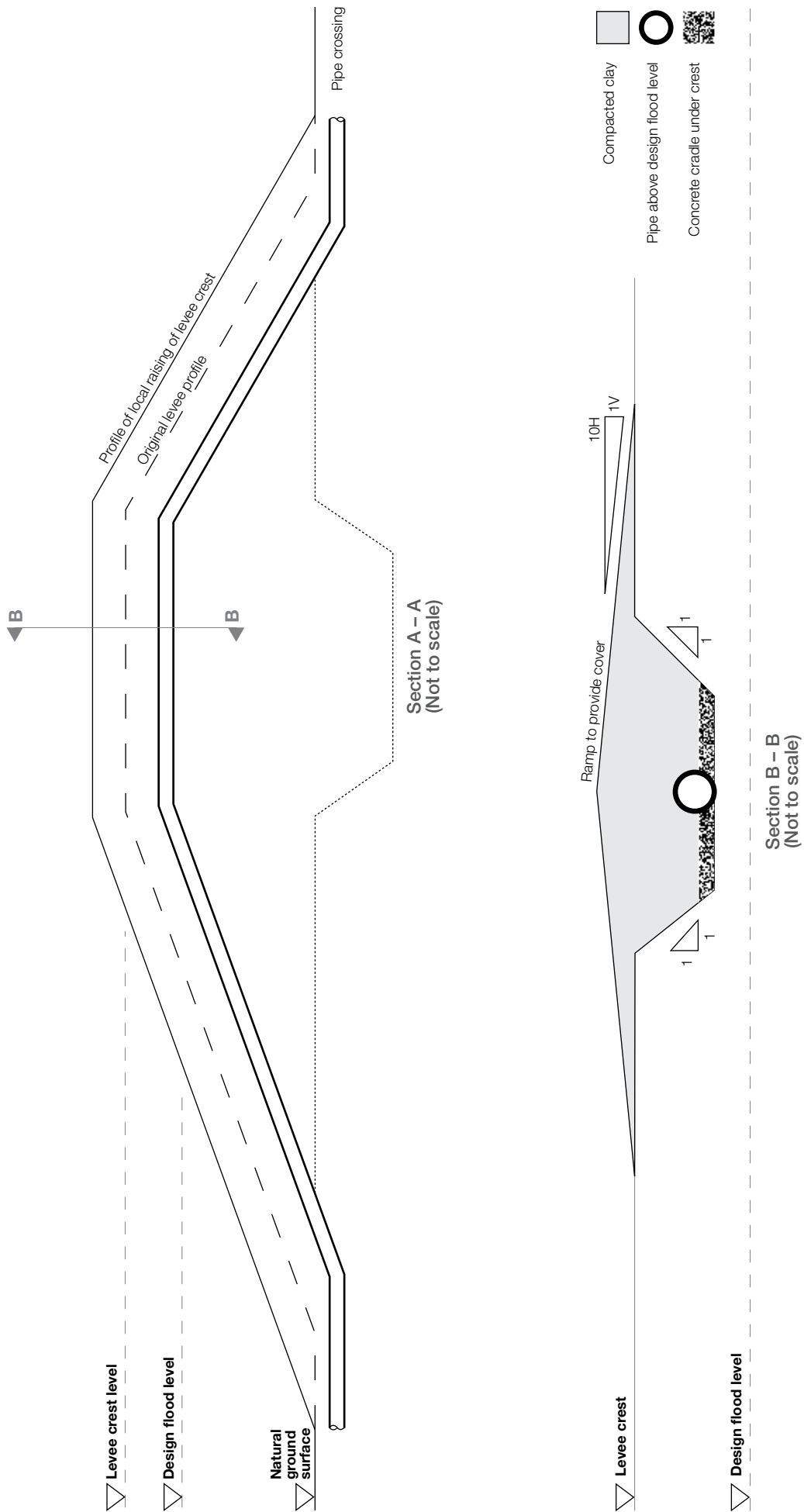
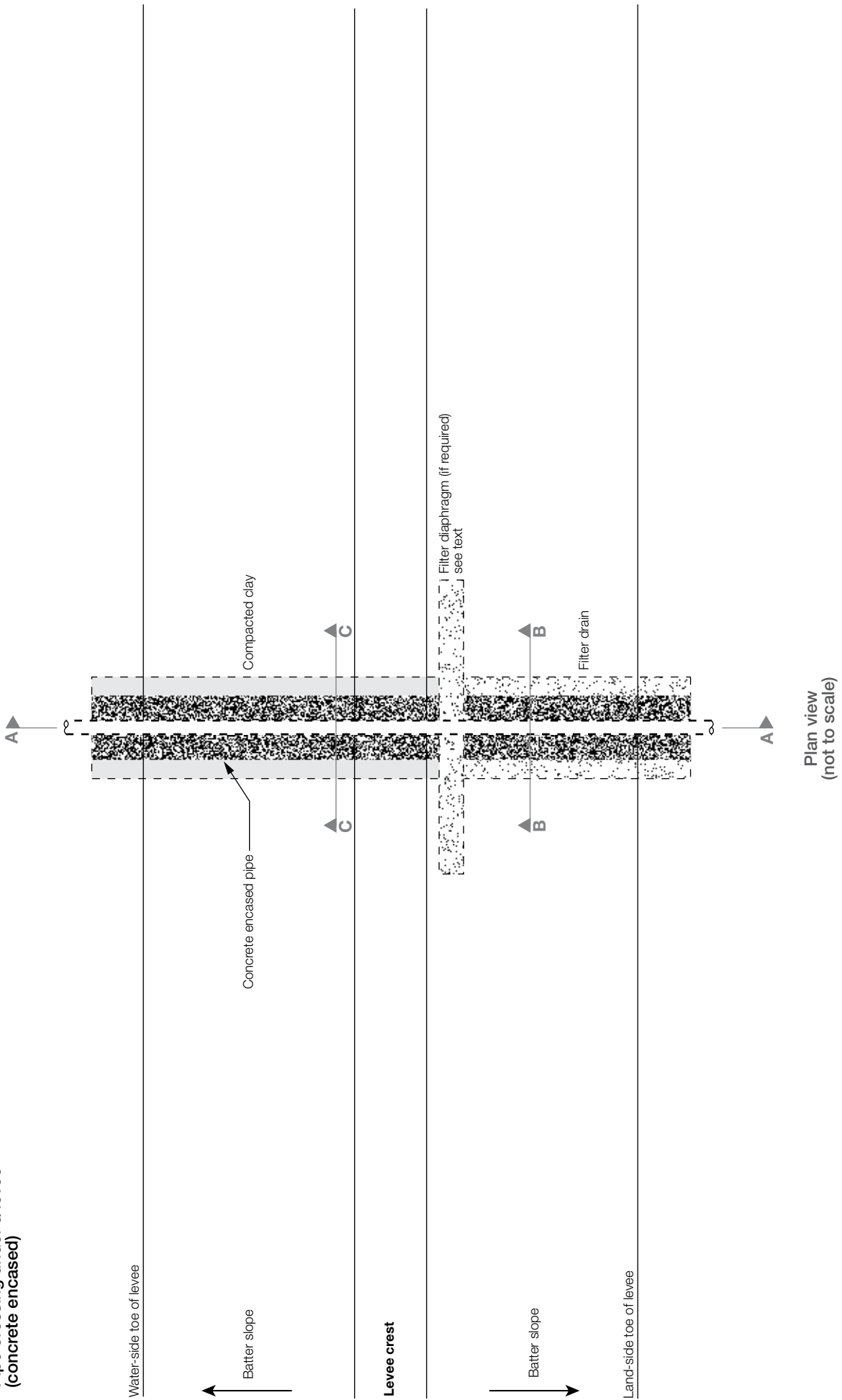
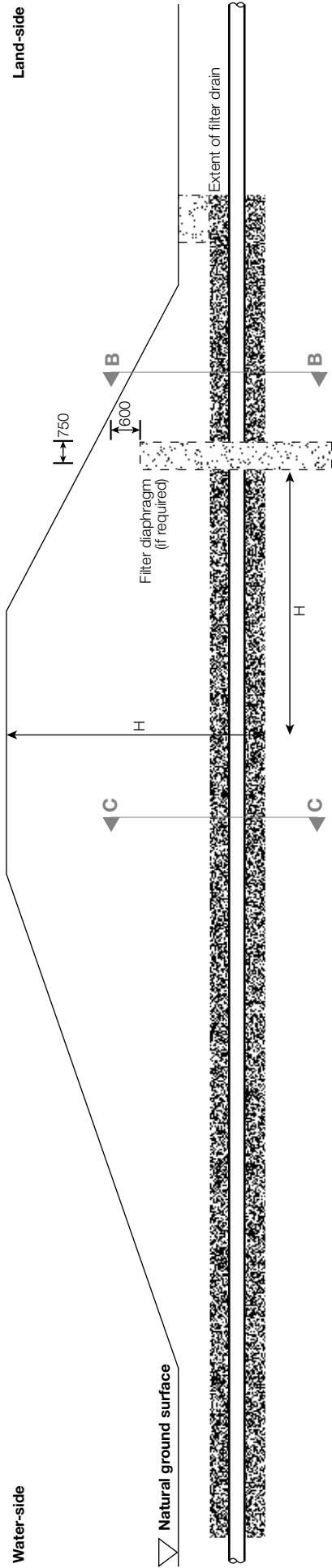
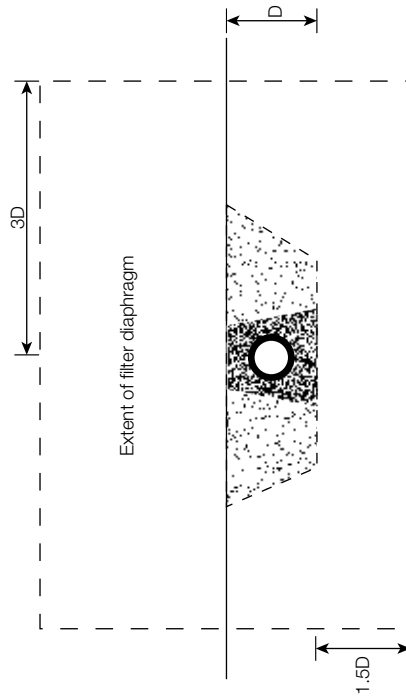


Figure C-2
Pipe crossing under a levee
(concrete encased)

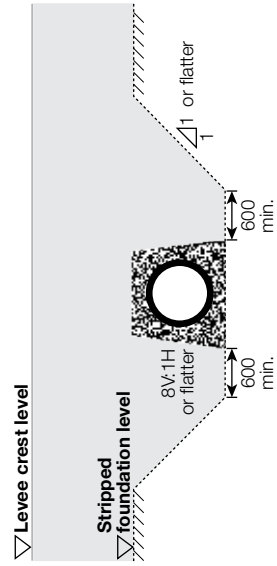




Section A-A
(not to scale)



Section B - B
(not to scale)



Section C - C
(not to scale)




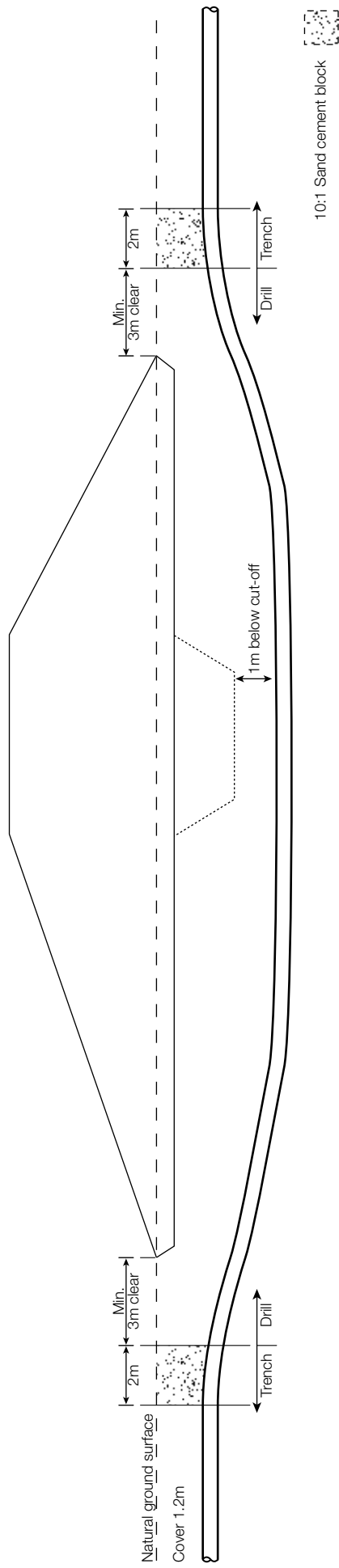
-  Graded filter sand
-  Compacted clay backfill
-  Concrete encased pipe through levee

Figure C-3
Placement of drilled pipeline under levee



Appendix D – Template for a Levee Management Manual

Levee owners/managers who do not currently have a Levee Management System (LMS) should prepare a Levee Management Manual (LMM) to document a formal procedure for the surveillance, operation and maintenance of the levee or levee system.

Levees and levee systems are essentially site specific and levee owners/managers range from individuals to local councils, each with different staffing and resources levels, and asset management tools and systems. As a result, each LMM will be different.

Useful references for guidance in compiling a LMM include:

- ANCOLD, 2003: Guidelines on Dam Safety Management, Chapters 4 and 5
- USACE, 2006: Levee Owner's Manual for Non-Federal Flood Control Works
- USDHS, 2012: Emergency Preparedness Guidelines for Levees
- CIRIA, 2013: The International Levee Handbook, Chapters 4, 5 and 6.

The manual should include 'as constructed' drawings of all components of the levee system. Where such drawings are not available, topographical surveys should be undertaken and record drawings compiled.

If the LMM is to be regularly accessed by multiple users in one or several organisations, it should also be a 'controlled' document, i.e. each modified version displays the revision date and approver on every page. A 'live' version of the document on an organisation's server or intranet is also another way to maintain a controlled document that is accessible to all staff. In such cases, the printed version is considered to be uncontrolled.

The manual's revision number and the name of the levee/levee system should be included on each page of the manual.

This template is provided as a guide for levee owners/managers to compile a LMM. It is not necessarily appropriate or complete for all levee systems and should be used with caution. The information should be modified as required, including adding information or sections as appropriate to the specific levee or levee system.

The template contains text insertions that are considered to be typical input that could be used in a LMM. Where specific information is considered to be required, the type of information is listed under the heading of 'SUGGESTED MANUAL CONTENT' in italics.

Example Table of Contents

Introduction

Asset description

Elements of the constructed system

Asset technical information

Inspection and maintenance program

Strategic maintenance

Operational maintenance

Record keeping

Management for operational readiness

Preparing a levee before a flood event

Levee operation during a flood event

Manual levee closure points

Locks and keys

Drainage

Inspections

Contingency planning

Record keeping

Levee inspection and follow up tasks after a flood event

Assessing levee performance after a flood event

Budgeting

Introduction

This manual describes the elements of the levee/levee system, including design/as-built drawings and specifications of the civil works, operating instructions for associated pump and drainage assets, and manufacturer information on repair and maintenance procedures and sources of parts for connected assets, where applicable.

It specifies the type, extent and timing of maintenance inspections, including the testing and repairing of all components associated with the levee system.

It also provides guidance on how the system should be managed immediately before, during and after a flood event. If required, the information should be in accordance with the requirements of the appropriate Municipal Emergency Management Plan (MEMP), and its sub-plans, particularly the Municipal Flood Emergency Plan (MFEP).

The manual is a 'live' document, a constant work-in-progress that is regularly updated as conditions change.

[SUGGESTED MANUAL CONTENT]

- *Full reference details of background studies for the levee/levee system.*
- *Full reference details of design report for the levee/levee system, and as-built drawings of levee system.*
- *Information on the location of all levee-related documentation.*
- *Levee/levee system construction details in terms of funding, proponent and contractor.*
- *Details on ownership of the land on which the levee/levee system is located.*
- *Contact details of owners and occupiers of properties protected by the levee/levee system.*
- *Details of level of protection (i.e. annual exceedance probability [AEP] and levels of design flood).*
- *Details on the management of the levee/levee system (including contact details for the levee/levee system manager).*

Asset description

Elements of the constructed system

[SUGGESTED MANUAL CONTENT]

Provide details of the levee/levee system including all relevant components. Some or all of the following may be relevant:

- *earthen embankments*
- *retaining walls*
- *flood control valves*
- *flood control pits*
- *retarding basins*
- *roadways*
- *drainage works*
- *pumping units*
- *trash grates*
- *crushed rock wearing surfaces*
- *locking systems*
- *temporary barriers (demountable barriers, drop bars, water bladders)*
- *sections requiring sandbags.*

Provide Figure showing the general arrangement and extent of the levee/levee system at a minimum of A3 size. The Figure may need to be more than one page for long levees/levee systems. Provide a cross reference to 'as constructed' survey information for the levee/levee system in an appendix to the manual

Asset technical information

[SUGGESTED MANUAL CONTENT]

Provide details of all system components and associated reference documents. Table 1 is a guide for what might be relevant but the elements in the table should be tailored to suit each specific levee/levee system.

Table: Flood protection system asset technical information

Element	Component descriptions	Reference documents
Earthen embankments	<ul style="list-style-type: none"> List each portion of the levee/levee system separately, with start and end chainages For each portion of the levee/levee system, state the level of protection Note any areas where spillways have been incorporated into the levee/levee system (i.e. chainage, level of protection, erosion protection) 	<ul style="list-style-type: none"> Flood studies of relevance Design report As-built drawing numbers Construction specification
Retaining walls	<ul style="list-style-type: none"> List each portion of the levee/levee system that consists of a retaining wall, with start and end chainages Detail the type of construction for each portion of the retaining wall For each portion of the retaining wall state the level of protection 	<ul style="list-style-type: none"> Flood studies of relevance Design report As constructed drawing numbers Construction specification
Flood control valves	<ul style="list-style-type: none"> List the location of all flood control valves with a specific chainage State the number, type and model of each valve 	<ul style="list-style-type: none"> As-built drawing numbers Construction specification Valve supplier documentation or maintenance manuals
Flood control pits	<ul style="list-style-type: none"> List the location of all flood control pits with a specific chainage List the dimensions of each pit List the outlet details for each pit 	<ul style="list-style-type: none"> As-built drawing numbers Construction specification
Retarding basins	<ul style="list-style-type: none"> List the location of all retarding basins with specific chainages State the level of protection for each retarding basin State the method of construction for each retarding basin 	<ul style="list-style-type: none"> Flood studies of relevance Design report As-built drawing numbers Construction specification
Roadways	<ul style="list-style-type: none"> List each separate portion of the levee/levee system that is a defined roadway For each roadway portion state the level of protection For each roadway portion state the pavement construction details 	<ul style="list-style-type: none"> Design report As-built drawing numbers Construction specification
Drainage works	<ul style="list-style-type: none"> List the location of all drainage works with a specific chainage List the inlet/outlet details for each location 	<ul style="list-style-type: none"> As-built drawing numbers Construction specification
Pumping units	<ul style="list-style-type: none"> List the location of all pumping units with a specific chainage State the number, type and model of each pumping unit 	<ul style="list-style-type: none"> As-built drawing numbers Construction specification Pump supplier documentation or maintenance manuals
Trash gates	<ul style="list-style-type: none"> List the location of all trash grates with a specific chainage Provide details of material type for each trash grate 	<ul style="list-style-type: none"> As-built drawing numbers Construction specification Maintenance information
Manual levee closure points	<ul style="list-style-type: none"> List the locations of all 'holes' in the levee/levee system with specific chainages Provide details of the type of 'hole' and the closure requirements 	<ul style="list-style-type: none"> As-built drawing numbers Construction specification Location of closure elements

Inspection and maintenance program

This section outlines tasks that should be undertaken within a strategic timeframe (every five years), operational timeframe (at least once every year) and during a flood event (*ad hoc* as required).

Strategic maintenance

To ensure the levee remains functional throughout its working life, the following should be undertaken every five years for Significant and High hazard classification levees and every 10 years for Low hazard classification levees:

- A survey of the levee crest and key features, undertaken by qualified surveyors, to identify any changes from the as-built drawings or previous survey results.
- A detailed visual audit of the system, undertaken by professional engineers with appropriate civil engineering, earthworks, concrete works, pipe laying and pumping experience, to identify areas of concern that could compromise the level of service of the levee if not addressed.
- A review of the asset management system to ensure that all requirements are achievable (documentation accessible, staff informed and trained, funding available, etc).
- A work plan developed and implemented to rectify any short-comings identified by the above, timed to ensure that identified maintenance, repair and renewal issues are completed and documented before the next survey and audit are due.

Operational maintenance

At the operational level, to ensure a levee remains in a constant state of readiness, the following should be undertaken at least once every year:

- Regular maintenance for each defined component of the levee/levee system, such as mowing of batters, checking and cleaning of drainage systems, testing of valves, pumps, etc, testing of demountable items (e.g. drop bars, gates), etc.
- A general visual inspection of the system once a year (as a minimum), undertaken by someone with experience in the techniques used in the construction of the levee and associated works.
- Follow-up activities on issues identified by the general visual inspection (e.g. removal of saplings, removal of rabbit burrows, repair of rilling and other weather erosion, repair of fencing, improved management of stock access, etc).
- Recording and entering into the asset management system of the above activities.

[SUGGESTED MANUAL CONTENT]

Where check lists have been developed, these should be located in one or more appendices to the manual as a guide to what tasks should be completed and when.

Record keeping

All design and construction records (studies, maps, design documents and drawings, construction reports, as-built drawings, etc) should be held in digital and/or hard copy format by the levee manager and should be readily available to relevant personnel and emergency services personnel as required.

All reports of activities (inspections, maintenance activities, check lists, defect reports, contingency plans, defect repairs, etc) should be logically filed, so that information can be easily retrieved and communicated internally or externally as needed, especially during flood events. It is important to ensure that, even with personnel changes, the knowledge built up over a number of years is not lost.

[SUGGESTED MANUAL CONTENT]

- *Provide design and construction records (studies, maps, design documents and drawings, construction reports, as-built drawings, etc) in an appendix to the manual or place a reference in the manual to the location(s) of these documents.*
- *Provide an appendix where records of maintenance works and repairs can be filed.*
- *Provide an appendix where the results of inspections can be filed.*
- *Provide an appendix where details of alterations to the levee/levee system can be filed.*
- *Provide an appendix where a photographic record of each flood event, referenced to date, time and flood level, can be filed for future reference.*

Management for operational readiness

This section provides guidance on the types of actions that should be undertaken in order to ensure the flood protection system is operationally ready to provide the designed level of protection during a flood event.

Preparing a levee before a flood event

When the owner/manager becomes aware that a flood event may be imminent, the following tasks should be completed:

- visually inspect the levee/levee system to ensure it is operational and identify any potential weaknesses or operational constraints
- ensure any flap gates/valves are clear and will not be jammed in an open or partially open position
- place and test pumps, drop bars and other temporary barriers, etc, and instructions re the timing or other triggers for operating pumps, closing gates, etc
- ensure adequate personnel and other resources are available to cover levee system management tasks before and during the flood
- put systems in place for the capture, documentation and exchange of information between the levee manager and emergency response agencies as required
- arrange for a levee/dam engineer to be on standby, if a large flood event is expected
- prepare for any additional actions listed in contingency plans.

The types of information that may be required include details of historic floods, the levels they reached at various locations, details of the areas at risk if a levee breach occurs, and the steps to be taken, requirements for the distribution of sand and sandbags, etc. Some of this information should already be included in the MFEP.

Levee operation during a flood event

Manual levee closure points

In some cases a levee/levee system may be constructed with one or more of 'holes' in it for stormwater drainage pipes. Also, portions of a levee/levee system may be omitted to provide access. Manual operation will be required to 'close the holes' at certain times during a flood event.

A difficult question to answer is WHEN to operate these elements. The following guidance will help ensure the efficient operation of the levee/levee system.

1. Monitor river levels closely to determine river level behaviour by using the following sources:
 - a) local gauges
 - b) water authority gauges
 - c) official forecasts of river heights issued by the Bureau of Meteorology.
 2. Install and/or test dedicated pumps or other drainage equipment at the highest priority location first. Equipment at other locations should then be installed/tested as needed depending on river level and rainfall predictions.
 3. Be mindful of any sandbagging requirements at nominated locations.
 4. Do not close drainage outfalls (if present) unless intolerable service conditions or property damage will be brought about by an imminent rise in river level.
 5. Immediately following the closure of any drainage outfall (where present).
 - a) pump the internal drainage line out to maximise the storage within the underground drainage system in the event of subsequent rain
- OR
- b) commence pumping in accordance with pumping priorities if rain is falling within catchment.
6. Be mindful of manual closure points and ensure they are closed in the correct sequence as and when warranted by river level predictions.

[SUGGESTED MANUAL CONTENT]

- Provide cross references to Table 1 for all known 'holes' in the levee/levee system.
- List the specific elements of the levee/levee system that require manual operation (e.g. locking systems, flood control valves, drop bars, demountable or temporary levee sections, sandbags, pumping units, etc).
- Provide instructions on the procedures for manual closure for each element (see following sub-sections).
- Provide details on the locations of items needed to effect the closures.

Locks and keys

[SUGGESTED MANUAL CONTENT]

- Provide details on the location(s) of keys for gates, padlocks or manual control equipment.
- Where relevant, if there is more than one key, use a key numbering system cross referenced to the individual components listed in Table 1.
- Have a sign out/sign in system for any keys associated with the levee/levee system

Drainage

[SUGGESTED MANUAL CONTENT]

- *Provide details of permanent pump stations next to the levee/levee system required for drainage.*
- *Provide details of areas where portable pumps are required for drainage next to the levee/levee system.*
- *Provide locations and operating details for any flap gates that require closing as flood waters rise.*
- *List the trigger river levels for the closure of flap gates, commencement of sandbagging, commencement of pumping, etc, as appropriate to the specific requirements of the levee/levee system.*
- *Provide operating instructions for manual closure elements such as flood control valves, drop bars, sandbagging operations and pumping units.*

Inspections

During a flood event, inspections should be scheduled at least daily. As the flood approaches the Design Flood Event level, inspections should be scheduled more often and responses effected within a few hours if there is a danger of breach or overtopping.

Where regular levee inspections during a flood event identify any signs of distress, these should be referred to an experienced levee/dam engineer. Where considered necessary, the levee/dam engineer should inspect the levee in question as soon as possible to determine if any emergency works are required to maintain the integrity of the levee and prevent failure or breach.

Contingency planning

If, despite other interventions, such as adding rows of sandbags to increase the height of a levee, overtopping appears imminent, the only response available is to inform those who will, or may, be affected to prepare or evacuate in accordance with the planning processes outlined in the MFEP and as agreed with the flood event Incident Controller.

A note of caution is required in relation to raising the level of protection for any levee (i.e. by using sandbags) without due regard to the effect on increasing the hydraulic gradient and, therefore, the potential for piping erosion through the foundation or the levee bank itself. The advice of an experienced levee/dam engineer should be sought before undertaking such measures.

Record keeping

Reporting of activities (inspections, maintenance activities, check lists, defect reports, contingency plans, defect repairs, etc) should be logically filed in accordance with Section 3.3 of this manual.

A photographic record of each flood event should be compiled, referenced to date, time and flood level. The photographic record should be filed in accordance with Section 3.3 of this manual.

Levee inspection and follow-up tasks after a flood event

After a flood event, even if the levee was not breached or overtopped, a thorough inspection should be scheduled as soon as practicable. Depending on resource availability, a comprehensive inspection may not be possible until clean up and recovery is well under way. In this case, a two-step approach should be undertaken, using a RAM (rapid assessment methodology) approach first, that would result in the scheduling of any interventions needed immediately, and an indication of the timing within which the comprehensive inspection should be undertaken.

Assessing levee performance after a flood event

Peak flood levels should be obtained as soon as practicable from the general area, along the water-side of the levee and at nearby gauging stations.

Any signs of distress in the levee system observed during the flood, such as concentrated leakage, slumps in the levee bank, sand boils or sinkholes should be documented. Record the precise location, extent, flow rate if applicable and details of any measures taken during the flood to address the issue.

A topographical survey to pick up maximum water levels and key features may be required.

A review of the levee performance against expectations should be investigated and documented. A key assessment is whether the levee freeboard was compromised, for example the flood magnitude that occurred was below the design event.

A photographic record of the flood event referenced to date, time and flood level should be compiled and filed in an appendix to the manual for future reference. Consideration of new civil works may be required if the required level of protection is no longer provided or structural deficiencies in the levee or foundation have been identified.

Other matters to consider helping with this assessment are:

- Coordinating discharge measurements at key locations, including relevant gauging stations and floodways that pass strategic locations.
- Data from flood studies, design and historic flood profiles and estimated discharge rates.
- If works and buildings have been constructed at inappropriate locations since the levee was design or implemented.

Budgeting

To ensure a levee is able to consistently meet its required level of service, due diligence in financial planning is just as important as the management of the physical asset. The owner/manager needs to ensure that enough funding has been budgeted, and is available as and when needed, to undertake all maintenance tasks, as well as repair and upgrade works (if required).

The goal of asset management is to meet a required level of service in the most cost-effective way through the creation or acquisition, operation and maintenance, renewal and disposal of assets to provide for present and future communities. The life cycle approach is central to asset management by taking account of the total cost of an asset throughout its life. A better service, not a better asset, is a key indication of successful asset management.

Appendix E – Potential modes of levee failure

The following information is presented to help levee owners/managers identify problems that could arise in and around levees and may cause them to fail by breaching. The possible cause and potential consequences are indicated, and appropriate action recommended.

While a number of the conditions described in the following tables can be corrected by routine and periodic maintenance by the owner, a significant proportion of the conditions threaten the safety and integrity of the levee and require the attention of an experienced levee or dam engineer. Prompt corrective action will promote the safety and extend the useful life of the levee, while possibly preventing costly future repairs.

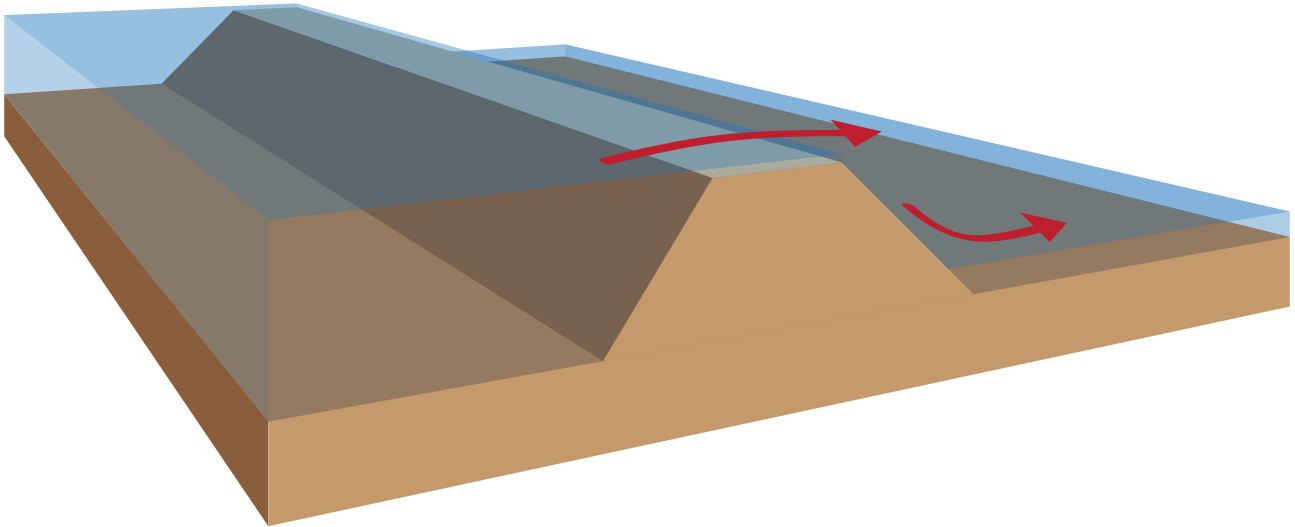
It is not possible to cover all the problems that might arise; this appendix includes only the more common problems.

As a general rule, if owners have any concerns they should obtain advice from an experienced levee or dam engineer.

USACE, 2006 and CIRIA, 2013 (Chapter 6) provide useful references for emergency actions to prevent levee failure.

Overtopping

Problem: Floodwater overtopping the embankment



Possible causes

1. Floodwater height exceeding the top of the levee. Can be due to a flood in excess of the design flood level or settlement of the levee.

Harm

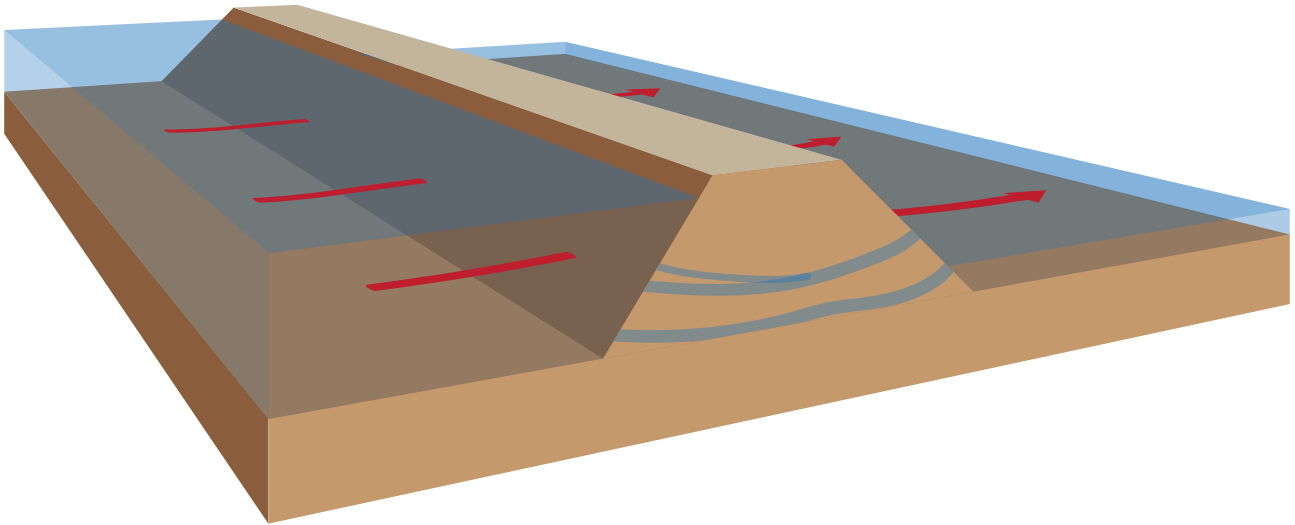
1. Overflows can lead to erosion of the embankment material and failure of the levee.

Action required

1. Minimise overflow through placement of sandbags before levee overtops.
2. If possible, open drains under levee to permit protected area to flood in a controlled manner
3. Evacuate land-side landholders who are likely to be affected if flows and escaping materials are not stabilised.
4. Monitor overflows from a position of safety. Do not enter floodwater.
5. An experienced levee or dam engineer should immediately inspect the condition and recommend further action to be taken.

Seepage

Problem: Seepage water exiting from a point on the embankment's land-side batter



Possible causes

1. Rabbits, yabbies, rotting tree roots, settlement or shrinkage cracks or poor construction have allowed water to create an open pathway or pipe through the embankment.
2. The water is eroding and carrying away embankment material in one or more concentrated locations causing a seepage path directly through the embankment.

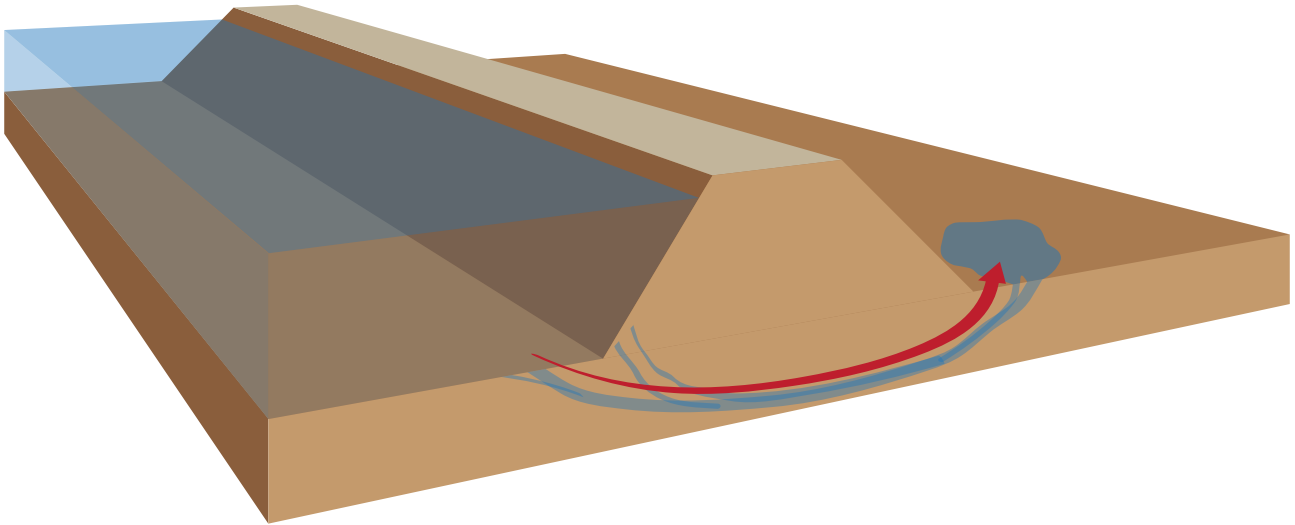
Harm

1. Continued flows can saturate portions of the embankment and lead to slides in the bank which could cause failure of the levee.
2. Continued flows can further erode embankment materials. This can lead to a piping failure of the levee.

Action required

1. Stake out the saturated area and monitor wet area for growth.
2. Begin measuring outflow quantity and establishing whether water is getting cloudier, staying the same or clearing up, and whether the rate of flow is increasing or not.
3. If soil particles are moving downstream, sandbags or earthfill should be used to create a bank around the seepage. Do not excavate near the toe of the levee for the earthfill installation. The back pressure caused by the water level within the bank may control flow velocities and temporarily prevent further erosion or at least reduce the rate of erosion.
4. Alternatively, backfill the seepage area and adjacent bank and toe with a permeable rockfill or gravel lined with a geotextile.
5. Search for an opening on the upstream side and plug it if possible. From a safe position. Hay bales, as well as a combination of dumped rockfill, geotextile, sand and gravel, can limit inflow. Plastic sheeting weighted down with sand bags and rockfill can also be used.
6. Evacuate downstream landholders who are likely to be affected if flows and escaping materials are not stabilised.
7. An experienced levee or dam engineer should immediately inspect the condition and recommend further action to be taken.

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



Possible causes

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

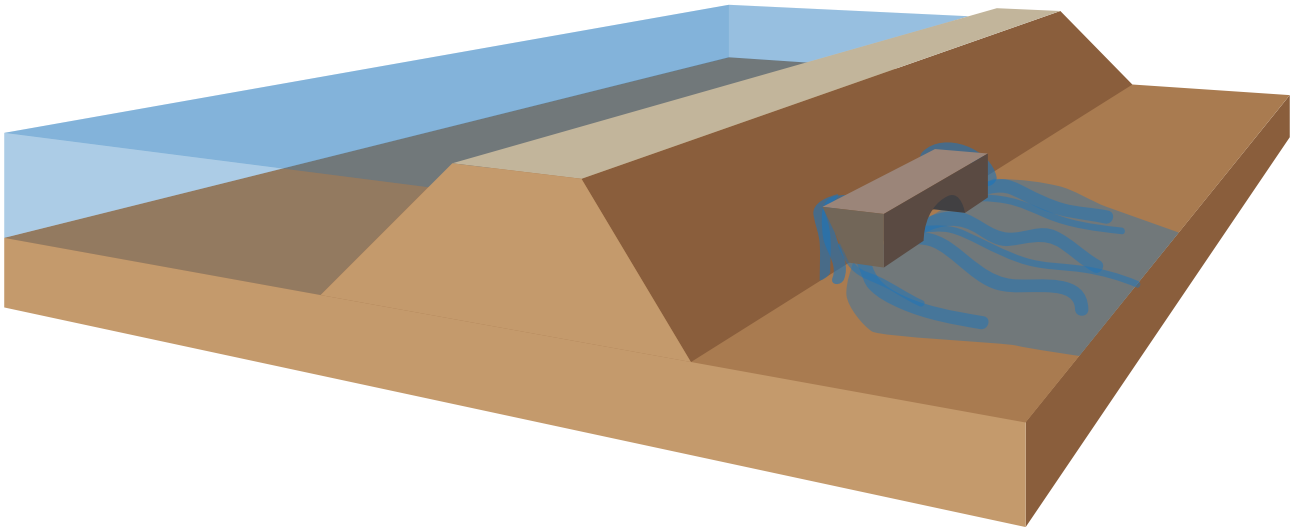
Harm

1. Increased flows can lead to erosion of the foundation and failure of the levee.

Action required

1. Examine the boil for transportation of foundation materials.
2. If soil particles are moving downstream, sandbags or earthfill should be used to create a bank around the boil. Do not excavate near the toe of the levee for the earthfill installation. The back pressure created by the water level within the bank may control flow velocities and temporarily prevent further erosion or at least reduce the rate of erosion.
3. Alternatively, backfill the seepage area and adjacent bank and toe with a permeable rockfill or gravel, lined with a geotextile.
4. Evacuate downstream landholders who are likely to be affected if flows and escaping materials are not stabilised.
5. A suitably qualified levee or dam engineer should immediately inspect the condition and recommend further action to be taken.

Problem: Seepage water exiting from a point adjacent to a pipe through the embankment



Possible causes

1. Fracture or joint failure in pipe.
2. A path for flow has developed along the outside of the pipe (poor construction).

Harm

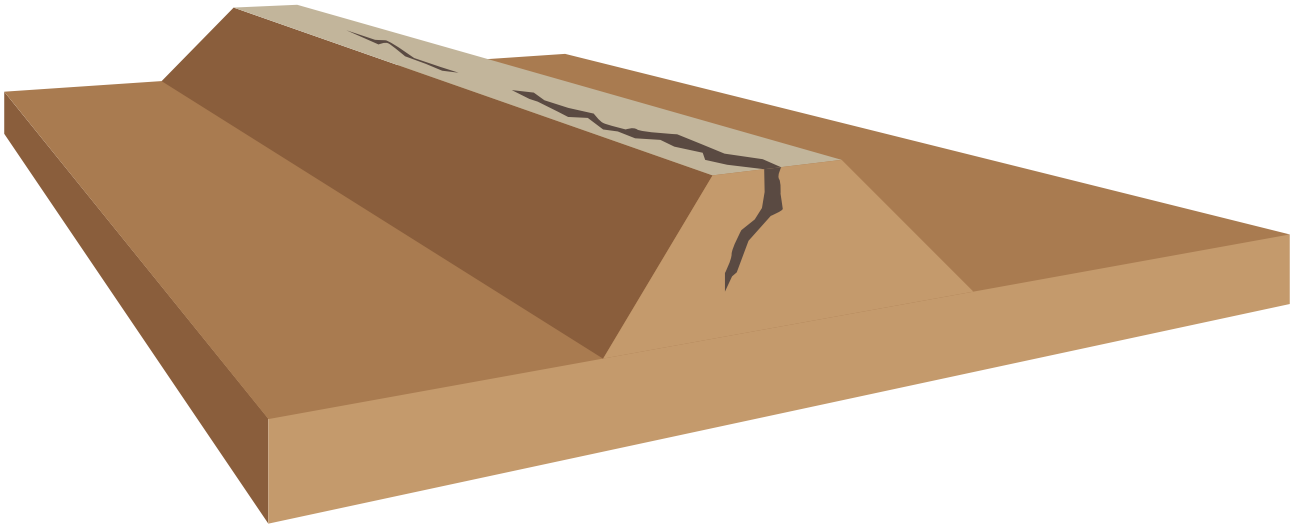
1. Continued flows can lead to rapid erosion of embankment materials and failure of the levee.
2. Can be difficult to stop once it progresses beyond a seep.

Action required

1. Thoroughly investigate the area by probing to see if the cause can be determined.
2. Determine if leakage water is carrying soil particles and monitor flow rate changes.
3. If soil particles are moving downstream, sandbags or earthfill should be used to create a bank around the seepage. Do not excavate near the toe of the levee for the earthfill installation. The back pressure caused by the water level within the bank may control flow velocities and temporarily prevent further erosion.
4. Alternatively, backfill the seepage area and adjacent bank and toe with a permeable rockfill or gravel, lined with a geotextile to create a seepage berm.
5. Evacuate downstream landholders who are likely to be affected if flows and escaping materials are not stabilised.
6. An experienced levee or dam engineer should immediately inspect the condition and recommend further action to be taken.

Cracking, deformation and movements (even if not associated with seepage or leakage of water)

Problem: Longitudinal cracking



Possible causes

1. Drying and shrinkage of surface material.
2. Downstream movement or settlement of embankment.
3. Differential drying out of embankment materials (between shoulder and 'core').

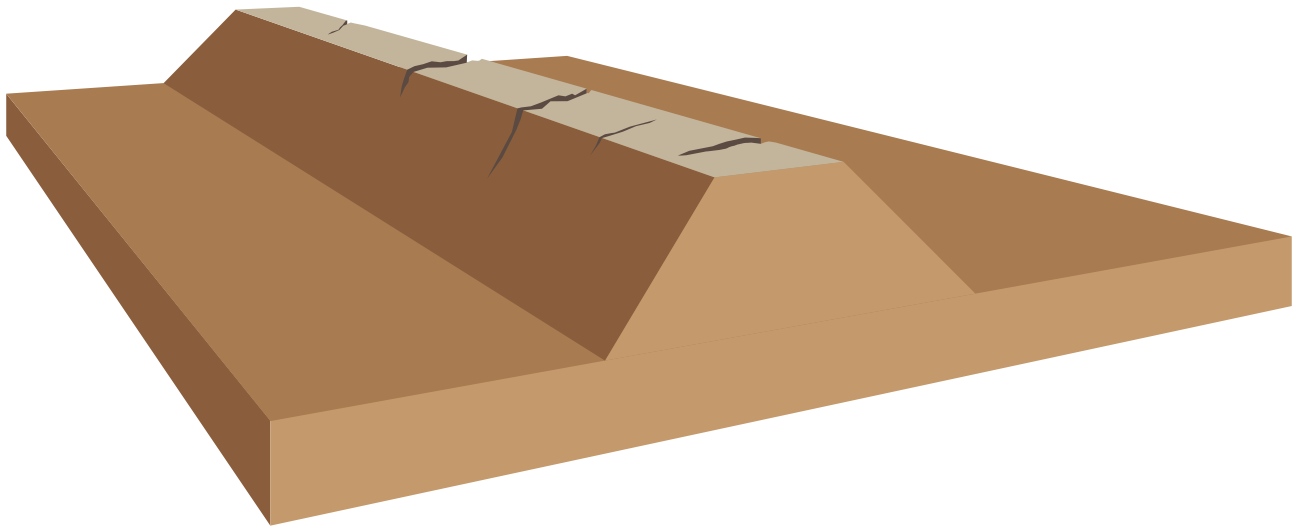
Harm

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.

Action required

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, an experienced levee or dam engineer should inspect the condition and recommend further action to be taken.

Problem: Transverse cracking



Possible causes

1. Drying and shrinkage of surface material is most common cause.
2. Differential settlement of the embankment also leads to transverse cracking.

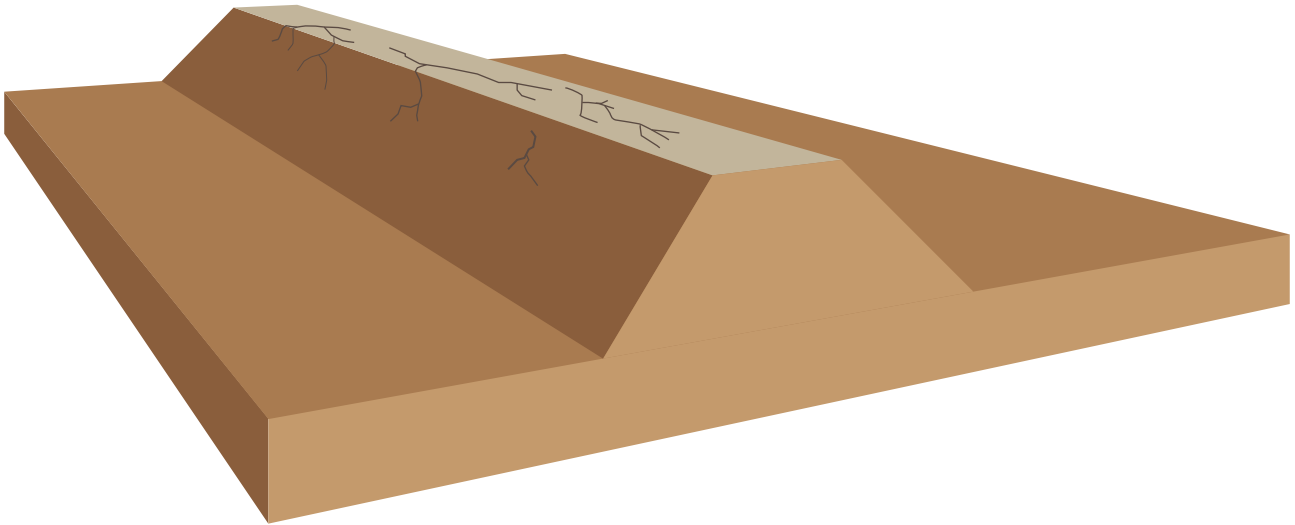
Harm

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 water through the levee causing erosion and failure.

Action required

1. If necessary, plug upstream end of crack to prevent flow.
2. Clean up cracks and backfill with compacted material. If cracks are extensive, or growing in length, width or number, an experienced levee or dam engineer should inspect the condition and recommend further action to be taken.

Problem: Cracking due to drying (random pattern)



Possible cause

1. The soil loses its moisture and shrinks, causing cracks.

Harm

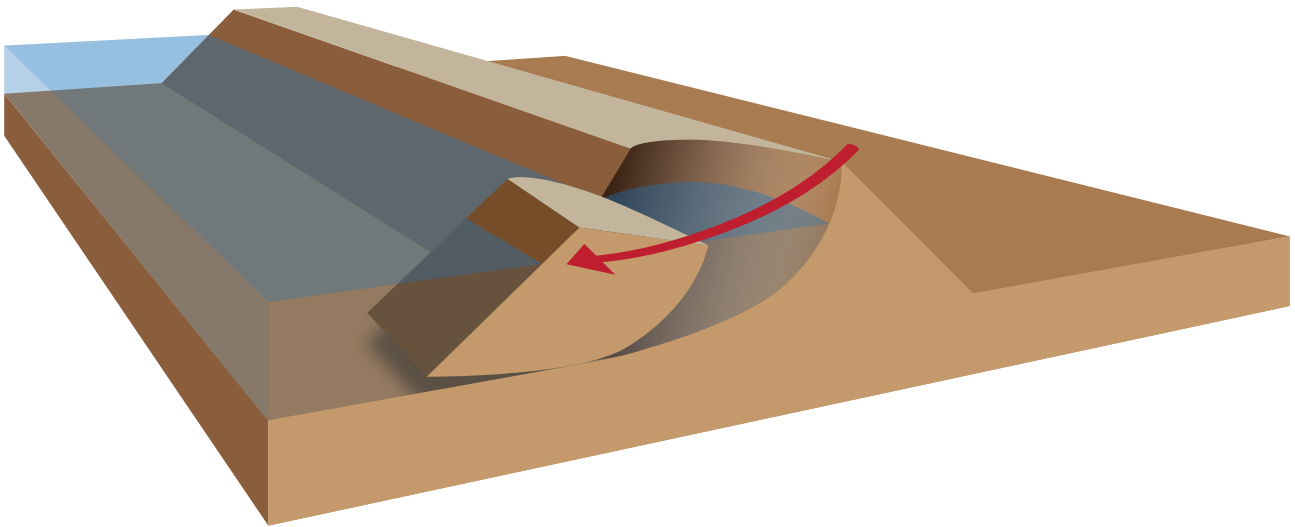
1. Heavy rains can fill up cracks, soften the soil and cause small portions of embankment to move along internal slip surfaces.
2. Provides points of entrance for surface runoff, leading to deterioration of the crest and/or batters.

Action required

1. Monitor cracks for increases in width, depth or length.
2. On crest, seal surface cracks with tight, impervious material.
3. Routinely grade crest to provide proper drainage and fill cracks while maintaining crest height.
4. Cover crest with with non-plastic (not clay) material to prevent large moisture content variation with respect to time.
5. An experienced levee or dam engineer should inspect the condition and recommend further actions to be taken.

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

Problem: Slide, slump or slip



Possible causes

1. Lack 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 the slope along a slippage surface because they were on too steep a slope or the foundation moves.
4. Slumping after flood levels have dropped rapidly due to a build up of pressure in the embankment.

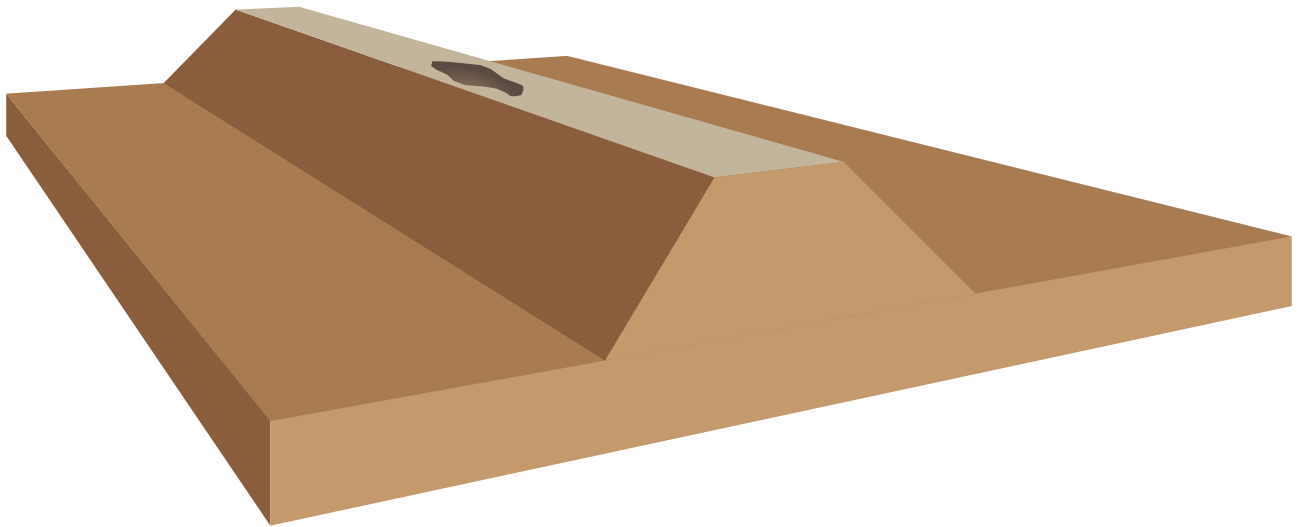
Harm

1. A slide can reduce the levee's seepage path. This can accelerate the rate of seepage and lead to loss of material.
2. A series of slides can lead to failure of the levee.

Action required

1. Evaluate extent of the slide if safe to do so.
2. An experienced levee or dam engineer should inspect the condition and recommend further actions to be taken.

Problem: Sinkhole in crest or upstream slope



Possible causes

1. Internal erosion or piping of embankment material by seepage.
2. Breakdown of dispersive clays within embankment by seepage waters or rain.
3. A hole in transverse pipe is causing erosion of embankment material.
4. Rodent activity.

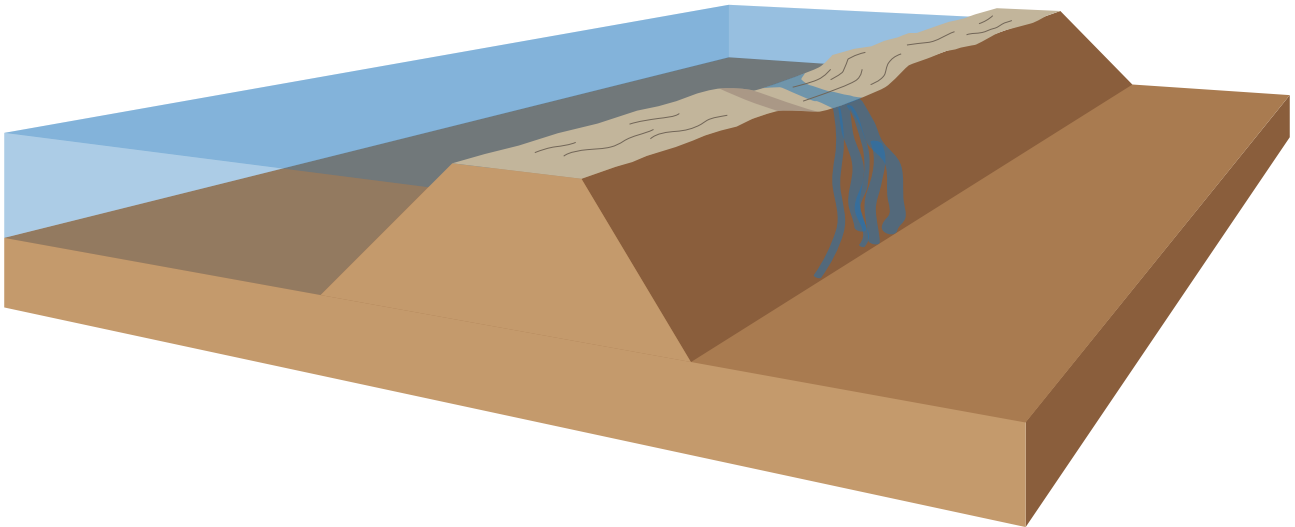
Harm

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

Action required

1. Carefully inspect and record location and physical characteristics (depth, width, length) of sinkhole.
2. An experienced levee or dam engineer should determine cause of sinkhole and supervise all steps necessary to reduce threat to levee 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.

Problem: Low area or dip in crest



Possible causes

1. Excessive settlement in the embankment or foundation directly beneath the low area in the crest.
2. Vehicle access across the levee.
3. Internal erosion of embankment material.
4. Foundation spreading in upstream and/or downstream direction.
5. Wind erosion of crest area.
6. Improper final grading following construction.

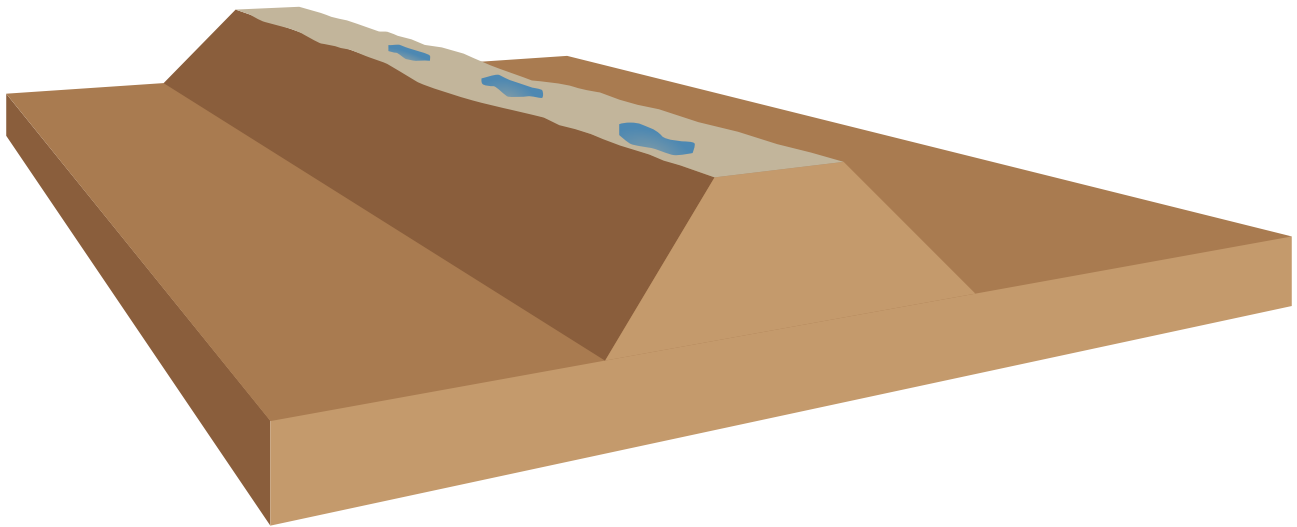
Harm

1. Reduces freeboard available to pass flood flows safely and increases risk of levee overtopping and failure.
2. Concentrates rainfall runoff and could lead to puddling (see next potential failure mode).

Action required

1. Determine exact amount, location and extent of settlement in crest.
2. An experienced levee or dam engineer should determine cause of low area and supervise all steps necessary to reduce possible threat to the levee and correct condition.
3. Re-establish uniform crest elevation over crest length by placing fill in low area using proper construction techniques. An engineer should supervise this.

Problem: Puddling on crest – poor drainage



Possible causes

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

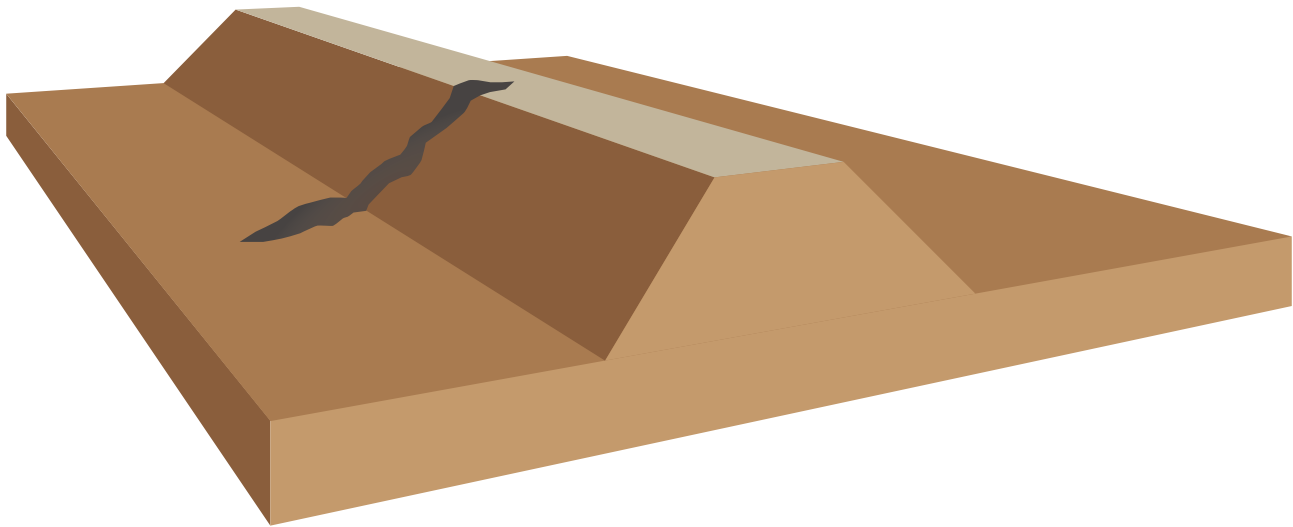
Harm

1. Causes localised saturation of the crest and loss of soil strength.
2. Inhibits access to all portions of the levee and crest.
3. Becomes progressively worse if not corrected.

Action required

1. Drain standing water from puddles.
2. Re-grade and re-compact crest to restore integrity and provide proper drainage.
3. Provide gravel or road-base material to accommodate traffic.
4. Perform periodic maintenance and re-grading to prevent reformation of low areas.

Problem: Erosion gully on crest and upstream or downstream slope



Possible causes

1. Heavy rainfall.
2. Poor grading and improper drainage of crest. Improper drainage causes surface runoff to collect and drain off crest at low point in upstream or downstream shoulder.

Harm

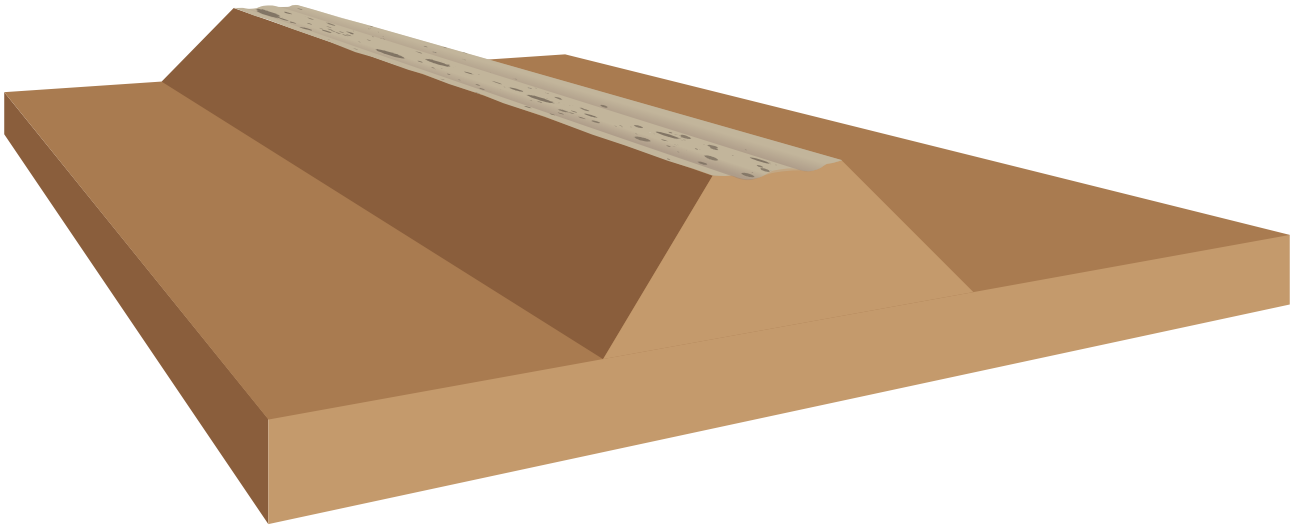
1. Can reduce available freeboard.
2. Reduces cross-sectional area of levee.
3. If allowed to continue, can lead to severe deterioration of slope and shorter internal drainage path.

Action required

1. Protect eroded areas with graded rock or clay.
2. Re-grade crest to provide proper drainage of surface runoff.
3. Re-establish protective cover.

Miscellaneous

Problem: Ruts along crest



Possible cause

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

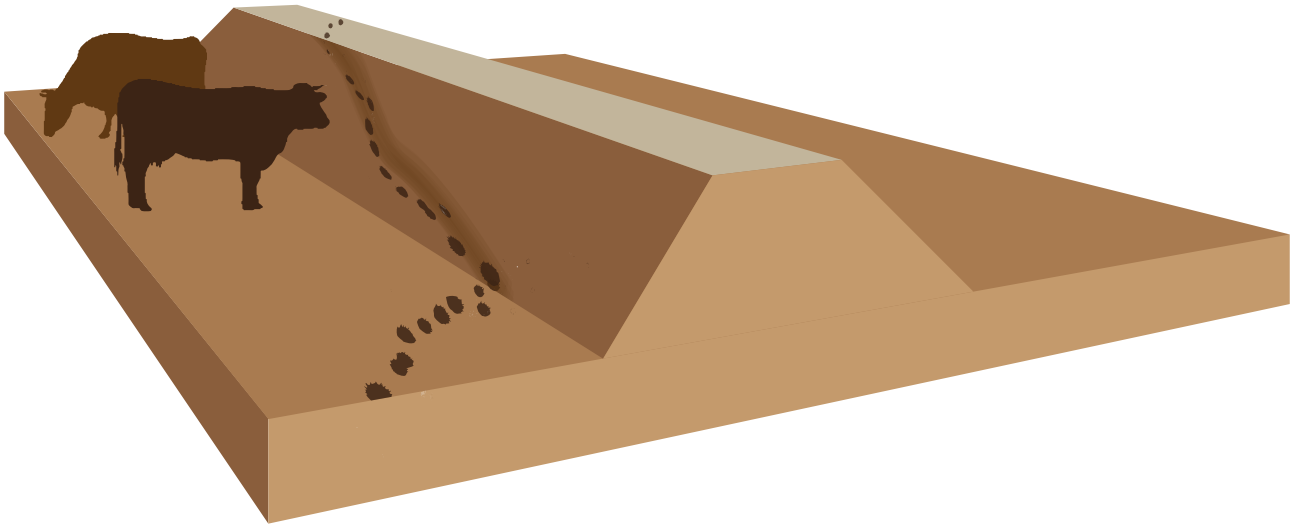
Harm

1. Inhibits easy access to all parts of crest.
2. Allows continued development of rutting. Allows standing water to collect and saturate crest of levee. This may initiate localised tunnel erosion through to downstream slope, particularly where cracking is present.
3. Loss of soil strength in embankment.
4. Vehicles can get stuck.

Action required

1. Drain standing water from ruts.
2. Re-grade and re-compact crest and provide proper drainage.
3. Provide gravel or road-base material to accommodate traffic.
4. Perform periodic maintenance and re-grading to prevent reformation of low areas.

Problem: Livestock traffic



Possible cause

1. Excessive travel by livestock especially harmful to a slope when wet.

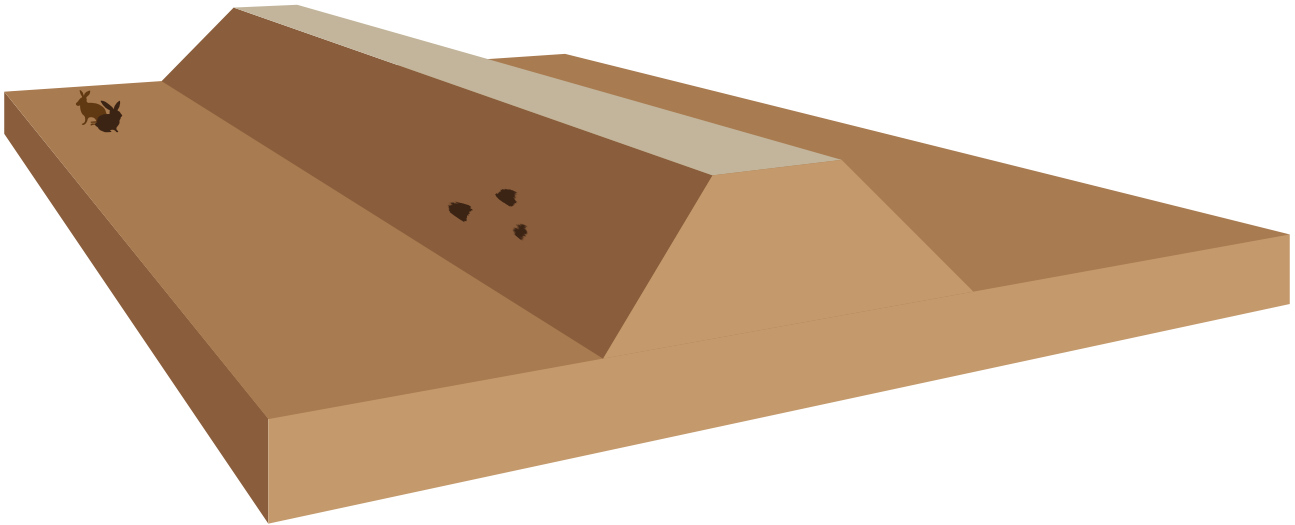
Harm

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

Action required

1. Fence livestock outside embankment area.
2. Repair erosion gully.
3. Re-cover with grass for protection.

Problem: Pest animal activity



Possible causes

1. Over-abundance of animal pests.
2. Favourable habitat or burrowing conditions in levee.

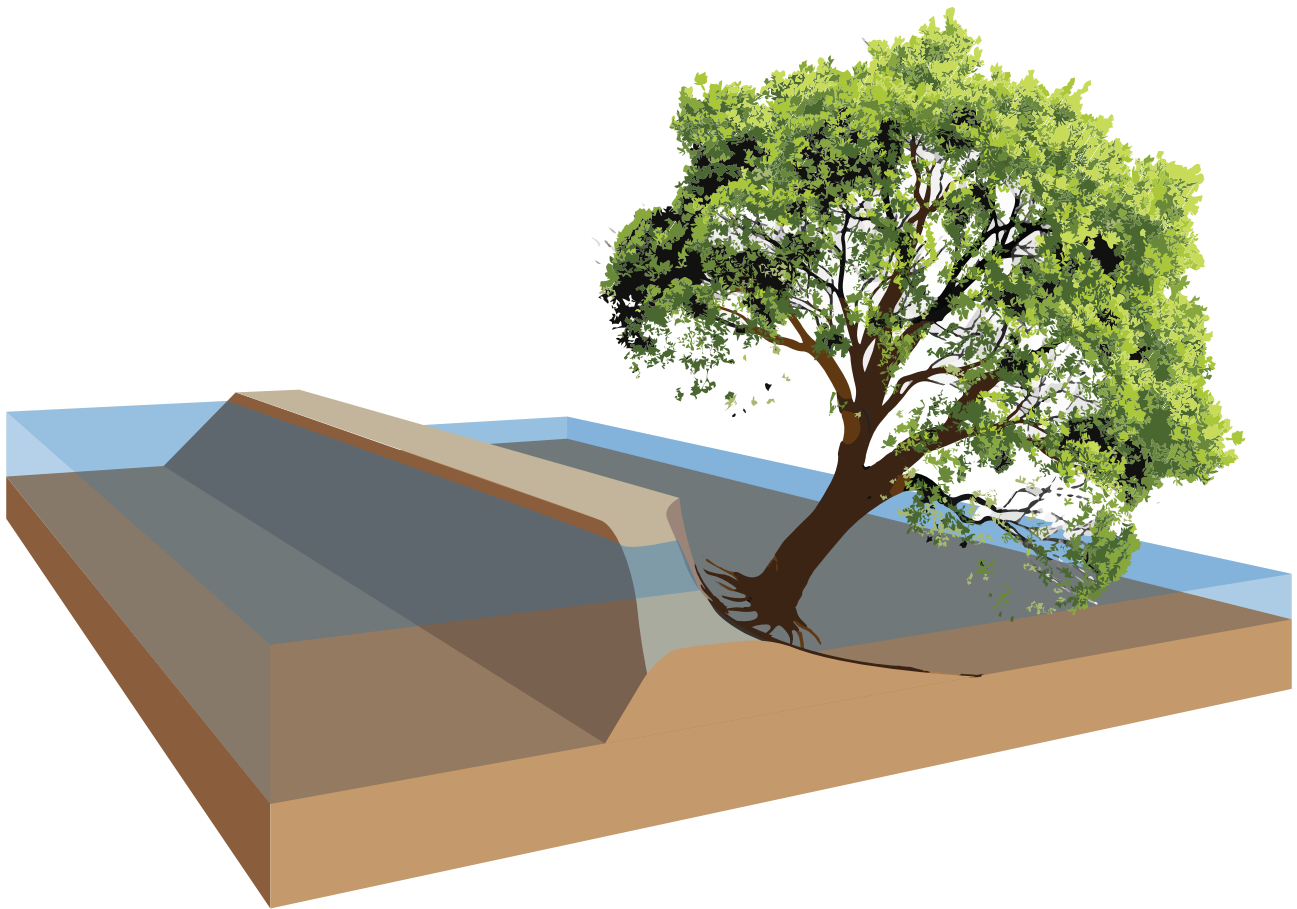
Harm

1. Burrows can substantially reduce length of leakage path, leading to piping failure.

Action required

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.

Problem: Vegetation



Possible causes

1. Natural vegetation (self sown).

Harm

1. Large trees 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.

Action required

1. Remove large, deep-rooted trees and shrubs on embankment. Need to monitor the levee to ensure this doesn't lead to the formation of leakage pathways along decaying tree roots that may initiate piping erosion.
2. Properly backfill void left by tree stump with compacted earthfill.
3. Control all other vegetation on the embankment that obscures visual inspection.

Glossary

Australian National Committee on Large Dams (ANCOLD): A membership organisation of individuals and organisations concerned with the ownership, management, design, construction, operation and maintenance of dams in Australia. ANCOLD has produced a number of guideline documents to assist in promoting appropriate dam safety management practices in Australia.

Annual Exceedance Probability (AEP): The likelihood of the occurrence of a flood of a given or larger magnitude occurring in any one year, expressed as a percentage.

Cut-off: An impervious barrier of material to prevent seepage flows along structures such as pipelines through or beneath a levee. Typically, a trench backfilled with compacted clay fill for embankment levees or concrete for floodwalls. Concrete collars around pipes were also referred to as cut-offs but are no longer recommended.

Dam engineer: A professional engineer who is suitably qualified and recognised by the engineering profession as experienced in the engineering of dams.

Defined flood event (DFE): The flood event selected for the management of flood hazard.

Dispersive clay: A clay soil (or clay component of a soil) whose micro-particles break apart (or disperse) in contact with water in certain circumstances. Such clays occur in many parts of Victoria (also in other States). Dispersive soils in levee embankments or foundations increase the likelihood of piping failure of the levee unless appropriate measures are taken.

Emergency: In terms of levee operation, any condition that develops naturally or unexpectedly, endangers the integrity of the levee and adjacent life or property, and requires immediate action.

Filter: A granular, cohesionless material consisting of sand or a sand/gravel mixture that permits the drainage of water but retains finer soil particles. The size and gradation of the filter material depends on the grading of the material being protected by the filter. Typically, a filter for an earthfill embankment consists of a washed sand.

Flood: Water overflowing the normal confines of a stream or other body of water, or the accumulation of water by drainage over areas that are not normally submerged.

Flood event: A flood incident or situation in a particular place during a particular interval of time. This may be an historical event that is later usually referred to as the <date-location> flood event, or it may be a modelled statistical event that is referred to as the <X% AEP> flood event.

Floodplain: The low-lying land bordering a watercourse (creek, river, lake, sea coast or artificial channel) that conveys or stores floodwaters.

Flood hazard: The potential for loss of life, injury and economic loss as a result of a future flood event. The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, rate of rise of floodwaters, duration), topography and emergency management.

Flood risk: The potential risk of flooding to people, their social setting, and their built and natural environment. The degree of risk varies with circumstances across the full range of floods. Flood risk is divided into three types – existing, future and residual.

Existing flood risk refers to the risk a community is exposed to as a result of its location on the floodplain.

Future flood risk refers to the risk that new development within a community is exposed to as a result of developing on the floodplain.

Residual flood risk refers to the risk a community is exposed to after treatment measures have been implemented. For example: a town protected by a levee, the residual flood risk is the consequences of the levee being overtopped by floods larger than the design flood; for an area where flood risk is managed by land-use planning controls, the residual flood risk is the risk associated with the consequences of floods larger than the DFE on the community.

Freeboard: Freeboard is an additional height allowance used in the design of levees to cover variables inherent in that design. It is a safety factor typically used in relation to the setting of floor levels, levee crest heights and so on. Freeboard compensates for a range of factors, including wave action, localised hydraulic behaviour and levee settlement, all of which increase water levels or reduce the level of protection provided by levees. Freeboard should not be relied upon to provide protection for floods that are bigger than the relevant design flood event.

Hydraulic gradient: The difference in water pressure in metres head divided by the length in metres of its potential flow path. For an embankment levee, the maximum hydraulic gradient in the levee foundation is the height of the levee divided by the base width of the levee.

Internal erosion: The movement of soil particles as a result of seepage forces and or chemical reactions produced by percolating water.

Land-side: The side of a levee away from the water, i.e. the side being protected by the levee. The opposite of 'water-side'.

Levee: A raised, predominantly earthen structure that is not reshaped under normal conditions by the action of waves and currents, whose primary objective is to provide protection against flooding. Levees form part of flood defence systems that may also include flood walls, pumping stations, gates, closure structures, natural features, and other associated structures.

Levee engineer: A professional engineer who is suitably qualified and recognised by the engineering profession as experienced in the engineering of levees.

Level of Protection: The maximum flood event that a levee, with a high level of assurance, can accommodate without failure and the inundation of the protected area. It is usually associated with an Annual Exceedance Probability (AEP) and also referred to as design flood event (DFE).

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

Monitoring: Recording of data from measuring devices and visual observations to check the performance and behavioural trends of a levee and associated works/services.

Optimum Moisture Content: The water content at which the maximum dry density of a soil is obtained for a specific effort of compaction. In the case of a particular soil, the Optimum Moisture Content is defined by a standard laboratory test. The appropriate Australian standard is AS 1289.5.1.1.

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

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

Piping: The creation of flow channels within a levee or its foundation as a result of seepage and the progressive erosion of soil particles. The initial seepage is usually initiated by cracks or other high permeability features and the flow increases as the soil is progressively eroded.

Piping failure: The resulting failure of a levee due to the progression of the internal piping erosion resulting in a breach of the levee and the uncontrolled release of floodwater into the area protected by the levee

Remedial work: The work required to repair, strengthen, re-construct, improve or modify an existing levee, appurtenant works, foundations, or surrounding area to reduce the risk of failure.

Seepage: The exit of retained water by percolation through, under or around a levee.

Storage capacity: The volume of water that can be temporarily stored by a floodplain to be later discharged as the flood recedes. Developments tend to place obstructions on a floodplain, which decreases storage capacity, alter flow paths and increase flow rates, thus increasing the severity of floods both upstream and downstream of the development.

Water-side: The side of a levee towards the water against which the levee is providing protection. Also known as the 'river-side', it is the opposite of 'land-side'.

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