Public Works Advisory

Levee Owner's Guideline

for NSW Flood Levee Systems

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AGENCY TERMINOLOGY

Where referred to throughout this document:

- Public Works Advisory (PWA) of the Department of Regional NSW was formerly known as NSW Public Works
- Environment, Energy and Science (EES) of the Department of Planning, Industry and Environment was formerly known as Office of Environment and Heritage
- Resilience NSW was formerly known as Ministry of Police and Emergency Services

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This methodology supersedes the methodology outlines in the PWA report DC13140 of 2015. This update considers lessons learnt, improved practices and changes in technology since the previous version of the methodology was released.

A levee generally involves an embankment and related infrastructure. It is an important asset that protects the community and its infrastructure from flooding up to the levee's design flood event, reducing the frequency of damage due to flooding to a rare event. It can only do this if the levee is well designed with adequate capacity to resist sizable floods, and is properly built, maintained and operated. Levees that were originally poorly constructed or upgraded, or were not well maintained may fail prematurely. Any levee will, however, have limitations in terms of reducing rather than eliminating the risk of flooding to the community. Floods higher than the design event may result in the levee being overtopped or failing with consequent impacts upon the community. This is contrary to public perception that a levee will protect the community from any flood event, no matter how large.

In NSW there are more than 110 levees protecting urban communities with an aggregate length in excess of 350 km. The levees are managed for the protection of the communities principally by Local Government Agencies, with a smaller number by Land Councils and State Government Agencies. This represents a sizable asset for NSW.

The owner of a levee has responsibility to ensure their levee is fit for purpose, is well maintained and able to operate during a flood event. In addition, the owner has responsibility to ensure information on the levee and its operation are readily available to inform decision making in government, including land use planning, flood risk management and emergency response. This information is needed well in advance of a flood to manage development behind the levee and develop plans on how to respond to flood emergencies. The use of outdated information, which may no longer accurately reflect the levee's "safe" capacity, has the potential to put the community at additional risk in terms of emergency response to flood events.

When a flood emergency occurs, there will usually be insufficient time to undertake properly engineered repairs, remedial or strengthening works if there are inherent problems with the levee. Weather and ground conditions may also not be ideal for these works. Additionally, up to date key information on the levee will be needed immediately by Emergency Services responders for critical decision making. Where there is a significant change in condition or a lack of information, conservative decisions would be needed, such as the early evacuation of towns.

There are very few specific Australian guidelines or information on the design, construction and operation of levees. Manuals of practice originating from the United States and Europe do not directly translate well to Australia due to the disparity in their size and construction, and the frequency of flooding experienced.

This guideline has been specifically prepared for NSW levees and draws on best international practice experience from US Army Corps of Engineers Manuals and the International Levee Handbook. It is provided as part of the technical support provided to Local Government under the NSW Flood Prone Land Policy.

The purpose of this guideline is to provide general guidance for levee owners in NSW on the basis of what needs to be undertaken to ensure the ongoing successful operation of their levee during a flood event. This will maximise the benefits provided by a levee in protecting the community from the impact in flooding and assist in reducing the State's risk from flooding. The guidelines aims to give sufficient background information on Levee characteristics within a NSW context to

The manual is intended to be used by appropriately qualified and experienced technical staff of the levee owner.

When using these guidelines, it must be understood that each levee is different and there will be individual circumstances to consider for each levee. This guideline provides only general guidance for levee owners and managers and does not replace professional judgement. The guidelines are not intended to be used as a levee design manual.

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- NSW State Emergency Service.
- Stakeholders at the NSW Floodplain Managemeent Association 2014 Conference, Deniliquin.

1. INTRODUCTION

1.1 Background

The primary objective of the NSW Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods. Primary responsibility for floodplain risk management for communities rests with Local Government. Financial and technical support is provided to Local Governments by the State Government, through Environment, Energy and Science of the Department of Planning, Industry and Environment (EES) for the development and implementation of floodplain risk management plans. The NSW State Emergency Service (SES) is the State's Flood Combat Agency and leads the development of local flood plans (LFP), which are emergency management plans dealing with flood events.

Many urban communities in NSW are protected, to an extent, from flood impact by levees, which generally involve an embankment and related infrastructure. The majority of levees are owned and managed by Local Government. However, a small number are owned and managed by the State Government (Hunter Valley Flood Mitigation Scheme) and by Aboriginal communities.

A well-engineered and maintained levee is an important asset that can reliably protect the community and its infrastructure from external flooding, up to the levee's design flood event. Larger floods than the design flood event would be expected to result in the levee overtopping or failing with associated impacts upon the community protected by the levee.

In NSW, there are varying levels of adequacy and condition of levees.

There is no single over-riding legislative requirement specifically covering levee systems, comparable, for example, to dams that are regulated under NSW's Dams Safety Act 2015, setting out requirements such as design, monitoring and inspection regimes.

1.2 Purpose of Guideline

This guideline is intended for use by those responsible for maintaining, monitoring and operating levees in NSW (levee owners). It provides information of a general nature on the basics of levees and levee management. This forms part of the State's continuing technical support for levee owners to assist improvement in the knowledge of levees, their capabilities and limitations. This will ultimately lead to an improvement in the management and condition of levees in NSW, the sharing of knowledge on levee conditions and the consideration of condition in government decision making.

Levee owners should only apply this guideline:

- With reference to:
  - the levee owner's statutory and common law obligations.
  - any applicable owners' operations and maintenance manuals.
  - applicable engineering standards.
  - flood investigations.
  - the procedures of NSW emergency management combat agencies, specifically the SES.
  - any other requirements applying generally to levees or to a specific levee.
- With the advice of qualified professional advisors (including technical advisors).

The guidelines assist levee owners to:

- Develop a levee owner's manual for their levee, by identifying the information needed to inform strategic management of a levee.
- Develop an understanding of the capacity of the levee based upon recent design or other engineering reports that provide a current reliable flood operating level.
- Share knowledge on levee condition to inform government decision making.
- Understand how this information is used in emergency response planning.

Exclusions:

This Guideline does not constitute design advice.

It does not alter or affect the legal obligations of levee owners to maintain levees.

In particular, and to avoid doubt, adherence to this guideline does not guarantee that a levee owner has complied with or discharged its legal obligations.

1.3 Outline of the Guideline

The Guideline covers the following:

- Section 2 – An overview of levees in NSW.
- Section 3 – Levee owner's responsibilities relating to due diligence requirements, e.g. Operations and Maintenance (O&M) activities, communications.
- Section 4 – Basic principles, covering types of levees in NSW, basic design principles, gauge levels and flood slopes, flood operating level and Interim Flood Confidence Limit.
- Section 5 – Levee Owner's Manual.
- Section 6 – O&M requirements, covering documentation and records management, inspections required and maintenance program.
- Section 7 – Communication plan to share knowledge and make sure everyone knows when significant changes to the levee occur.
- Section 8 – Emergency response planning.

2. NSW LEVEES

2.1 Development History of NSW Levees

While a few levees were constructed prior to 1950, levee construction in NSW on a wider scale was undertaken in the 1950s and 1960s following a series of major floods affecting coastal and inland townships in many areas of NSW.

The majority of the early levees constructed, which still constitute the majority of existing Urban Levees in NSW, were not originally "engineered" when first constructed. They were constructed and sometimes "topped up" prior to an impending flood event using any material and construction equipment that was available, with no detailed design or little quality control of material selection, foundation preparation or compaction.

As a consequence, where levees have not subsequently been subject to a properly engineered upgrade, they may have a range of problems, including poorly compacted earth embankments, a high degree of cracking, susceptibility to erosion, low level areas in the crest, and inappropriate flood retaining levels and standards. Often, the stated "flood operating level" (also commonly referred to as the Design Flood Level (DFL)) is unreliable.

However, where levees have been upgraded or newly built to an adequately engineered standard, satisfying best practice objectives, and subsequently well maintained, they are expected to reliably cope with a pre-determined flood operating level and are far more robust against structural failure and erosion during flooding.

2.2 Levee Types in NSW

The more common types of levees (specifically, the structures designed and constructed to retain floodwaters) used NSW are described below.

2.2.1 Earthfill Embankments

The most commonly used levee type is the conventional, compacted earthfill embankment levee. This levee consists of a central section of well-compacted impervious material, which is usually obtained from local approved excavations. The central section of levee can be encased in topsoil and/or random fill. This central section generally includes a cut-off, which is a key trench excavated into the levee foundation. The cut-off is filled with compacted earth fill to intercept any leaks from defects in the upper foundations (for example, cracking, permeable seams or root paths) that may otherwise result in uncontrolled seepage under the levee.

Earthfill levees are commonly two to four metres high and have maximum batter slopes ranging from 1V:3H to 1V:4H on the flood side and 1V:2H to 1V:3H on the town side, though flatter batters are recommended to allow for enhanced slope stability and maintenance activities where space permits. Water side batters are normally well vegetated (grass) to combat erosion. The crest of the levee embankment is commonly three metres wide to accommodate maintenance / inspection traffic. One metre wide crests are also common for the accommodation of pedestrian traffic, where authorised. The crest is usually gravelled to facilitate all-weather access. It is not uncommon for this to be used as a walking or cycle path with the incorporation of a stable cap (concrete or sealed footpath) to minimise impacts upon the crest and at key access points.

This type of levee requires a significant area for construction, however should there be no other major conditions that hinder this type of construction, it is usually the most economical levee type to construct. Where the location is restrictive, as may be the case in and around some urban areas, other options to achieve the desired location for the levee may be required. These options include crib walls, concrete retaining walls and incorporating the levee into roadways, or a combination of these.

Long term access arrangements need to be maintained for operations, maintenance and surveillance activities.

2.2.2 Concrete / Block Retaining Walls

Reinforced concrete retaining walls are a useful alternative levee, particularly in and around town areas where space is at a premium. Depending on the height required, the wall may be free standing (with a buried base and cutoff) or backed up by earthfill for desired aesthetic reasons. An alternative to traditional reinforced concrete walls is concrete core-fill block walls with reinforcements, which could be a cheaper option depending on source locations.

The main disadvantage of this type of levee is that, unlike the earthen levee, it is not easy to temporarily raise the levee if necessary. However, a concrete retaining wall provides a consistent crest height and is not subject to subsidence, which would reduce available freeboard.

2.2.3 Sealed Roadways

Where there is no alternative location available, an existing roadway may be used / raised to serve as a levee, depending on the embankment's geotechnical properties. This could provide a reasonable levee with no access problems and the "crest" is maintained as part of normal road maintenance arrangements. It is an advantage if the roadway is sealed as the levee / road moisture level would be maintained at a consistent level. Access during times of flood events would not an issue with this type of levee, however, the suitability of any existing road embankment to serve as an impermeable water retaining structure shall firstly be investigated. Geotechnical aspects such as clay content, dispersivity, degree of compaction, presence of a cutoff structure, etc. must be carefully considered.

2.2.4 Crib Walls

The use of a full or part crib wall is a useful alternative where there is limited room to locate a levee. A full crib wall consists of two near vertical walls with a compacted clay core, whereas a part crib wall is constructed with a conventional batter on one side, a crest and a crib wall on the other side (generally the "town" side), which may adjoin a road or other asset. Crib walls also provide the opportunity, as with conventional levees, to incorporate a walking or bike track along the crest. It is uncommon to use crib walls on the water face of a levee, however if necessary, a geotextile fabric should be laid behind the crib to avoid scouring out of the wall.

2.2.5 Sheet Piles

The use of sheet piles walls as levees is uncommon due to high installation costs and aesthetic reasons, but however is considered a very reliable water retaining structure. The main advantages include durability, minimal seepage through the pile connections, buried portion of the pile acting as cutoff and occupies a minimal plan footprint. However, in terms of suitability, factors such as geotechnical conditions, proximity to other existing structures (installation vibration effects), pile driving methodology and temporary footprints of installation machineries, etc. must be carefully considered.

Reinforce Concrete, Block and Sheet Pile Wall Levees



Earth Levees



Figure 2-1 Common Levee Types

2.3 Maintenance Issues

Typical problems associated with the maintenance of levees are:

- Erosion of the levees.
- Burrowing animals.
- Inappropriate / excessive vegetation.
- Cracking.
- Seepage.
- Settlement.
- Piping and sand boils.
- Slope instability, slips and slumps.
- Sinkholes.

These issues can degrade the integrity of the levee and lead to premature failure at a floodwater level below the flood operating level, set as part of the levee design.

Examples of some of these problems are shown in the following Figure 2-2.

Erosion of Levee

Animal Burrows

Inappropriate / Excessive Vegetation

Sand Boils

Slope Instability

Sinkholes

Figure 2-2 Typical Levee Maintenance Problems

3. LEVEE OWNER'S RESPONSIBILITIES

3.1 Statutory Frameworks

In NSW, responsibilities for the prevention, management and response to flood events exist across Local Councils, State Government Agencies (with responsibilities for flood risk management, emergency management planning and response to floods, land use planning and managing river gauges) and the Commonwealth (Bureau of Meteorology for flood predictions).

The obligations of levee owners are set out across a number of statutory frameworks. Unlike dams, there is no single or overarching statutory framework that sets out all owner obligations in relation to levees.

The majority of levee owners in NSW are Local Councils. The levee management functions of Councils are set out in Chapter 6 of the Local Government Act 1993, and include "the provision, management or operation of storm water drainage and flood prevention, protection and mitigation services and facilities".

The Floodplain Development Manual: the management of flood liable land (April 2005) is gazetted as the manual relating to the development of flood liable land for the purposes of section 733 of the Local Government Act 1993. The manual provides guidance to Council on managing its flood risk and is available on the Office of Environment and Heritage website. This manual outlines the importance of undertaking proper maintenance to ensure levees are in a state of continual readiness and implementing an asset management plan with schedules of inspections and remedial works (see Subsection 3.1.5 and Appendix J, J5.1).

Construction and maintenance of some levees are regulated under Part 8 of the Water Act 1912. These are private levees in rural areas and Council owned levees that are licenced under the Act. The majority of urban levees are not regulated under this Act.

Chapter 13 of the Local Government Act also establishes the Local Government Integrated Planning and Reporting Framework. This framework requires local councils to develop a set of plans and reports that strategically shape council and community activities, priorities and resources. This framework requires council to assign responsibility, financial resources, key objectives and strategies in the community strategic plan. Councils should look to take the opportunity to ensure that their levee systems, as a key community asset, are incorporated into the framework and the associated resourcing strategy through the long term financial plan, asset management plan and workforce management plan, as appropriate.

In addition to statutory obligations, levee owners also have obligations under common law to manage risks associated with their levees. A person or public authority that causes personal injury or damage to the property of another person may be liable in negligence, where a duty of care is owed and is breached. The greater the likelihood and seriousness of risk of injury or damage is, the higher the duty of care will be on the levee owner.

Levee owners are responsible for determining the extent of their legal obligations and risks.

3.2 Basics of Ownership

Levee owners should apply a risk management approach to determine an appropriate standard of service for the levee, covering the level of flood protection and the consequent design, construction, maintenance and operation of their levee.

In owning and operating a levee, levee owners should:

- Have good knowledge of the levee and its adequacy, and keep good records of basic information on the levee.

- Share knowledge of the levee to facilitate informed local and state government decision making, including flood risk management, emergency management planning and response, land use planning.
- Develop and maintain an effective levee management program, including operation, maintenance, surveillance and where necessary, contingency planning.
- Utilise sufficient trained personnel who are responsible for the operation, maintenance and surveillance programs.
- Maintain the levee in an adequate state for its intended purpose in particular, timely rectification of identified issues.
- Consider the adequacy of the levee to protect the community and the need to rehabilitate or upgrade the levee where necessary.
- Regularly reassess the levee's flood operating level (or DFL) based upon its condition.
- Use competent designers and construction contractors for construction and upgrades.
- Respond to changes in accepted flood protection standards, engineering standards and industry practices.
- Develop a Levee Owner's Manual (LOM), which brings together all the information relevant to the management of their levee(s) so that there is a documented understanding of the levee design, construction, operation, maintenance and asset management regimes, with consideration of the current levee condition, the full range of potential flood behaviour and associated emergency response to flooding.

4. BASIC PRINCIPLES OF LEVEES

4.1 Basic Design Principles

4.1.1 Design

Levees are generally designed to provide protection to an area for a design flood event. This event could be a key historic flood event or a flood event of a certain magnitude or probability at the location.

In general, a properly engineered levee is designed to safely withstand flood events up to a particular severity level with an associated probability of occurring in any year, for example, a 1:20 year, 1:50 year, 1:100 year or 1:500 year Average Recurrence Interval (ARI) flood events, equivalent to 5%, 2%, 1% and 0.2% Annual Exceedance Probability (AEP) respectively.

The selection of a design floodwater level for a particular levee is generally a decision made as part of the development of a floodplain risk management plan, which should consider issues including the benefits of the levee to the community (social, financial and safety) relative to the levee cost, tolerability of flood related risks (damages and loss of lives – with / without levee for multiple design flood events, may consider consequences of levee breach events) physical feasibility and financial capacity. For NSW levees, the 1% AEP design flood event or similar magnitude historic flood event is typically used as the basis for setting the Design Flood Level

A "freeboard" allowance is added to the DFL to arrive at the levee's Design Crest Level (DCL). The DCL is not required to be static and may be sloped in parallel with the design flood event's maximum longitudinal flood profile. This freeboard is included to allow for:

- Inherent uncertainties in flood prediction.
- The impact of wind and wave action, which can increase the local water level.
- Floodwater surges, which can increase the local water level.
- Potential changes in rainfall patterns as a result of climate change.
- Computational uncertainties, inadequacies in survey data and other sources (e.g. flood modelling inputs and outputs, etc.) of error
- Settlement of the levee after construction.
- Normal deterioration of the levee condition and capacity during its service life (but would assume that regular adequate maintenance and refurbishment, when needed, have being undertaken).

The total allowances typically give a design freeboard of 0.50 to 1.00 m for earth embankment levees.

Note that the combined use of modern design, construction, inspection and maintenance techniques for contemporary levees means that they would be expected to remain structurally sound, at a "safe" level, for flood events up to the levee's DCL, from when it is first constructed (i.e. above the DFL).

A typical levee design cross-sections are shown in the following figures.

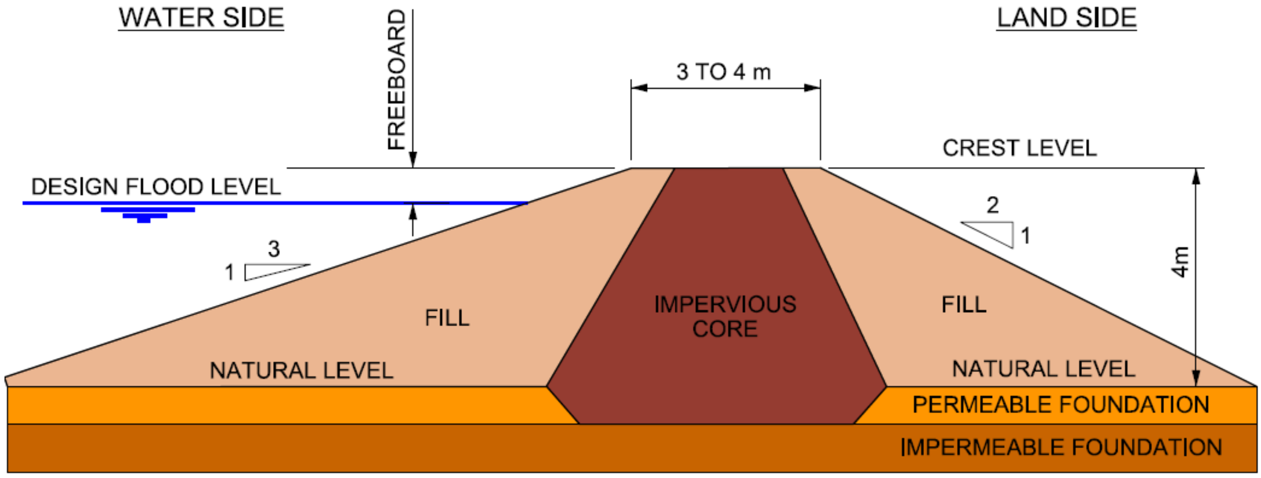


Figure 4-1 Typical NSW Earth Embankment Levee Design Cross-section

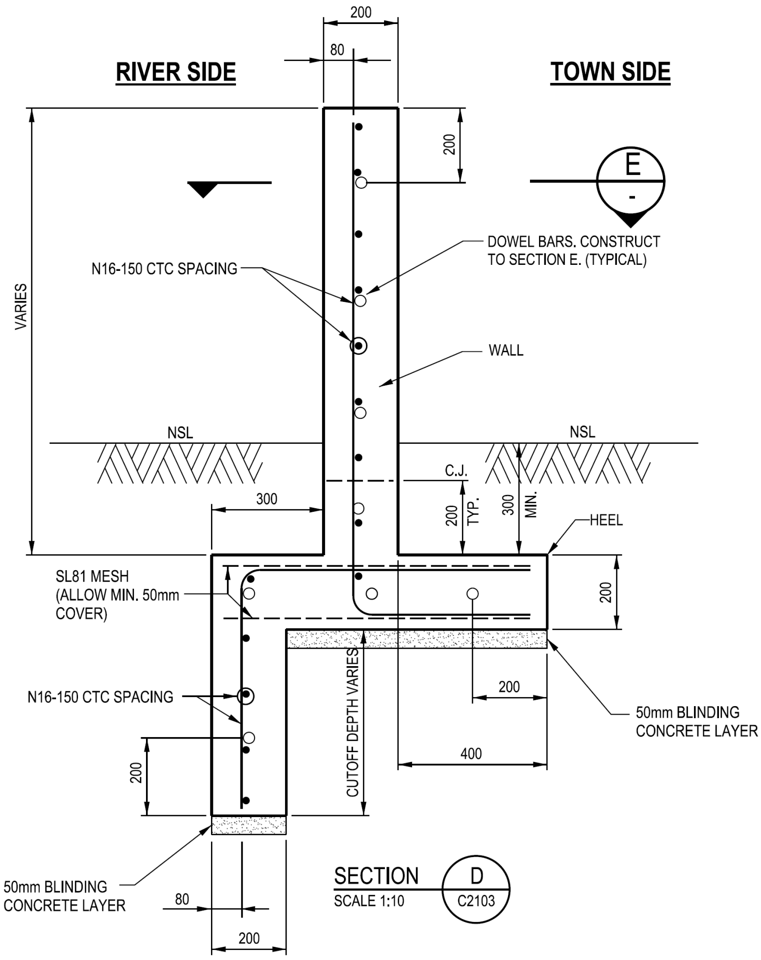


Figure 4-2 Typical NSW Reinforced Concrete Levee Wall Design Cross-section

In summary, the basis for structural design of a levee relates to the DFL, the corresponding AEP and the freeboard allowance.

There are a number of internationally recognised methods to assess structural stability of levees, such as calculation of factors of safety, developing fragility curves, or full engineering assessment. Some of these methods are highly technical and require detailed survey and geotechnical information on the levee at regular cross-sections. Some can be costly and time consuming to undertake and are considered to be more appropriate for large levees that are part of major flood protection systems. See the International Levee Handbook (Ref 1).

For NSW levees, which are usually smaller in scale than the international systems, the method of design is typically based on reference to precedent, supported by crest level survey, stability analysis and limited geotechnical investigations.

The key issues to be considered in the design of a levee include:

- Location:
  - proximity to river banks or similar areas with poor foundations can destabilise a levee structure (more detailed stability analysis would be required).
  - existing structures – other assets in the area, such as roadways or channel banks can be incorporated into the design, where appropriate
  - levees are long term assets and future plans for the local area need to be considered, as relocating a levee to accommodate developments is expensive.
- Crest width.
- Side slope.
- Need for, and position of overflow spillways, which can protect the main levee wall and control internal inundation.
- Foundation treatment (such as cutoffs) and geotechnical quality of foundation materials.
- Materials used in construction.
- Failure prevention, including piping prevention, uneven settlement and erosion protection.
- Impact of levee on the flood behaviour – it is necessary to ensure that the levee provides an adequate waterway area to accommodate the design flood event and does not create restrictions that would worsen the impact of the event. Works to offset adverse impacts may also be considered.

Note that this guideline is not intended as a levee design manual. Any design or assessment work should be undertaken by suitably qualified and experienced engineers.

4.1.2 Spillways

Levee design has evolved to incorporate a section of the levee that acts as a spillway. This recognises that a larger flood event than that the levee design is possible and therefore a controlled spillway is more beneficial than the uncontrolled alternative. A guideline for construction of spillways is available in the Floodplain Risk Management Guideline No 14 – Spillways for Urban Levees.

In general, a levee spillway is located at or towards the downstream end of a levee, or the lowest part of the town. The spillway is designed to allow flow over the levee before a general overtopping or failure occurs. The volume of water that is delivered via the spillway before the levee overtops is designed to try to minimise the development of hazardous flows that could result from the levee being overtopped or a levee failure occurring.

The level and width of a spillway is determined by the following characteristics:

- Provide reasonable protection against wave action during the design event.
- Provide for reasonable tailwater build-up prior to the levee overtopping.

- Do not operate until above the Design Flood Level.
- Construction cost.

It should be noted that due to the magnitude of the area protected by the levee, and the range and variability of floods that exceed the design flood, it is not possible that all protected areas will be inundated prior to levee overtopping from all floods that exceed the design flood.

4.1.3 Flood Operating Level

The flood operating level for a levee is the maximum water level that the levee can be considered "safe" in engineering terms at the time of the actual flood event. A sufficient factor of safety is used to give a low probability of failure.

At the time of a reassessment of the current flood operating level, the required flood event freeboard will be for a particular time in the Levee's life. Some of the original design freeboard components will therefore be known and included in the assessment. Thus, they do not need to be additionally included in freeboard as a factor of safety (for example, actual settlement will be determined from a crest level survey).

The only remaining freeboard components needed to calculate flood operating level are wind wave action, local surge conditions and a condition defects allowance.

It is not uncommon for the flood event freeboard to be about one half of the design freeboard, assuming that the levee is a reasonable state of repair.

The levee may not fail at higher floodwater levels up to the crest level, but the reliability will be reduced.

For some older levees, the original flood operating level may no longer be relevant due to its age or condition, or may simply not be known. The need for regular engineering reassessment is emphasised.

The flood operating level is one of the appropriate factors for emergency flood planning and response. It should be regularly reassessed, at least once every five years.

4.2 Levee Failure

It is rare for an urban NSW levee to suffer catastrophic failure (structural collapse), although they can be overtopped, as occurred in 1990 to the Nyngan Levee.

It is noted that some failures that developed in NSW levees during flood events were either temporarily reinforced, had emergency repair work undertaken, or the failure did not develop to sufficient severity to cause catastrophic collapse.

4.2.1 Failure Modes

Some of the possible modes of levee failure are described below and are illustrated for reference in Figure 4-2.

Internal Erosion / Foundation Piping

Internal erosion is initiated by hydrodynamic forces acting on soil particles inside or through the body of a levee. Internal erosion occurs when soil particles within a levee (or its foundation), are carried downstream by seepage flow. In this process, migration of material forms pipes through the levee (or its foundations). These pipes may undermine the structure of the levee and lead to the progression of erosion and ultimately, failure and a breach.

The main factor for the development of internal erosion is seepage, generally caused by the presence of permeable layers or lenses within the fill or by the existence of cracks or fine fissures. Other factors can also trigger or aggravate internal erosion through the creation of pipes in the levee, such as:

- Animal activities with the uncontrolled development of burrows.
- Vegetation, particularly shrubs and trees with the uncontrolled development of roots
- Human activity with any type of conduits (e.g. pipe culverts) or other penetrating structures through the levee.

Overtopping

Flood overtopping the crest of a levee can induce major damages as a result of initial surface erosions. The impact and velocity of flow induces a "wearing away" of the levee materials, particularly if there is no erosion protection measures, such as a well gravelled (or bitumen) crest, well vegetated / rock lined town-side batter, etc. Scour and erosion can rapidly develop on the crest and / or the town-side batter of the levee leading to slipping and / or slumping of the embankment. For concrete wall levees, substantial overtopping may induce stability / structural failures by overturning and "snapping" of vertical members by bending or shearing of the wall.

Overtopping can occur as a result of a number of scenarios, including:

- Flood magnitude exceeding the design flood event.
- Lowering of the DCL (as a result of e.g. crest erosion, settlement) allowing more frequent flood events to reach the levee crest.
- Changes in the floodplain, affecting flood behaviour.
- Flood debris accumulation at downstream obstructions (for example, bridges), which increases the floodwater level at the levee.
- Local obstructions beside the levee (for example, fallen trees).

Traditionally when analysing overtopping failures of unprotected earthfill embankments, practitioners have often loosely used the informal "rule of thumb" values of 0.30 m overtopping in excess of 30 mins to be the critical condition that could potentially lead to an overtopping breach. Other factors that can influence overtopping failure is the embankment slope and vegetation cover. A study regarding overtopping failure probabilities for flood retarding basin embankments conducted by Jacobs (2016), the conditional failure probabilities increase sharply for steep unprotected town-side batters and long overtopping durations. The following table summarises Jacob's findings.

Table 4-1 Probability of Levee Breach due to Unprotected Flood Overtopping

Overtopping Height (m)	Overtopping Duration < 6 hours 1V:3H Town-side batter	Overtopping Duration > 6 hours 1V:3H Town-side batter	Overtopping Duration < 6 hours 1V:2H Town-side batter	Overtopping Duration > 6 hours 1V:2H Town-side batter
0 to 0.15	0.05	0.10	0.10	0.20
0.15 to 0.30	0.10	0.30	0.30	0.50
0.30 to 0.50	0.30	0.50	0.50	0.80
0.50 to 1.00	0.50	0.70	0.70	1
> 1.00	1	1	1	1

After Jacobs (2016) – Table 3.1.

Whilst levees are not designed to be overtopped, vulnerable overtopping locations along an embankment levee should be identified and suitable erosion protection measures designed and installed.

Sliding

Levee structures can undergo a translational sliding failure. The presence of very weak surface layers (for example, decaying vegetation or weak clays) in the foundation or body of an embankment levee, can result in a horizontal block movement when the shear strength of the surface layer is insufficient to resist the hydraulic forces created by the high floodwater acting on the levee.

Wave Action

Waves can be generated by wind acting over a large expanse of floodwater, by boats operating during flood events or by obstructions in the path of rapidly flowing floodwater. These waves can cause erosion of the face (or toe) of the levee, commonly in the form of steep scarps, which may collapse as the flood progresses. The erosion can reduce the width of the levee, initiate slides and even cause a breach in the levee during a flood event.

Surface Erosion

Surface erosion is the wearing away of the levee by flood events, rainfall, waves, wind or any other natural or mechanical process. The erosion occurs when the surface material of the levee is not sufficiently resistant to the effects of the environment (for example, highly dispersive materials). This problem can arise over time due to deterioration of surface materials, but it can also be due to an increasing impact from the environment (for example, wave action during major flood events).

The material that is exposed, due to surface erosion, is not usually designed to resist severe environmental impacts and continued exposure will result in an acceleration of the surface erosion process.

Tree Damage

Of particular concern are trees (especially large trees) that are located in, or close to the levee structure (for example, on the levee embankment or immediately adjacent to a retaining wall type levee). Prolonged saturation of the surrounding ground, followed by high winds is sometimes sufficient to topple these trees, with consequences including loss of surrounding/supporting levee embankment or upheaval of retaining wall levees, which may result in a levee breach.

Slope Failure

Embankment levees are commonly subject to high level flooding followed by rapid decline in river level. During the flooding process, internal hydraulic pressures are created inside the levee embankment and these may not readily dissipate as the flood recedes. If a levee bank is too steep to be stable under high internal hydraulic pressures, slip failures, due to rapid drawdown (RDD), will occur. This occurs as the flood recedes. As is not unusual for flood events to be multi-peaked, the levee may be seriously compromised by the first peak and not be able to safely withstand the second peak.

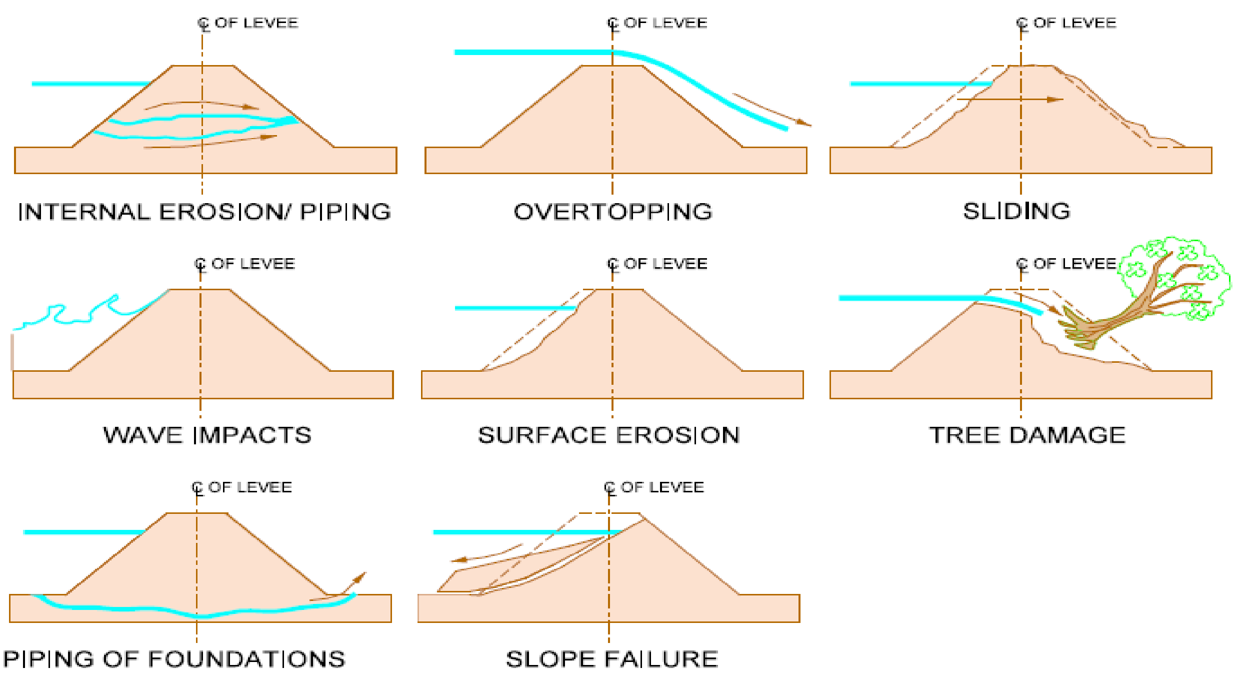


Figure 4-3 Levee Failure Modes

4.2.2 Lessons From Levee Failures in Hurricane Katrina

It is worth noting that some of the levees around New Orleans failed during Hurricane Katrina before the design floodwater level was reached *(see "Overview of New Orleans Levee Failures: Lessons Learned and Their Impact on National Levee Design and Assessment". Journal of Geotechnical & Geoenvironmental Engineering. ASCE May 2008)*.

In summary, the storm surge produced by Hurricane Katrina, overwhelmed the levee system. In some cases, retaining wall levees (for example, reinforced concrete, sheet piles) failed at water levels well below their design due to a combination of misinterpretation of foundation conditions, unforeseen failure mechanisms and erosion.

However, no embankment levee failures occurred without overtopping. The extent of breaching and overtopping scour of these levees was a function of soil type and compaction effort that was applied during construction. Well compacted embankment levees that were constructed of cohesive materials were able to survive overtopping without breaching.

Overtopped, retaining wall levees failed due to erosion and subsequent loss of supporting foundations. Failure of retaining walls, at floodwater levels below the top of these levees, was caused by instability of the foundation soils. This instability was a result of deflection in the levee walls and subsequent "opening up" of large and uncontrolled seepage paths.

4.3 Relating Floodwater Levels to Levee Crest Levels

This section of the guidelines outlines river gauge levels, flood slopes and flood predictions as they relate to a levee.

As water must flow downhill to move unassisted, the water level downstream of a certain point in the river will normally be at a lower level than the water level upstream. This drop or "sloping" of the water level is known as the flood slope and is usually described as **metres drop in water level per kilometre length of river**, m/km, as shown in Figure 4-3. The difference in level is the energy necessary to overcome energy losses due to friction, change in profile and obstructions in conveying the floodwater between the two locations.

Using Figure 4-3 as an example, the floodwater level varies by approximately 1.70 m from the upstream end of town to the downstream end of town. It should be noted however, that there can be significant variability in the flood slope between different AEP flood events and different locations. This can be a particular issue where flood flows come from different sources, for example from tributaries or arms of a river.

Floodwater levels for the river gauge location may be available from historic or design events and may be predicted by the Bureau of Meteorology for locations indicated in the State Flood Plan.

Where the levee is within the gauge reference area, the floodwater level or range along a length of river upstream and downstream of the gauge could be indicatively used to indicate a floodwater level elsewhere in the gauge reference area (as shown in Figure 4-3). The floodwater levels at the gauge could be translated to approximate floodwater levels at different points along the levee.

Determination of the floodwater levels along a levee can be assessed using the river gauge data, by:

- Estimation from historical observations / records (an initial estimate).
- Reference to a Design Report and / or an O&M Manual, where surveys and flood data may be held.
- A flood study, which includes a hydraulic model study, covering a range of event magnitudes, to accurately determine floodwater levels and account for any hydraulic irregularities, such as weirs, tributaries or chokes.

This information may assist with the development of SES Flood Intelligence Cards (FICs), which in turn is considered in the development of local flood plans for the emergency response to a flood event.

The most accurate information for specific modelled events will be provided by a specific flood study, which would be undertaken by specialist engineering service providers. Results from these studies should include a longitudinal flood profile along the length of the levee, for a range of historic and design flood events. The flood study should identify all issues that would be pertinent to the design floodwater levels, including where tributaries join the river downstream of the gauge, within the length of the levee under consideration, and structural works, such as road and rail embankments in the flood channel.

Careful assessment of the hydraulic irregularities in the gauge reference area should be undertaken so that the limitations of various floodwater level relationships are understood for decision making. For the purposes of estimating heights at a levee based on observed gauge heights, it may not always be valid to have a direct one to one relationship, even though hydraulic models or observed historical heights may imply this to be the case. The circumstances of the real event will likely vary from data derived in other methods. It may be appropriate to consider a range in flood heights at the levee for a particular height at the gauge. These ranges may be recorded on SES FIC.

The data from one (or more) of the above sources can be used to:

- Determine the appropriate range of flood slope and floodwater level data.
- Check the levee crest level with predicted floodwater levels to assist in assessing the levee adequacy, in relation to its intended capacity.

As the actual flood progresses, the predicted flood slope can be refined by using measured water levels at points along the levee and comparing with the level at the flood gauge.

Other information that needs to be collected to allow an assessment of how the flood predictions relate to the levee includes:

- Levee crest levels obtained from recent survey information and audit inspections.
- Gaps in the levee (for example, road and rail openings) that may require temporary treatment, such as closing gates, placement of temporary panels, barriers or sandbagging. The temporary treatments will be outlined in the O&M Manual for the levee. These actions should be considered when examining crest levels
- Stormwater pipe culverts (or other types of open conduits) through the levee – Unless there are floodgates on their outlets or actions in the O&M Manual to close these structures, pipe culverts provide a potential pathway for water to enter the area protected by the levee. This can result in internal flooding without the levee being overtopped or breached.

It is for these reasons that flood studies, surveys and O&M Manuals are considered essential documents for the levee owner to hold and readily access.

In the example shown in Figure 4-3, the levee crest is higher than the predicted 1% AEP design floodwater level at the gauge, but for locations upstream of Wick Street the levee crest levels are lower than the predicted 1% AEP design floodwater levels (e.g. possibly due to crest erosion). Using this methodology, with a flood of this magnitude, the levee could be expected to overtop at these "low points". Whereas if the levee crest level was only examined at the gauge location, the levee would not have been expected to overtop. This example indicates that this levee would currently be unable to serve at the DFL, if it was initially designed to cater for the 1% AEP design flood event. If so, the previously known flood operating level would no longer be valid.

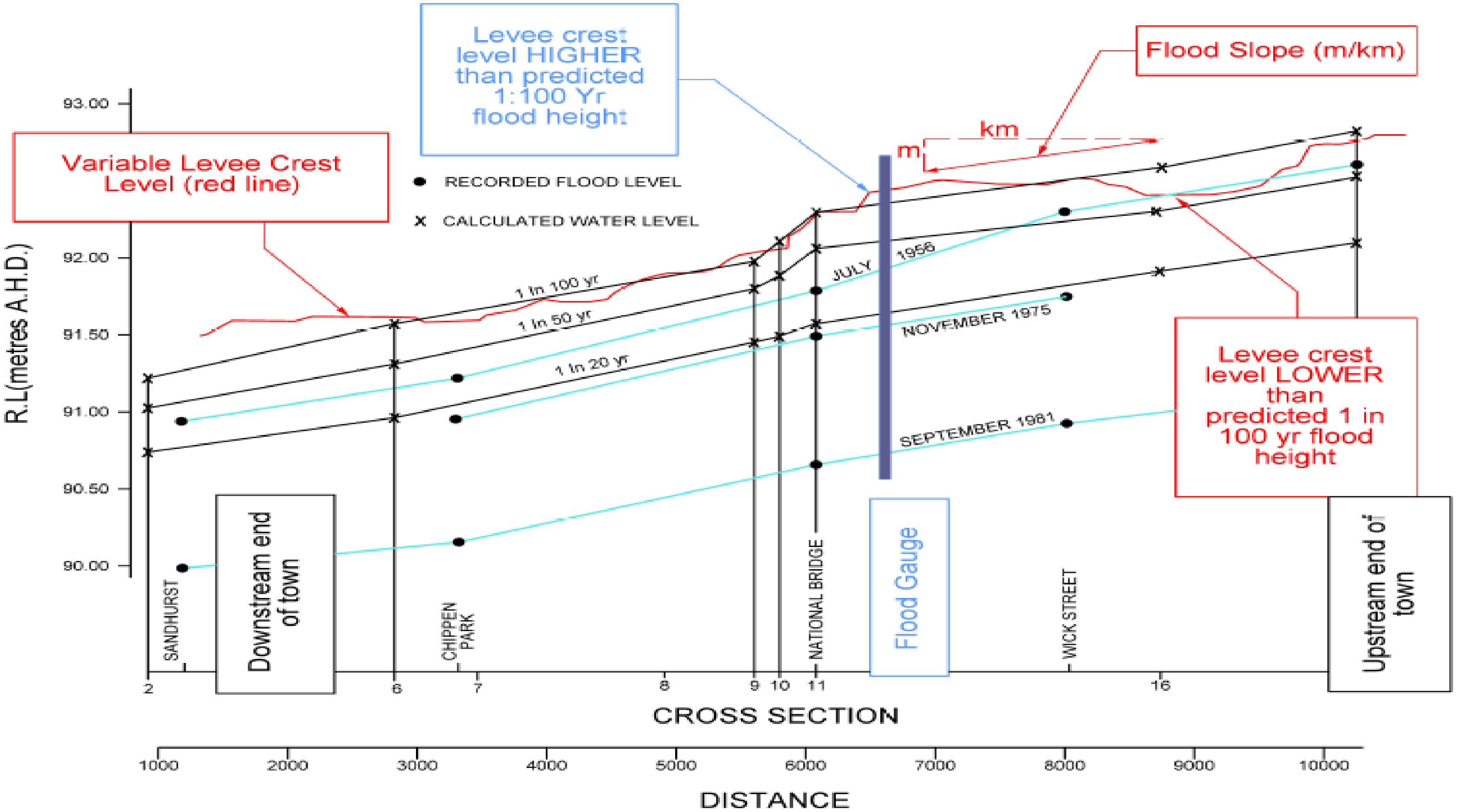


Figure 4-4 Example of Floodwater Levels vs Levee Crest Levels

5. LEVEE OWNER'S MANUAL (LOM)

The Levee Owner's Manual (LOM) is essentially the levee's O&M Manual.

An approaching flood event is a time when measures are required to organised and executed as efficiently as possible. In past flood events, many levee owners used the limited time available to get themselves and others "up to speed" on their levee. From experience, during these emergencies, critical up-to-date information has often been unavailable to both the owner and emergency managers, hampering the implementation of local flood plans and emergency response during flood events. Critical information should be shared with other government agencies and be readily available for access during a flood event, as this could mean the difference between success and failure in responding to rapidly rising floods.

5.1 Overview

Comprehensive documentation on a levee is invaluable for current and future planning and management. Good documentation helps demonstrate adequate management, assists the evaluation of a levee's expected performance against past behaviour, analyses for future needs and upgrading, eliminates the need for costly investigations to restore lost information, and assists emergency response and flood risk management planning.

Where levees have been constructed some time ago, information held by levee owners on their levee is often incomplete, misplaced or lost, and staff who have held this corporate knowledge are no longer under employ.

Documenting levee information is essential to preserve important corporate knowledge for current and future managers of the levee, clearly communicating key requirements to manage the levee to all parts of the owners' organisation, and provide an instant guide for emergency response planning.

The LOM is a compilation of all relevant information on the levee to give a basis for levee owners, managers and emergency managers to manage the levee, undertake adequate planning, decision making and emergency response, and have adequate records for future managers.

5.2 Documentation and Records

A list of the documentation that should be included in the LOM includes those shown in Table 5-1.

Having this documentation readily available in the LOM has a number of practical uses including:

- Providing an understanding of the levee design, construction, operation, maintenance and asset management regimes, relevant to the current levee condition.
- Understanding the original design flood situation, upon which the levee was built, and any limitations of the levee to cope with this design flood event in its current condition, including defining the operating level for the levee.
- Illustrating the full range of potential flood behaviour and an understanding of flood situations.
- Providing instructions on the mechanisms required to be operated / installed / constructed to comprehensively flood-proof the entire levee system.
- Roles and limitations of the levee system in the emergency response to the full range of flood events.

- Understanding land tenure and entry limitations to land upon which the levee is located or through which, access is required to the levee for operation, maintenance or inspection.
- Maintenance regimes to ensure the entire levee system is consistently and readily in appropriate conditions to safely serve as an impermeable floodwater retaining structure for the design flood event.
- Maintaining the best available information on the levee system and associated components, and their current condition.
- A communication plan to share this information with relevant government agencies
- Monitoring levee condition and using the findings in operation, maintenance and asset management regimes as well as the development of any associated contingency planning.

Table 5-1 Summary of Items to be included in the LOM

Document	Information
1) Base Documents	
Drawings	Detailed design and WAE drawings indicating design levels, long-sections, cross-sections, etc.
Design Report	Defines the design assumptions and criteria, and considerations for O&M items, specification for levee appurtenances.
Construction Report	Physical details of levee, including compaction effort, moisture content, materials used and their source.
Cadastral plans	Land or easement boundary and ownership information.
History	When constructed and upgraded, maintenance history, record of past flood events and levee performance etc.
2) Planning and Operations	
O&M items and procedures	Inspection, monitoring and maintenance regimes, coordination and mobilisation of personnel for the operation of closure mechanisms and emergency engineering works, etc.
Flood Study	Design flood flows, velocities, depths, hazards, inundation extents, profiles, etc.
Asset Management Plan	The life cycle asset management plan covering levels of service required, maintenance, upgrades and replacement.
Contingency Plan	Flood response plans, including the IFCL, contingency planning for emergency repair work, plant / equipment and resource needs, location of any temporary works, and associated materials and resources. Emergency Contacts for engineering / technical advice.
3) Current Information	
Crest Level Survey	For the comparison with the levee DCLs to identify existing crest low points.
Visual Audit Reports	Condition of the levee, known defects, changes from last inspection.

4) Communications Plan	
Communications Plan	Plan outlining how information on levee condition is shared with other government agencies to inform flood risk management and emergency response planning. The plan needs to also identify how this information will be readily available in the lead up to and during a flood event to inform about levee operation and emergency response.

6. OPERATION AND MAINTENANCE ITEMS

6.1 Audits

6.1.1 Purpose

Routine audits are an important part of levee management. Their purpose is to alert the levee owner to current or emerging problems that can reduce the integrity of the levee.

An inspection regime (frequency and scope) should be developed for each levee. The level of inspection detail and frequency should be based on a number of factors, including the potential consequences to life, property and infrastructure in the event of a failure, and the capacity, design and condition of the levee.

There are also special inspections needed for certain conditions, such as during flood events.

6.1.2 Frequency of Inspections and Visual Audits

For NSW levees, failure due to structural collapse has been rare. Most NSW levees are only infrequently impacted by flood loading.

Table 6-1 suggests the range and frequency of inspections and audits. More frequent inspections should be undertaken if:

- an assessment shows high risk levels (i.e. likelihood vs consequence) from levee failure.
- the structure is different from a typical NSW levee (i.e. other types of floodwater retaining structure up to five (5) metres high).
- all or part of the levee has serious issues of concern.
- site specific recommendations for more frequent inspections have been made.
- any external factors could have affected the levee (e.g. drought, significant rain / flood events, earthquakes, sabotage, etc.).

Refer to PWA's Development of Methodology and Visual Audit for Urban Levees (Updated July 2020) for more detailed guidance.

Table 6-1 Typical Inspections and Frequencies

TYPE	FREQUENCY	OUTCOME
Operational Inspection (OI)	Routine: Yearly	Visual inspection to identify issues needing rectification. Undertaken by levee owner's trained staff. Observation data should be collected onto a smart devices / cloud collection services. NSW government uses the Fulcrum app/database for visual audits. Post-processing / extraction procedures of the data should be established for asset management and records.
Crest Level Survey	Routine: 5 yearly	Usually undertaken by suitably qualified surveyor to check for any vertical changes, for example, detecting settlement.
Visual Audit (VA)	Routine: 5 yearly	Comprehensive visual audit undertaken without special equipment and special investigations. Identify major problems or emerging issues that need attention to maintain the integrity of the levee. Undertaken by independent specialist engineers experienced in dam / levee safety inspections and management. Similar to the OI, smart devices and assessment tools such as Fulcrum should be used in this investigation for handling the data.
"Pre-flood" Inspection	As soon as a significant flood event has been forecasted	Verify that all parts of the levee are in good order, or which areas need emergency work. Check whether there are any impediments to instigating operations such as installing temporary works and implementing contingency plans. Undertaken by levee owner's trained staff.
"In-flood" Inspection	While the levee is subject to flood loading	Identify weak or susceptible areas that could lead to a potential failure under the existing flood loading or in the future. These inspections are vital to plan emergency repairs and/or trigger evacuation. Undertaken by the levee owner's trained staff.
"Post-flood" Inspection	As soon as the flood recedes	Observe any damage that may have occurred as a result of a flood event and may require immediate repairs. This may be aided by a non-routine Visual Audit of the levee which may assist in obtaining grant funding. Evaluate the ability of the levee to withstand a future flood loading event. This type of inspection is also used to validate, verify and to add to information collected during the flood event. This could lead to establishing a program for urgent work. Undertaken by levee owner's trained staff.
Detailed Specialist External Audit	As required	These may be undertaken to confirm the capacity or integrity of the levee, investigate problems found by visual audit or post flood audit in more detail, and to design an upgrade. They are performed by specialists from various engineering disciplines as required (hydraulic, geotechnical, structural, or mechanical engineering). Specialist inspection equipment may be required (e.g. CCTV cameras, non-destructive testing equipment).
Other	As required	Initial inspections for new levee or unusual factors (e.g. earthquake, acts of terrorism, etc.).

An EES-endorsed VA reporting template is available upon request to EES.

6.2 Crest Level Survey and Levee Chainage System

The Crest Level Survey is initiated as part of a levee investigation to firstly define the topological features of a levee, its alignment and elevation features. Levees vary in elevation due to original design considerations such as levee freeboard, settlement, deformation and weathering over time or defects arising to name a few reasons. A Crest Level Survey is a means to checking the current height of a levee against historical and design levels and estimating its operating capacity. If significant defects, such as deformation or slumping is encountered during inspections, it is advised that a Crest Level Survey be undertaken outside of the 5 yearly cycle in order to determine if the levee design height has been compromised.

The adopted system for a Crest Level Survey is to commence the survey at the upstream extent of a levee, confirmed on site by technicians and the levee owner. This location is then used as the starting chainage reference location and a monotonically increasing centreline route chainage system follows the survey features to the end of the levee, the location similarly confirmed on site. If unknown, location (i.e. levee chainage) of levee appurtenances such as floodgates, road crossings, pumping station, etc. should also be captured as part of the compilation of the LOM.

An example of a levee survey convention is provided below.

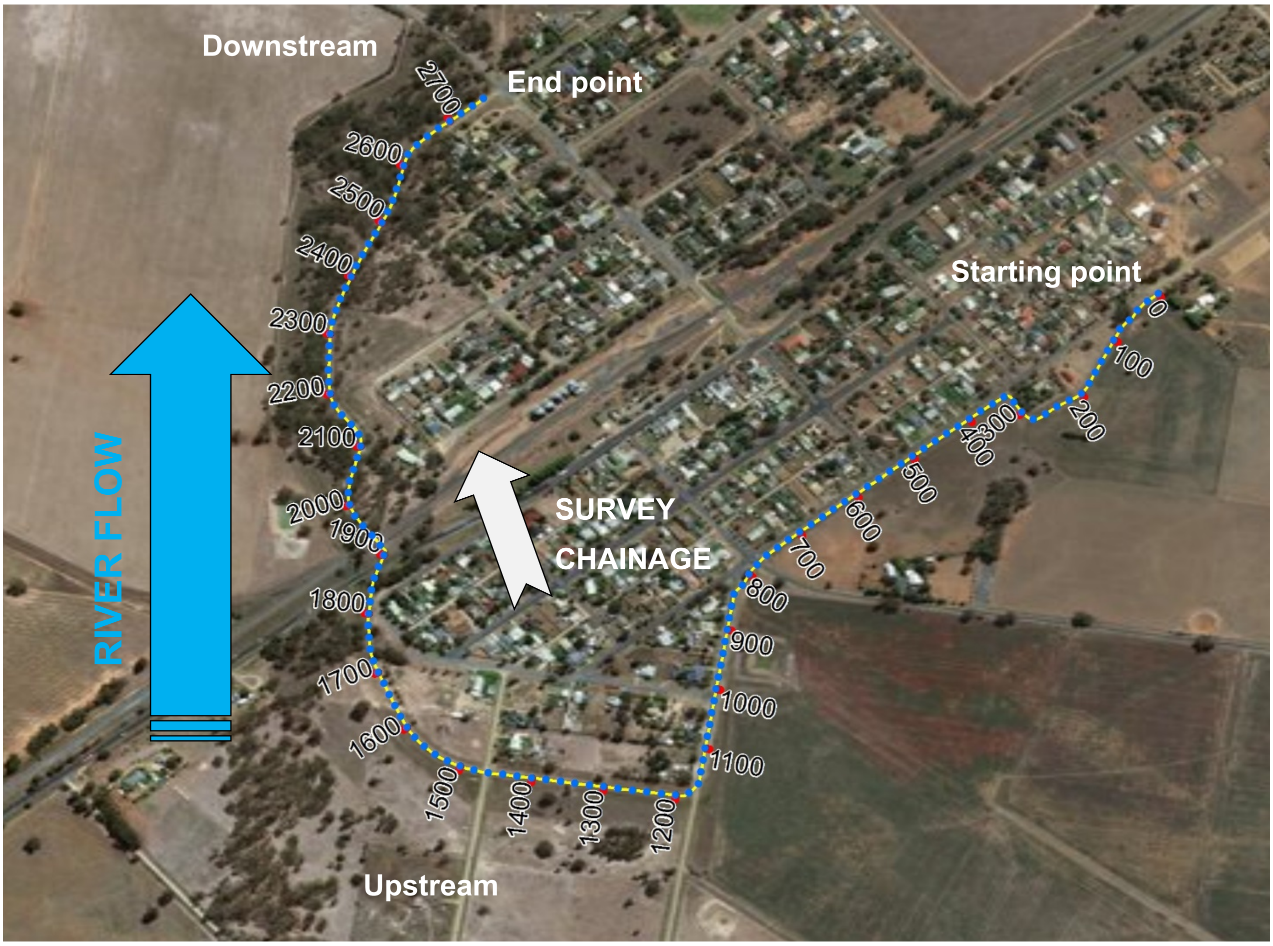


Figure 6-1 Convention for CLS Chainage System

6.3 Activation Levels

Activation Level is defined as the maximum floodwater level before which a feature (e.g. floodgate, road crossing, etc.) must be fully operated to prevent the ingress of floodwater. This level is approximated to the closest relevant stream gauge by using a flood gradient from either historic floods or flood modelling results. The feature invert levels are then attributed a flood gauge level for activation, known as the Activation Level. The Activation Level should include a response time to allow for travelling to the feature and fully operating it.

Activation Levels are required to be determined and documented to form the Flood Action Plan as part of the levee system's LOM. The Flood Action Plan is perhaps considered the most important levee operation aspect.

6.4 LOM

Levees are major assets to the communities they protect. Levees in NSW, especially in the inland, usually remain unused for long periods but are then required to perform to a predetermined floodwater level, often at short notice. To ensure the levees can consistent perform adequately when required, it is essential to provide appropriate maintenance.

To maintain a minimum level of protection from flooding, it is necessary to provide a basic level of maintenance so that the levee crest level, cross-section and general standard of the levee are preserved over time.

In order to achieve the desired level of maintenance, levees should be treated as any other valuable asset and have a maintenance program developed. For this reason, development of the LOM should be an integral part of the management, design and construction process for a new or an existing levee.

Refer to Section 5 for further LOM details.

The LOM should be prepared by appropriately qualified and experienced personnel including specialists such as civil, geotechnical, mechanical and electrical engineers as required by the type and complexity of the levee and its appurtenances.

Levee owners should ensure that there are suitably trained and experienced personnel available to operate and maintain their levee systems in accordance with the LOM.

The LOM must be stored in a secure but accessible location and regularly updated to ensure that the emergency procedures are applicable and can be readily executed.

An example Table of Contents for an LOM is included in Appendix B.

6.5 Maintenance Program

A list of typical maintenance activities and a suggested schedule is given below.

6.5.1 Batter Maintenance

Batter maintenance is generally confined to a range of routine tasks that are carried out on a needs basis, or as part of the annual maintenance program. Priority for works will depend on the location of the levee, the nature and extent of the issues and the assessment of the responsible maintenance officer.

Batters can be protected from runoff erosion by topsoiling and seeding with an appropriate grass species. Alternatively, seeding and mulch treatment can be carried out by specialist contractors.

Where it is necessary to mow the batters to maintain the general appearance of an area, the mown grass will act as mulch, which assists in maintaining bank moisture and stabilising of batters.

It is preferable to use the more prostrate or creeping grass varieties to avoid creating a potential fire hazard, and because these grasses have a greater binding capacity, they provide a greater resistance to wave action. Trees and shrubs should not be planted on or near batters as they increase the potential of risk of failure of the levee due to cracking, piping failure or falling over in strong winds, thereby dragging a large volume of earth from the embankment with the resulting displacement of the root ball.

6.5.2 Batter Slumping

This problem may appear following a flood event and the return of waters to their normal levels. The slumped section of bank should be fully excavated and reconstructed using suitable material and, where possible, with a flatter batter slope to improve stability of the bank section. When replacing the slumped section, it is vital that the remaining existing face of the levee is treated appropriately to prevent a joint between the old and new material.

6.5.3 Levee Ancillary Equipment

A levee may have ancillary equipment that needs to be assembled to enable it to perform to its design objectives. Typical ancillary features may include:

- Removable flood barriers.
- Pumps.
- Removable gate operations.
- Locking mechanisms for gates or fences.

The levee owner should coordinate the safe storage of ancillary equipment in a planned location that can be easily accessed during operation. A planned maintenance procedure should be carried out in accordance with the design recommendations of the equipment on a regular basis. Sufficient practice in operating ancillary equipment should be provided to staff to facilitate operation during a flood event.

6.5.4 Mowing

The main area that requires mowing on levees is at road crossings, to ensure visibility for safety reasons. It may also be necessary to mow levees to reduce fire risk or to enhance the general appearance of an area. Mowing should be carried out as part of the normal maintenance activities. The cut grass adds mulch to the batters assisting grass growth and improving stability of the levee, as well as reducing moisture loss.

Mowing is also recommended as an aid to levee inspections, whereby otherwise concealed defects can be readily identified.

6.5.5 Tree Removal

Trees growing on a levee should be removed at the earliest possible opportunity. Mature trees in a levee will lead to cracking of the levee embankment by increasing the drying of soils and could also be blown over, damaging the levee. This scenario would be particularly critical during a major flood event, where the dislocated root ball of a fallen tree may reduce the level of flood protection provided by the levee.

Trees can be removed as saplings with little problem, however, larger trees require that they be fully removed, including all of the roots, to ensure that no seepage paths remain. The excavation created needs to be backfilled with suitable materials and be adequately compacted.

6.5.6 Rabbit and other Animal Burrows

Rabbit burrows (and other animal burrows such as wombats) in a levee can lead to a weakening of the structural integrity of the levee by the creation of a weak spot in the bank. The more extensive burrows may penetrate the levee and provide a path for floodwater to breach the levee.

Repairs should be carried out immediately, and should consist of clearing the burrows, digging them out and filling the resultant holes with suitable and properly compacted clay.

Animal burrowing should be discouraged by whatever means are safe, practical and legal.

6.5.7 Excess Vegetation

Excess vegetation such as overly long grass, dense shrub cover and trees can harbour burrowing animals and snakes. It can also cause difficulties for a levee inspector to adequately assess the condition of the levee. In areas where it is difficult to establish vegetation on the levee slopes, a balance should be made between maintaining the vegetation as erosion protection, against the problems of regularly inspecting a levee with excess vegetation.

6.5.8 Erosion

On levees where there is prolonged high water level against the levee batter, some protection may be required from the effects of the flow or from the effects of wave action in undermining the face of the levee. Where the water is normally below the levee bank then maintenance will generally only be required after flood events.

On both sides of the levee the faces will be prone to erosion from rainfall and runoff resulting in runnels, which if left unattended, will erode the levee leading to premature failure under load. When surface erosion becomes severe, the surface should be excavated and backfilled with suitable earthfill, with great care being taken not to form a “dry joint”.

Generally, runoff erosion can be minimised by having a good cover (but not excessive) of grass on the levee banks.

Piping holes and internal erosion tunnels should be repaired by completely excavating the surrounding section of levee and rebuilding the levee in that location, again taking great care not to form a dry joint between the new and existing portions of levee.

Maintenance of the levee crest, by eliminating uneven crossfall and resulting concentration of rainfall runoff, will minimise runnel erosion in levee batters.

6.5.9 Crest Maintenance

Irrespective of the type of crest protection, the objective of crest maintenance is to maintain the desired height of the levee, as well as the crest profile that enables rainfall to be evenly shed across the bank. Maintenance is basic and consists of light grading, as required, and filling potholes. These measures will help avoid the possibility of:

- Water ponding;
- Piping failures;
- Development of high internal pressure;

- Softening of the embankment.

In the case of a gravelled crest, periodic re-gravelling may be required, and for topsoiled banks, topping to maintain the crest level. On-demand repaving may be required for bitumen sealed crests.

6.5.10 Drainage Systems

Levees interfere with drainage lines, and drainage outfalls under levees can be potential weak spots in the levee.

All drainage structures need to be inspected regularly, to ensure their effective operation in a flood event. The inspection should cover:

- Earthworks;
- Headwalls;
- Cutoffs;
- Beaching / riprap
- Operation of valves, gates or stop logs, to ensure the integrity of the structure is complete and satisfactory.

During a flood event, where drains pass through a levee, it may be necessary to provide pumping facilities enabling drainage flows to be pumped to the outfall after the control gates have been closed. Pumping arrangements, including the timing of gate closures, need to be strategically planned and detailed in the LOM. The inclusion of this information ensures that staff are aware of the necessary mechanisms and procedures to render the levee completely closed against river flooding.

6.5.11 Grazing of Stock

Generally, grazing should not be permitted on levees, because it destroys the vegetative and mulch cover on the batters, as well as the underlying bank.

The most difficult feature of grazing is managing the level of activity the levee can tolerate. If this can be achieved, light grazing of levees on an occasional basis, may be acceptable, particularly during periods of heavy grass growth.

6.5.12 Work, Health and Safety (WHS)

There are many WHS issues that should be considered within the context of levee ownership and O&M. A levee Visual Audit (VA) alone cannot be relied upon to identify all the potential WHS issues along the entire levee. For routine day-to-day O&M activities, the levee owner must establish, implement and manage the use of safety measures in accordance with the relevant and current WHS Regulations and Guidelines (e.g. SafeWork NSW). Relevant Australian Standards also offer guidance on minimum safety requirement of auxiliary structures such as stairs, platforms, handrails, floor grating, etc.

Some key WHS issues associated with levees and their appurtenances are:

- Access, operation and security of floodgates / flood barriers.
- Trip and Fall hazards.

- Confined spaces.
- Protruding edges.

The identification and elimination (or mitigation of risks) of such WHS hazards are important for the levee operators as well as the general public, where levee access is permitted.

Refer to PWA's Development of Methodology and Visual Audit for Urban Levees for more detailed guidance.

7. COMMUNICATION PLAN

As well as the levee owner, there are many stakeholders with interests in a levee system both before and during a flood emergency. Some of these stakeholders are:

- NSW State Emergency Services (SES) – primary responsibility for emergency response planning (legislated).
- Environment, Energy and Science (EES) – supports local government and other state agencies with flood risk management guidance.
- Police and Emergency Services – coordinates and executes security and recovery operations
- General community – level of protection afforded, requirement / obligation to evacuate
- Business owners – potential for disruption and damages to businesses.

The abovementioned parties all have right of knowledge of the levee and its appurtenances.

7.1 State Government Agencies

Under the NSW State Emergency Management Doctrine of PPRR (Planning, Preparation, Response & Recovery), it is vital that State Agencies have up to date information on levees to allow effective PPRR for flood events.

Levee owners must regularly share current knowledge of their levee so that government decision making is informed and responsible and staff do not make critical decisions using outdated, inaccurate or wrong information (e.g. whether or not to evacuate a community).

Any significant changes to a levee system must be communicated to the SES and EES for updating the NSW Flood Database and intelligence. Examples of these changes include upgrades that improve the levee capacity, revised flood operating levels, developed IFCL, capacity limiting issues such as a low section in levee or serious defects, etc.

7.2 Community Consultation

Sharing of knowledge and imparting "ownership" of the levee can be enhanced by way of community consultation and communications. Community consultation can result in:

- Acceptance of responsibility for public / community / individuals / environment, and overall well-being and economic development of the region, state and in some cases, the country.
- Local / regional concerns being better understood and more readily addressed, with other improvement opportunities identified and included or allowed for in any levee safety improvement.
- Stakeholders, especially public who bear levee failure risks, having the chance to participate in an effective manner, being given early opportunity to understand risks, and either:
  - openly accept risks as tolerable.
  - endorse proposed risk mitigation measures.
  - lobby for greater risk reduction.
  - move family and property elsewhere.

It does not mean achieving agreement from all interested stakeholders although overall concurrence to a proposed solution is always the aim. Achieving a win / win outcome can be maximised or alternatively the impacts minimised and more equitably shared, within overriding constraints:

- Stakeholders being better informed and better able to understand the wide range of issues and can assist in developing/trading off, so the levee owner can determine the most cost-effective levee safety improvement, if required.
- Stakeholder ownership of outcomes and development of trust or at least adequate disclosure to these stakeholders.
- Objections and delays to improvements being minimised and there is greater potential for the key stakeholders to work with, rather than against, levee owners during upgrade.

7.3 Community Engagement

Apart from the previous arrangements, there are a number of important subsidiary activities that affect the ability of a community to satisfactorily manage a significant flood event. These include areas such as flood monitoring, communication, road monitoring/closures, media releases, evacuation and relief, livestock management, asset protection and registration of volunteers.

These activities rely heavily on a community that is aware of the nature of the emergency and the plan to combat it, as well as having a minimum core of skills necessary to carry out the various tasks involved.

To improve community response in a flood event, it is necessary to develop a strategy that will increase their general knowledge, awareness and basic skills. Development of this strategy or program should consider the following points:

- Distribution and explanation of Council's Flood Plain Risk Management Strategy and Plans or associated community newsletters.
- Working with SES to update the local flood plan (LFP) and the local Flood Safe Guide. (SES may have specialist community engagement co-ordination in local areas).
- Evacuation procedures for caravan parks and other low lying areas.
- Pre-preparation of media releases and bulletins.
- Media interview techniques for selected positions.
- Training support agencies.
- Revision / training on sandbag laying techniques.
- Developing inter-agency liaison arrangements.
- Disseminating flood management handbooks and awareness material.
- Addressing community groups and schools.
- Arranging pre-flood briefings.
- Arranging pre-flood public meetings.
- Arranging post-flood briefings.

8. EMERGENCY RESPONSE PLANNING

8.1 NSW Flood Emergency Response Planning

Under the SERM Act and EMPLAN, NSW SES is the combat (lead) agency for floods (including coastal inundation), storms and tsunami events. As such the SES is responsible for planning for and responding to these hazards. Also, under the State Emergency Service Act 1989, it is able to issue orders for mandatory evacuations.

In conducting its planning and response to incidents, the SES adopts a range of principles that form a decision making paradigm. Although the following principles have been articulated and generally understood within most areas of the emergency management community, the report of the Victorian Bushfire Royal Commission (Victorian Bushfire Royal Commission 2010) has given particular emphasis to them in recent times. The core principles can be readily applied to the management of hazards other than bushfire and have been specifically applied to flood events and levees by SES, as follows:

- Protection of life is the highest priority.
- Property protection is always secondary.
- Urban design and development must take into account expected human behaviour.
- Urban design and development must take into account the expected range of severity of hazards.
- Emergency management strategies must take into account expected human behaviour.
- Emergency management strategies must take into account the expected range of severity of the hazards.
- The safest place for people to be during the impact of hazard is away from the area being impacted.

The principles above highlight the complexity of emergency management and that emergency response plans must be maintained for all communities.

Accordingly, the SES oversees the preparation of local flood plans (LFP) for NSW Council areas with significant flood risk. The SES also maintains a flood intelligence system that records and provides access to flood consequence information at key warning gauges across NSW.

LFPs are prepared in consultation with all stakeholders through a local Flood Planning Committee and endorsed by the LEMC. A primary outcome of this consultative Emergency Risk Management process is a shared understanding of the roles and responsibilities of stakeholders and of the strategies, planning and actions to support community safety.

LFPs are reviewed on a five-yearly basis but are amended at any time, such as after significant flooding or where changes to the floodplain occur. This is particularly important with respect to levees and it is of the upmost importance that up to date information, especially changes to levee performance, are communicated to SES and emergency management committees so that planning remains current.

The SES information requirements and the linkages across levee management, council flood risk management and SES emergency management are critical to implementing successful community safety strategies. Poor or out of date information contained in plans or public information resources, is a key factor that often leads to problematic implementation of emergency response strategies with communities.

8.2 Decision Making for NSW Levee Emergencies

When the above mentioned principles are specifically applied to NSW levees, the following key levee decision making principles and paradigm are established:

1. All levees, unless designed for the Probable Maximum Flood (PMF) event, will ultimately be overtopped by less frequent (i.e. more severe) events than their design or operating levels, or possibly fail through lack of maintenance, inadequate construction or unforeseen circumstances.
2. Evacuation of the Population At Risk (PAR) behind a levee is the most effective strategy for a reliable and defensible public safety strategy.
   - Evacuation is the temporary movement (relocation) of people from a dangerous or potentially dangerous place (for example, from behind a levee) to a safe location, and their eventual return. It is a safety strategy that uses distance to separate people from the danger created by a hazard.
   - Evacuation is well established throughout the world as the primary strategy for managing the safety of people in flood environments.
   - Evacuation is not a simple solution as many factors influence its effectiveness.
3. Levee design heights and effective flood operating heights are primary triggers for planning to evacuate communities. Planning must take into account the time required to enact the evacuation before flooding prevents it being completed.
   - The levee design height or effective flood operating height designate the limit of reliability or confidence in that levee. Above this height, unless exceptional and evidenced circumstances occur, it will not be safe for communities to remain behind the levees.
   - If there is uncertainty over the upper limit of future river levels, or if river levels are predicted to reach or exceed the design or effective flood operating level then an evacuation will be commenced.
   - Evacuation will be planned for and enacted until it is proven beyond reasonable doubt that it is no longer required. In other words, if there is uncertainty over whether river levels will threaten the levee, or if there are structural or other issues with the levee that may endanger the community, the SES will plan and conduct evacuation of at-risk population.

8.3 Levee Evacuation Considerations

The planning for flood evacuation should commence with an assumption that evacuation is the most effective strategy. However, given the likelihood of some proportion of the population failing to evacuate, either by choice or impediment, a rescue contingency must also be planned for.

SES has developed an analytical approach to planning for flood events, which includes assessing the likely triggers for evacuations, their potential scale and the time required to affect them.

A key aspect of the analysis and planning is the Flood Evacuation Timeline Model (the Timeline), (see Subsection 8.4 for further references). The key outcome of the Timeline is an assessment of the time required for evacuation versus the time available for evacuation. With respect to levees, the assessment is used to plan when an evacuation must commence so it can be completed before a key trigger or critical end point is reached or when a threat to community safety is expected to occur. In most cases this trigger or end point will be the design height or the effective flood operating height, or the closure of key evacuation routes by floodwater.

8.4 Recommended Resources for Levee Owners Assist SES

To assist the SES in its emergency response planning role, including evacuation planning, two guidelines have been produced to help those working in floodplain management provide the information which the SES requires. These guidelines are highly relevant when considering communities protected by levees.

The following are some of the applicable Flood Risk Management Guidelines:

- SES Requirements from the FRM Process (DECC, 2007a)
- Flood Emergency Response Planning Classification of Communities (DECC, 2007b).

These guidelines and other useful resources can be found at:

http://www.environment.nsw.gov.au/floodplains/StandardFloodplainRiskManagement.htm

In addition, the SES has developed a flood evacuation timeline model (Opper et al, 2009) to quantify flood evacuation needs for a locality or region and to assist the SES with their flood evacuation planning. Increasingly, the timeline evacuation model has also been used to assess the evacuation implications of proposed developments. Further information regarding this guideline can be obtained by contacting SES State Headquarters.

8.5 Information of Emergency Decision Making

A levee owner has responsibility to work co-operatively with SES during a flood event. Knowledge and data about levees should be exchanged through Emergency Management and Floodplain Management Committees that prepare and maintain a range of plans aimed at improving public safety. For local councils, the key committees are:

- **Council Flood Plain Risk Management Committee** – Levee information should be exchanged throughout the various stages of studies and plans completed in accordance with the Floodplain Development Manual.
  - Key Document: Floodplain Risk Management Studies and Plans.
- **Local Emergency Management Committee (LEMC)**, which is chaired by the Council's General Manager.
  - Key Document: Local EMPLAN.
- **SES Flood Planning Committee**, which reviews the LFP for the Council area.

Other Key Documents:

- The LFP, during periodic review or at any time changes to the levee occur.
- SES Flood Intelligence Cards (FIC).

As a minimum, the owner should ensure that the following information is provided to the SES as soon as it becomes available, to assist in emergency response planning:

- Levee crest level profile from the latest Crest Level Survey.
- Historic and design floodwater profiles parallel with the above, including stream gauge location.

- Levee location and other physical details and features (e.g. plan of floodgates, flood barriers, pump stations, openings requiring sandbagging, etc.).
- Flood operating level or IFCL.
- Levee condition assessment, including any areas of particular concern (latest OI / VA reports).
- Flood inundation maps, with and without levee failure.

For further details about information requirements to assist the SES to undertake emergency response planning, levee owners should consult guidelines published on the DPIE floodplain risk management documents website page. Specifically, the guideline titled SES requirements from the FRM Process (DECC, 2007) provides specific guidance on requirements.

8.6 Emergency Levee Work

8.6.1 History

A number of levees in the past have been pushed-up or raised / topped-up or repaired immediately prior to an impending flood event where floodwaters are predicted to exceed the levee crest levels. This is usually, of necessity, carried out on an emergency "ad hoc" basis and not to engineering design and construction standards.

Common features of these emergency construction works are:

- They have been constructed without thorough engineering inputs.
- They have been constructed in haste with non-compliant earthfill materials, limited foundation preparation or compaction control / testing using inappropriate construction equipment.
- They have been previously successively raised or topped up over the years immediately prior to flood events.

Such emergency work has typically remained in place after the flood emergency has passed but without any follow on confirmation of quality, and therefore the work is of unknown reliability.

Based on experience in the examination and geotechnical testing of a number of these types of levees, the general characteristics are that they:

- are poorly compacted.
- experience a high degree of cracking.
- are more susceptible to erosion in comparison to newly constructed levees.
- exhibit a very high degree of variability in their geotechnical properties (such as compaction, moisture content, permeability and erodibility).
- are likely to have highly varying floodwater retaining capacity.

The recommended approach is to not to rely on any such emergency levee work, unless it has been confirmed by detailed engineering assessment to be of equivalent standard of a properly designed and constructed levee.

8.6.2 Principles for Emergency Work

Emergency upgrade works (such as repairing weak spots, raising low areas of the levee, adding batter protection, or repairing leaks) may assist in avoiding property damage and civil disruption from a major flood event, but they must not be relied upon to protect lives as the level of confidence in its effectiveness will not be sufficiently high.

Every levee is unique and will require specifically engineered emergency works together with a degree of engineering judgement to achieve the desired outcomes. If possible, advice on these matters should be sought from engineers experienced in flood levee investigations, design and construction activities.

Principles for undertaking emergency repair work are given in **Appendix C**. Note that these principles are not engineering recommendations for design and construction of emergency works for a specific levee but only basic principles for undertaking emergency work. Application of these principles needs to be supported by specialist engineering expertise.

8.6.3 Emergency Work Preparation Plan

Owners of levees with defects can, as part of their contingency planning, have a suitable flood preparation plan with suitable, pre-positioned construction equipment and material stockpile. This is not recommended as a long-term solution. Table 8-1 shows the elements required in a preparation plan for emergency work.

Table 8-1 Elements of Emergency Work Flood Preparation Plan

Element	Pre-Emptive Measures
Suitably tested fill material	Levee owner could have a suitable borrow area predetermined and basic soil testing undertaken to confirm material suitability.
A levee design for potential work needed	A design for a new levee, levee upgrade design, or a list of repair work required, could be determined beforehand.
Resources and construction equipment (e.g. excavator, trucks, rollers, water carts etc.)	Levee owner could ensure that sufficient plant, equipment and resources (owned, hired or contracted) are available.
Quality Control testing (i.e. soil testing, compaction testing)	Nominated on-site geotechnical engineer can be arranged as required.
Sufficient time to undertake the work effectively	Sufficient construction resources could be identified as being available to construct/repair required levee sections before the floodwaters rise.

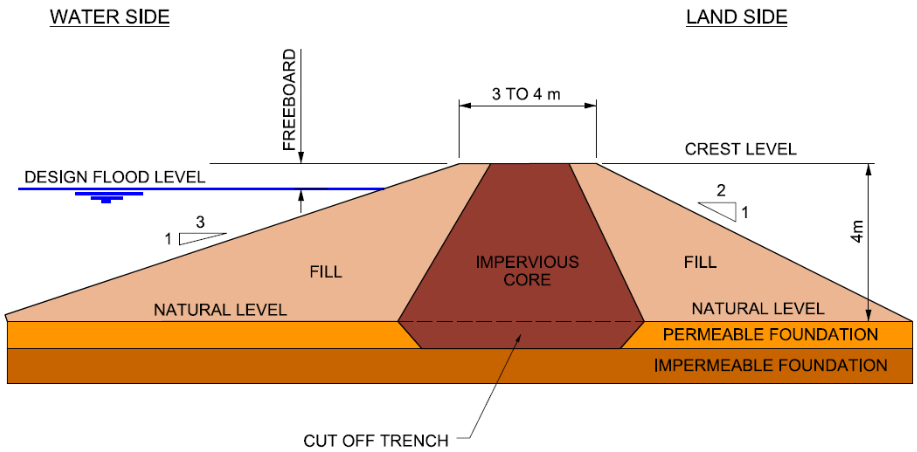
Provided that there is sufficient time to undertake construction of the emergency work before floodwater levels rise too high, and there has been enough pre-planning, then it may be possible to construct an emergency levee that does have better reliability.

Obviously, owners with defects in their levee are better served by addressing them well before a flood event.

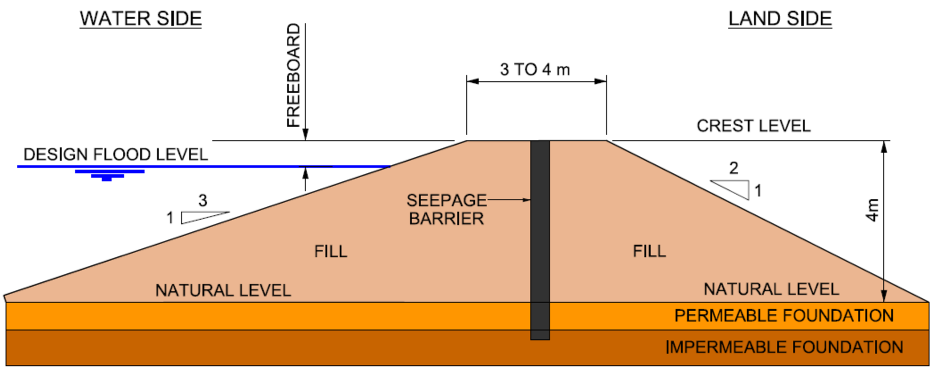
9. REFERENCES

4. CIRIA, Ministry of Ecology, USACE – *International Levee Handbook (November 2013)*
5. Department of Planning, Industry and Environment (DPIE) (previously known as Department of Environment and Climate Change (DECC) and Office of Environment and Heritage (OEH)) – *2007 Flood Risk Management Guideline – SES Requirements for the FRM Process*
6. Department of Planning, Industry and Environment (DPIE) (previously known as Department of Environment and Climate Change (DECC) and Office of Environment and Heritage (OEH)) – *2007 Flood Risk Management Guideline – Flood Emergency Response Classification of Communities*
7. Jacobs 2016 – *Retarding Basin Failure Mode Guidance Note (prepared for Melbourne Water) – Project No.: IS141700, 15th July 2016*
8. NSW Public Works 2013 – *Development of Methodology and Visual Audit for Urban Levees (Report Number: DC13004 – Updated July 2020)*
9. Opper, S. Cinque, P. Davies, B. 2009 – *Timeline modelling of flood evacuation operations Presented at First International Conference on Evacuation Modelling and Management, Netherlands*
10. Opper, S 2004 – *The Application of Timelines to Evacuation Planning*
11. Public Works Advisory (PWA) 2019 – *NSW Urban Flood Levee Interim Flood Confidence Limit Guideline, Version 1*
12. US Army Corps of Engineers 2000 – *Design and Construction of Levees*
13. US Army Corps of Engineers 2006 – *Levee Owner's Manual for Non-Federal Flood Control Works*
14. US Army Corps of Engineers, St Paul District 2016 – *Flood Fight Handbook 2016 Edition*

Appendix A Levee Definitions

Term	Definition
Annual Exceedance Probability (AEP)	Flood Frequency Floodplain Development Manual – The chance of a flood event of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger events occurring in any one year (see ARI).
Average Recurrence Interval (ARI)	Floodplain Development Manual – The long-term average number of years between the occurrence of a flood event as big as or larger than the selected event. For example, flood events with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Crest Level Survey	Is a survey of the crest level of a levee only. Picks up elevation levels and position. Levels are usually taken every 50 to 100 m (depending on the total levee distance), at changes in level and changes in direction or levee type.
Cut-off	International Levee Handbook – A cut-off wall or material zone may be installed at the junction between the impervious part of the levee and the impervious soil foundation. The cut-off may consist of excavated trenches back-filled with compacted clay, slurry trenches, steel sheet piling, vinyl sheet piling, or bentonite mats. 
Design Crest Level	Design Crest Level = Design Flood Level + Freeboard height
Design Flood Level	Design Flood Level is the level adopted by the levee owner for a flood event with a specific AEP.
Flood Slope	Gradient – Slope in the water level from the upstream end of the flood model to the downstream end. It is expressed in metres fall of water per kilometre of river length (m/km). It must be remembered that: • The water heights obtained from the gauge readings are only at one location along this flood slope. • The actual water height upstream or downstream of the gauge will be different to the gauge level. • The flood slope can be significant (for example, 1 m fall from the upstream end of town to the downstream end).
Flood Operating Level	Maximum floodwater level on a levee in its current state that provides a "safe" level of protection.

Term	Definition
Freeboard	Freeboard is incorporated into the Levee Design Height as the incremental difference in height between the Design Flood Level for the levee and the Design Crest Level of the levee. The purpose of freeboard is to provide a reasonable certainty that the risk exposure associated with a particular design flood event is actually provided.
Gauge	Is an instrument that measures the water surface elevation over time at a particular location. A variety of measurement devices may be used. These devices may be manual (a sight gauge), automatic and telemetered.
Gauge Height	International Levee Handbook – Stream gauging measures the water surface elevations over time. Water levels are measured relative to a reference point, which may be arbitrary or adjusted to the local vertical datum. Where an arbitrary point is used, this point (referred to as gauge zero) can be tied to the local vertical datum. Water level above the reference point is known as gauge height.
Gauge Zero	Where an arbitrary reference point is used, this point is referred to as gauge zero and can be tied to the local vertical datum.
Levee	International Levee Handbook – A levee is one of many features within the overall flood defence system that may include man-made and natural structures complementing one another to provide protection to a designated area from inundation. Levees have three primary hydraulic functions: • **Retain** – to reduce the risk of inundation to an area by temporarily retaining water, keeping it out of the leveed area to a defined water level in order to prevent worse flood conditions further downstream • **Channel** – to channel floodwater downstream or into a non-protected area to avoid inundation of the leveed area • **Control Release** – to provide a controlled release of water in a designated location that will minimise inundation downstream. Any levee can have one or all of these functions. There is, however, one exception to the aforementioned list of hydraulic functions: canals where the function is to keep water contained within the confines of the canal or land immediately adjacent to the canal.
Levee Batter	The sloping faces (waterside and landside) of an earth levee from the crest down to natural ground level.
Levee Crest	The crest is the flat, top surface of the levee. It is often designed with a small cross-slope to provide a preferential direction for rainfall runoff. The crest is usually provided with a gravel surface to aid vehicular access during wet weather and to protect the underlying levee embankment against rain damage and deterioration caused by vehicular traffic.
Levee Shoulder	The intersection point of the Levee Crest and the Levee Batters.
Levee Toe	The intersection point of the Levee Batter and natural ground.
Flood Study Report	Floodplain Development Manual – A report that defines the nature and extent of the flood problem, in technical rather than map form. Usually undertaken by consultants appointed by the council. A flood study is a comprehensive technical investigation of flood behaviour. It defines the nature of flood risk by providing information on the extent, level and velocity of floodwaters and on the distribution of flood flows across various sections of the floodplain for the full range of flood events up to and including the Probable Maximum Flood (PMF). Major components of a flood study involve determining discharge (hydrologic aspects) and water levels, velocities, etc (hydraulic aspects) for flood events of varying severity.

Term	Definition
Floodplain Risk Management Study	Floodplain Development Manual – Determines options in consideration of social, ecological and economic factors relating to flood risk. Usually undertaken by consultants appointed by the council. A floodplain risk management study is a multidisciplinary process that is lengthy and detailed. The management study balances a number of differing factors to generate recommendations for an appropriate mix of management measures to deal with the different types of flood risk.
Floodplain Risk Management Plan	Floodplain Development Manual – A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Seepage Barrier	International Levee Handbook – A seepage barriers may be implemented throughout the whole levee embankment and permeable foundation strata. 
Spillway	International Levee Handbook – A spillway is a structure that is designed to provide a controlled release of water from one area to another, either over the structure or through it. It can be designed to divert water from the river or restore water to the river. Most often, spillways release floods to prevent overflow or damage to the dam or levee. Except during high water events, water would not normally flow over the spillway. If the flow rate can be controlled by mechanical means, such as gates, it is considered a controlled spillway. If, however, the geometry of the spillway is the only control, it is considered an uncontrolled spillway.
Spillway Trigger Level	Spillway Trigger Level = Design Flood Level + Trigger Freeboard height

Appendix B Sample LOM Contents

The Levee Owner's Manual (LOM) is a Quality Controlled document with an Amendment Page to indicate what has been amended, by whom and when. A Distribution List must also be provided to indicate the relevant parties' acknowledgement of the LOM's existence. It should be annually reviewed by the levee owner and thoroughly reviewed as part of the levee's 5 yearly Visual Audit (VA). An EES-endorsed LOM template is available upon request to EES.

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Appendix C Principles for Emergency Repair Work

The following principles have been offered as "general guides only" and should not be interpreted as the universal technical specification for the execution any random emergency repair works. It is certainly not a basis for the design of permanent measures.

Every flood levee is unique and will require specifically engineered emergency works together with a degree of engineering judgement to achieve the desired outcomes. Advice on these matters should be sought from engineers experienced in flood levee investigations, design and construction activities. The levee owner should develop and document the most appropriate emergency measures with experienced engineers as part of the development of the LOM. It is imperative that the levee owner is involved with this process as it is the levee owner's responsibility to organised, coordinate and execute such tasks, while the SES may have some capacity to offer assistance.

Nevertheless, there are a number of basic principles for emergency work. Application of these principles, supported by specialist engineering expertise, may improve the protection provided by emergency levee works.

It is important to note that emergency upgrade works to increase the level of protection provided to the community may assist in avoiding property damage and civil disruption from a flood event, but they must not be relied upon to protect life as the level of confidence in its effectiveness will not be sufficiently high.

The following is a combination of extracts from the Flood Fight Handbook (2016) and some supplementary information provided by PWA. To reiterate, it is offered as a "general guide only". The guidance from the latest version of the Flood Fight Handbook should always be consulted with experienced engineers for tailoring to suit certain characteristics of the levee system. It would then be deemed suitable to be adopted and documented as part of the LOM.

EARTHFILL

There can be many choices of materials and equipment that are suitable, but in an emergency situation it comes down to the most readily available

Earthfill is the preferred material for large scale emergency flood works. Particular issues to consider include:

Borrow Areas

Borrow material can become a critical item of earthfill supply during a flood emergency. Two prime requisites for the borrow area(s) are that adequate material is available and that the site is accessible at all times.

It may become necessary to stockpile material near anticipated trouble areas.

Equipment

Under emergency conditions, obtaining normally specified earthworks equipment will be difficult and the work will generally be done with locally available equipment. If possible, this equipment should include compaction equipment (padfoot roller preferred). Scrapers should be used for hauling when possible because of speed (on short haul) and large capacity. A bulldozer of some size is necessary to help spread dumped fill and to provide some compaction.

Foundation Preparation

One of the primary differences in the construction of emergency levees and the construction of permanent levees lies in the preparation of the foundations. Prior to any embankment construction, it is very important that the foundation be prepared, particularly if the levee is to be left in place. Trees that may be present should be cut and the stumps removed and all obstructions above the ground surface should be removed, if possible. This will include brush, structures, snags, and similar debris.

The foundation should then be stripped of topsoil and the material pushed landward of the toe of levee and windrowed. After the flood, this material can be spread on the slopes of the levee to provide topsoil for vegetation.

Materials

Earth fill materials for emergency levees will come from local borrow areas. An attempt should be made to use materials that are compatible with the foundation materials, however, due to time limitations, any local materials may be used if reasonable construction procedures are followed.

These reasonable construction procedures include:

<u>Clay Fill</u> – The majority of earth fill levees consist of clay or predominantly clayey materials. Clay is preferred because it is relatively impervious and has relatively high resistance to erosion in a compacted state.

<u>Sand Fill</u> – If sand is used, flat slopes are necessary, as steep slopes without protection from a liner will result in potentially uncontrolled seepage through the levee. This may cause the levee formation to fail.

<u>Silt</u> – Material that is primarily silt should be avoided. If silt must be used, liners must always be applied to the river slope. Silt, upon wetting, tends to collapse under its own weight and is very susceptible to erosion.

Levee Section

The dimensions of the levee section are generally dictated by the foundation soils and the materials that are available for construction. Therefore, even under emergency conditions, an attempt should be made to make the raised levee embankment compatible with the foundation.

Some basic guidance on an appropriate emergency levee sections can be gained from three typical foundation conditions and associated levee design sections which are described below. These sections assume a sand foundation, a clay foundation, or a thin clay layer over sand foundation. It must always be remembered though, that actual field conditions generally depart from the ideals to various degrees.

In determining the top width of any type of section, consideration should be given to whether a revised floodwater level forecast will require additional fill to be placed. A top width adequate for construction equipment will facilitate raising the levee. Finally, actual levee construction will, in many cases, depend on available time, materials, and right-of-way access.

<u>Sand Foundation</u> – If the foundation material under the emergency levee is sand or some other pervious material, the following guidance for an emergency levee section to be constructed could be considered:

> Sand Section – If sand is to be used for construction of the emergency levee section, use a minimum ratio of 1V (Vertical) to 3H (Horizontal) on the riverside slopes, and a minimum ratio of 1V to 5H on the landward slope. The crest width should be at least 3 metres.

Clay Section – If clay is to be used for construction of the emergency levee section, use a minimum ratio of 1V to 2.5H for both the riverside and landside slopes. In heightened emergency conditions, steeper batters may be used. The bottom width of the levee section should comply with creep ratio criteria, calculated as follows:

L (across bottom) = C x H

where ;

C = 9 for fine gravel and

C = 15 for fine sand in the foundation, and

H = levee height.

These bottom width criteria can be met by using berms consisting of material placed on either the landward or riverward side of a levee that extends beyond the normal levee foot print. These berms are placed to control or relieve uplift pressures and lengthen the seepage path, although they will not significantly reduce the volume of seepage. Berms do not need to be as high as the levee itself, and thickness of the berm should be at least 1 metre.

<u>Clay Foundations</u> – If the foundation material under the emergency levee is clay or some other impervious material, the following guidance for an emergency levee section to be constructed could be considered

Sand Section – If sand is to be used for construction of the emergency levee section, use a minimum ratio of 1V (Vertical) to 3H (Horizontal) on the riverside slopes, and a minimum ratio of 1V to 5H on the landward slope. The crest width should be at least 3 metres.

Clay Section – If clay is to be used for construction of the emergency levee section, use a minimum ratio of 1V to 2.5H for both the riverside and landside slopes. In heightened emergency conditions, steeper batters may be used.

<u>Clay Layer over Sand Foundation</u> – If the foundation material under the emergency levee consists of a clay layer over sand (or other permeable) foundation, the following guidance for an emergency levee section to be constructed could be considered

Sand Section – If sand is to be used for construction of the emergency levee section, use a minimum ratio of 1V (Vertical) to 3H (Horizontal) on the riverside slopes, and a minimum ratio of 1V to 5H on the landward slope. The crest width should be at least 3 metres.

In addition, a landside berm of sufficient thickness may be necessary to prevent rupture of the overlying clay layer. The berm may be composed of sand, gravel, or clay material. Design of berms requires considerable information and detailed analysis of soil conditions, however prior technical assistance may reduce berm construction requirements in any emergency situation.

Clay Section – If clay is to be used for construction of the emergency levee section, use a minimum ratio of 1V to 2.5H for both the riverside and landside slopes. In heightened emergency conditions, steeper batters may be used.

A berm to prevent rupture may also be necessary as described above. Proper compaction of the emergency levee is critical to stability. Use of standard compaction equipment such as a padfoot roller, may not be feasible during emergency operations because of time constraints or limited equipment availability. It is expected that in most cases the only compaction available will be from hauling and spreading equipment, such as dump trucks and dozers.

Placement

Earthfill layers, which comprise the emergency levee, should be commenced to the full width of the required embankment base. Subsequent lifts should be placed in substantially horizontal layers. In general, the levee section should be homogeneous, however when materials of varying permeability are encountered in the borrow area(s), the more pervious material should be placed on the landside of the embankment.

Compaction

Obtaining proper compaction equipment for a given soil type will often be difficult under emergency flood situations. It is expected that in most cases, compaction will only be provided by the hauling and spreading equipment (i.e. construction traffic routed over the fill). In some circumstances even the minimum compaction requirements may not be possible or feasible, and if the situation demands, material should be placed and compacted in any way possible and the levee closely observed for signs of distress. Experienced earthworks personnel should ideally oversee the construction of emergency levees.

Notwithstanding the above, use of these guidelines should not be taken as a guarantee that a safe structure will be constructed.

Pervious Fill – Material should be placed in layers not more than 300 mm thick prior to compaction. In emergency situations, each layer should be compacted at the very minimum by one pass of the hauling equipment. However, whenever time and availability of equipment permits, a much safer structure will result if each layer is compacted by a minimum of three (3) complete passes of a crawler-type tractor, or by two (2) passes of a vibratory roller.

Impervious Fill – Fill material should be placed in layers not exceeding 200 mm thickness prior to compaction. In emergency situations, each layer should receive at least one complete coverage of the track or wheel of the placing equipment or equivalent. However, where time and availability of equipment will permit, a much safer structure will result if each layer is compacted by a minimum of 4 to 6 complete passes of a tamping (padfoot) type roller or four (4) complete passes of a rubber tyred roller.

SCOUR PROTECTION

Scour protection may be required for emergency levees. Factors that influence whether or not additional scour protection is required include levee material (clay levees tend to be much more resistant to scour than sand levees), channel velocities, presence of debris in the river/creek, wave action, and seepage. Methods of protecting levee slopes are numerous and varied. However, during a flood emergency, time, availability of materials and construction capability may limit the use of certain accepted methods of permanent slope protection.

Field personnel must decide the type and extent of slope protection the emergency levee will need. Several methods of protection have been established that prove highly effective in an emergency and resourcefulness on the part of the field personnel may be necessary for success. The following is a brief summary of some of the options for providing emergency scour protection for levees.

Polyethylene and Sandbags

A combination of polyethylene sheet and sandbags has proven to be an expedient and effective method of combating batter slope attack in a flood situation. Polyethylene and sandbags can be used in a variety of combinations, and time becomes the factor that may determine which combination to use.

Ideally, polyethylene sheet and sandbag protection should be placed before water has reach to toe of the levee – "in the dry." However, many cases of unexpected slope attack will occur during high water, and a method for placement "in the wet" is required. Because each flood fight project is unique (river, personnel available, materials, etc.), specific details of placement and materials handling cannot be covered, however field personnel must be aware of resources available when using polyethylene and sandbags.

Anchoring the polyethylene along the riverward toe is important for a successful job. It may be done in three different ways. The most successful is as follows:

Polyethylene is placed flat on the ground surface away from the levee toe and one or more rows of sandbags placed over the flap. The polyethylene is then unrolled over this bottom row of sandbags, and up the slope and over the top enough to allow for anchoring with sandbags (see Figure 1).

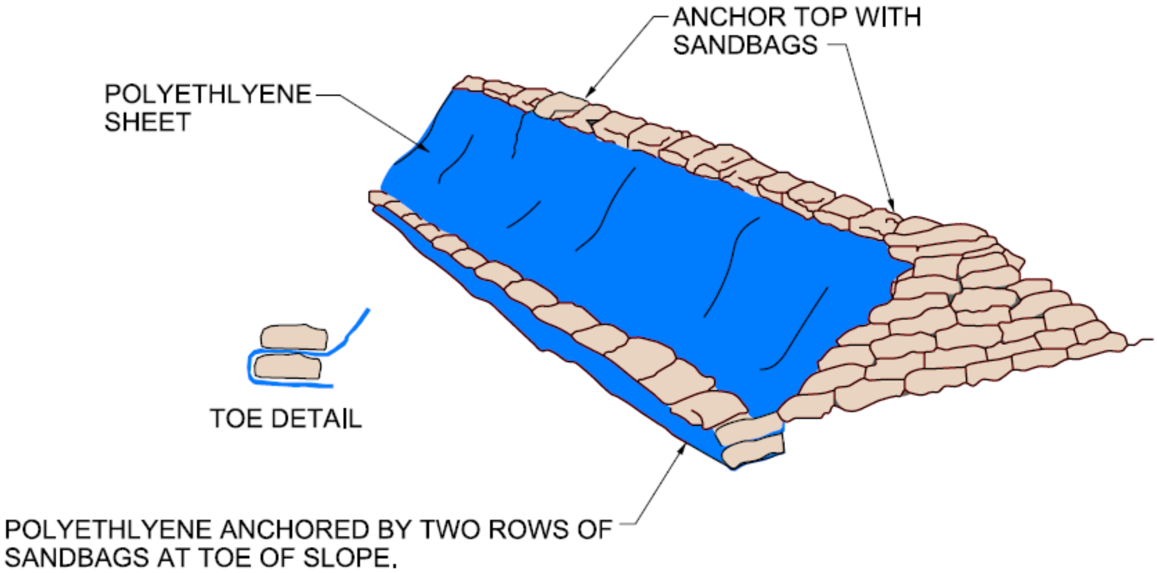

Figure 1 – Anchorage of polyethylene sheet with two rows of sandbags

Polyethylene is placed flat on the ground surface away from the levee toe, and sandbags are placed over the flap (see Figure 2).

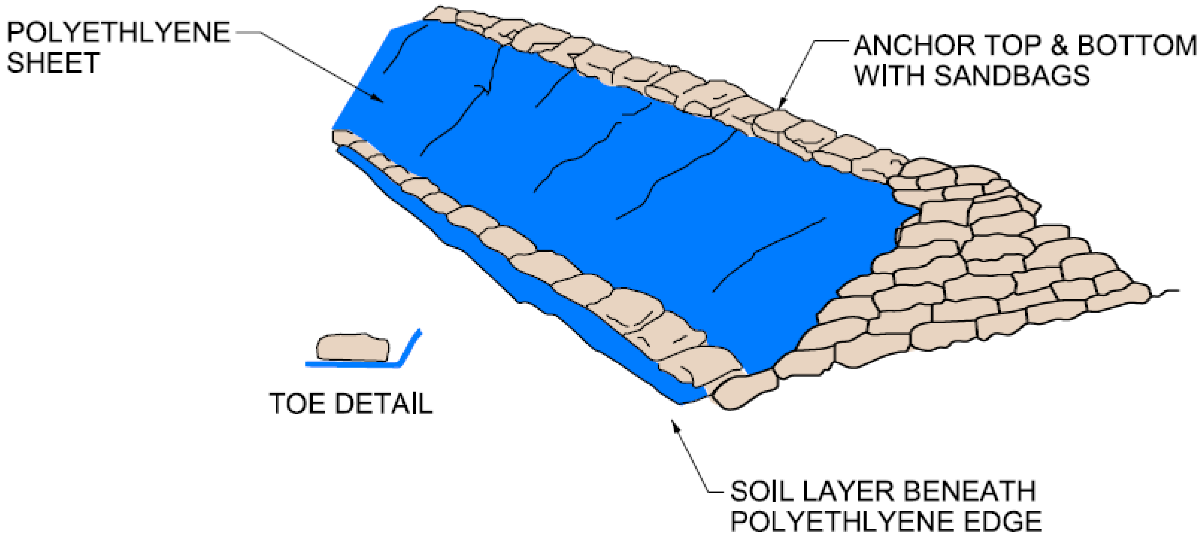

Figure 2 – Anchorage of polyethylene sheet with single row of sandbags

A trench is excavated along the toe of the levee, polyethylene is placed in the trench, and the trench is backfilled (see Figure 3).

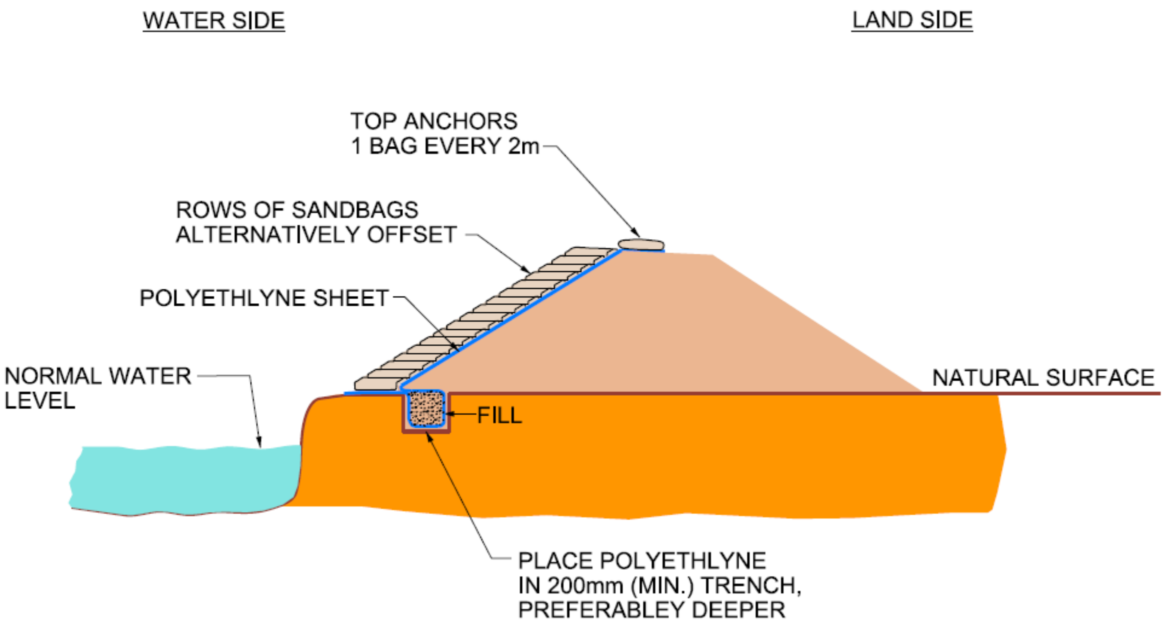

Figure 3 – Anchorage of polyethylene sheet in a trench (dry conditions)

Polyethylene should always be placed from downstream to upstream along the slopes and the next sheet upstream overlapped by at least one metre. Overlapping in this direction prevents the current from flowing under the overlap and unravelling the sheets (see Figure 4). Once the polyethylene is placed, additional sandbags are needed on top of the polyethylene to anchor it in place.

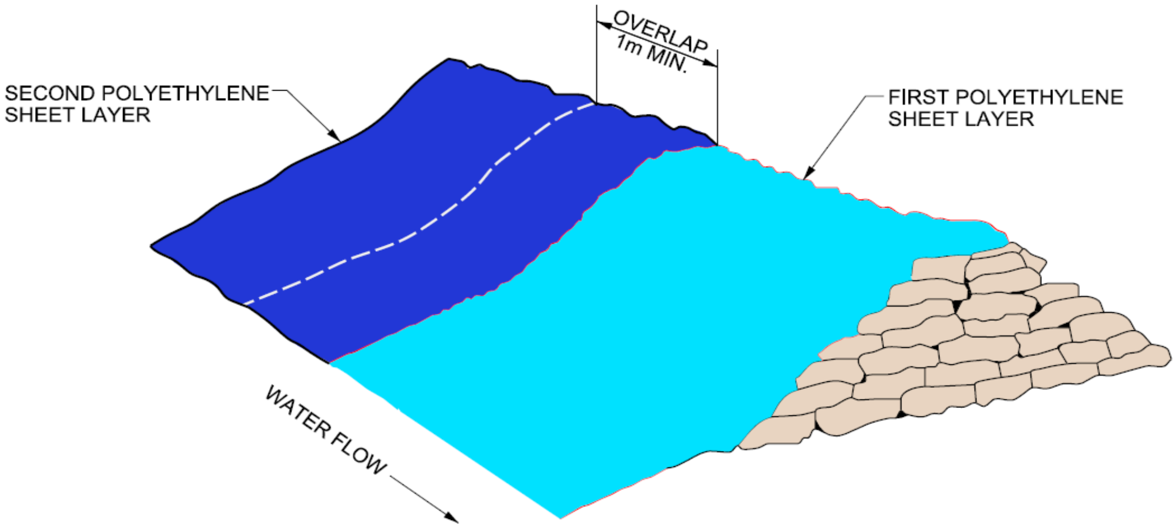

Figure 4 – Polyethylene sheet placement from downstream with overlap

It is mandatory that polyethylene placed on levee slopes be held down. Unless extremely high velocities or heavy debris is anticipated, an effective method of anchoring polyethylene is a grid system of sandbags. A grid system can be constructed faster and requires fewer bags and much less labour than a total covering.

Various grid systems include vertical rows of lapped bags, "4 x 2" timbers held down by attached bags, and rows of bags held by a continuous rope tied to each bag. For extreme conditions such as high velocity, excess seepage or debris in the water or wave action, a solid blanket of bags over the polyethylene should be used.

Counterweights consisting of two or more sandbags connected by a length of rope can also be used to hold the polyethylene down, and this is more suitable for placement under wet conditions. The rope is saddled over the levee crown with a bag on each slope. The number and spacing of counterweights will depend on the uniformity of the levee slope and current velocity. For the more extreme conditions, a solid blanket of bags over the polyethylene should be used. Sandbag anchors can also be formed at the bottom edge of the polyethylene by bunching the polyethylene around a fistful of sand or rock and tying a sandbag to each fist-sized ball. Wet placement may also be required to replace or maintain damaged polyethylene or polyethylene displaced by the action of the current.

Efficient placement of the polyethylene requires that a sufficient number of the rope and sandbag counterweights be prepared prior to the placement of each polyethylene sheet. Placement consists of first casting out the polyethylene sheet from the top of the levee with the bottom weights in place, and then adding counterweights to slowly sink the polyethylene sheet into place. In most cases the polyethylene will continue to move down slope until the bottom edge reaches the toe of the slope. Sufficient counterweights should be added quickly to ensure that no air voids exist between the polyethylene and the levee face and to keep the polyethylene from flapping or being carried away in the current.

While the implementation of polyethylene with sandbags is an effective remedy, it can be overused or misused. For example:

- On well-compacted clay embankments in areas of relatively low velocities, use of polyethylene would be excessive, as compacted clay is unlikely to be scoured out.
- Placement of polyethylene on landward slopes to prevent seepage must never be done. This will only force seepage to another exit that may prove more detrimental.

A critical analysis of each situation should be made before polyethylene and sandbags are used, with a view toward less waste and more efficient use of these materials and available manpower. However, if a situation is doubtful, polyethylene should be used rather than risk a failure.

Placement of Riprap

This is a positive means of providing slope protection and has been used in cases where erosive forces (caused by current, waves, or debris) were too large to effectively control by other means.

Objections to using riprap when flood fighting are:

- Relatively high cost.
- Large amounts may be necessary to protect a given area.
- Significant transportation and removal efforts.
- Limited availability.
- Limited control over placement, particularly in the wet.

Small Groynes

Small groynes extending 3 metres or more into the channel can be effective in deflecting current away from the levees. They can be constructed using sandbags, rock, compacted earth or any other substantial materials that are readily available. Preferably, groynes should be placed in the dry and at locations where severe scour may be anticipated.

Consideration of the hydraulic aspects of placing groins should be given because haphazard placement may be detrimental.

Miscellaneous Measures

Other available methods of slope protection include placement of straw bales pegged into the slope and spreading straw on the slope and overlaying/pegging with chainmesh fencing wire. Both have been successful against wave action.