MONITORING THE CONDITION OF LEVEES TO INFORM DECISION MAKING

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Abstract

Levees are a mitigation measure requiring significant upfront investment from communities and government. Effective maintenance of levees will help realise the benefits of this investment and avoid the situation where effectiveness can diminish significantly such that a levee may not be able to perform their design function for their intended design life.

On occasion, in the lead up to a flood, little is known about the current condition of the levee and any potential weaknesses that may be present. Such conditions may result in the need for contingency planning for a flood event.

Monitoring of levees is important so their condition is understood and where warranted specific defects can be rectified in a timely manner or monitored to assess future rectification needs. The NSW Office of Environment and Heritage of the Department of Premier and Cabinet (OEH) is working with the NSW Public Works, due to their expertise in levee construction and auditing levee condition, to develop guidance on an appropriate monitoring regime through visual levee auditing that will enable levee owners to:

- Monitor levee condition and any deterioration over time;
- Highlight the need for and prioritise efforts in rectification of specific issues;
- Track rectification where undertaken; and
- Make more up to date information on levee condition available to all relevant parties in the lead up to a flood.

This paper discusses the monitoring regime that could comprise: the monitoring of levee condition through the use of visual levee audits by engineering levee specialists and/or detailed levee inspections by staff with less expertise in levees. The aim of the regime is to enable timely and informed decisions on ongoing maintenance needs and emergency response and ensure levees are able to perform at their optimum level during a flood event. The considerations in this paper will be finalised in guidance to be published by OEH.

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Introduction

Flood mitigation works perform a vital role in the protection of communities at risk of flooding. Levees are one key type of flood mitigation work that provides significant protection up to their design flood event. Urban levees are generally earthen structures or a combination of earthen and concrete structures. They are expensive and involve major investment by the local community in partnership with the State (and sometimes the Commonwealth Government) to investigate, design and construct protection.

Therefore levees are an important mitigation work which, when maintained, decreases the degree and frequency of flood exposure of the community. The benefits of levees to vulnerable communities can be significant. They can remove or at least significantly reduce the impacts of flooding up to the design event. Lismore levee, for example, whilst only completed in 2005 and designed for a 10% annual exceedance probability (AEP) flood, has reduced the significant impacts of several floods each time reducing the impacts on the protected community by millions of dollars and saving it from the significant emotional and physical impacts of flooding. Levees also enable towns to function reasonably effectively and act as a base for supplying surrounding rural communities during long duration floods, such as occurred in inland NSW in early 2011 and again in early 2012.

The consequences of levees failing in floods less than or equal to their design flood has significant implications for the protected communities. The benefits provided by the levee will be partially, or potentially even fully, negated, depending upon the individual circumstances and the degree of failure.

Levees are generally designed to provide protection for an extended period and earthen levees would be expected to have a design life of at least 40 years. During this period they will need to have ongoing maintenance to ensure that they are fit for purpose, i.e., can manage the impacts of the design flood for their full design life.

The design and construction of levees aims to provide protection from a design flood event and proceeds after a thorough consideration of the relative costs and benefits of the range of available flood mitigation options. This means if a decision is taken to proceed with a levee, it will generally be the most cost effective option in terms of the upfront investment by communities and government for that location. However, it is important to ensure that the ongoing maintenance costs are factored into a decision, as increased maintenance costs would generally be borne by the local community. Therefore it is essential that life cycle costing of levees is considered during the investigation and design phase to ensure that there is an appropriate balance between upfront construction and long term maintenance costs in the project.

The design of levees also needs to consider the climatic conditions they will be exposed to and any potential limitations on maintenance. This is particularly important in environments where there is a limited water supply and/or human or other resources to maintain the levee, and its essential surface protection and foundations.

A key element of the design and construction of the levee is the development of an operation and maintenance manual. These manuals provide an important ongoing tool to assist with ensuring that levees are effectively maintained and to ensure that knowledge of operation is understood. These manuals need to not only document operation and

maintenance but should also include a copy of work-as-executed drawings for the levee and advice on the levee condition to ensure that these are available when needed.

Manuals should also be designed to be modular, to enable information on changes to the levee and its vicinity to be kept in one location. This enables tracking of modifications, improvements, and monitoring of problems or deficiencies, to be readily retrievable at short notice in the lead up to a flood event.

Why is a System for Monitoring Levee Condition so Important?

Floods of the magnitude of a levee design flood generally occur relatively infrequently and as a result the need to keep such valuable community assets in good condition is often not considered to be a high priority, particular when drought conditions may be experienced for a prolonged period and/or resources may be limited. The protection provided by earthen levees may deteriorate quickly if they are not effectively maintained, especially where drier climatic conditions prevail and the resources of levee owners are limited.

Depending on the location of the levee within a catchment, large floods can occur with little advance warning and a levee may be expected to perform its design function with limited opportunity for the levee owner to attend to defects. Therefore regular and thorough maintenance and rectification of identified defects is essential. Fixing the levee in the lead up to a flood should not be considered as an emergency response function of the State Emergency Service (SES).

Inadequate routine maintenance of urban levees and/or a failure to identify and promptly attend to developing defects in the levee structure and/or foundations in a timely manner may lead to the failure of the levee to perform its design function for its design life. A levee is just like a chain, it only takes one weak link for it to fail. It is desirable that the levee be in a "state of readiness" for when the flood arrives and does not have to rely on the owner doing repair/maintenance work "at the last minute" as sometimes occurs. It is recognised that for levees on the broad inland floodplains of NSW, away from the western influence of the Great Dividing Range, there can be many weeks or even months notice of an impending flood. However, it is advisable that the above principle of preparedness also be applied in these instances as weather conditions immediately prior to the arrival of a flood may prevent or at least hinder last minute repairs to a levee leaving the community dangerously exposed.

Therefore early identification of developing maintenance and structural issues, particularly those with significant ramifications to levee performance, is advisable to minimise the potential for failure and the associated impacts, and to reduce the potential for significant degradation requiring major rehabilitation at significant cost to the community, well in excess of the cost of ongoing maintenance.

An urban levee that has deteriorated to the point that it is no longer able to fulfil its design function can also have major liability implications for the levee owner, and planning and operational implications for those with a role in emergency response and recovery. It may be that robust emergency management planning developed in consideration of the protection provided could be compromised by levee failure leading to additional risk to life.

Decisions to ignore or postpone the maintenance demands of a levee can turn out to be very costly strategies for the local and wider community. Physical failure of the levee and

hence the flooding of the protected area can put lives at risk, create major operational problems and threaten the viability of the local community and the wider community normally serviced by the flooded town. Clean up and recovery is likely to impose a significant cost burden on the local and wider communities and all levels of government.

The flooding of Nyngan in 1990 cost the wider community approximately $50M at the time and the evacuation of the whole town for a period of three weeks. It is acknowledged that the failure of the Nyngan levee was not due to lack of maintenance, but it does illustrate the costs that may be associated with a levee failure.

The maintenance of flood mitigation structures, and particularly levees, is an issue of concern across NSW and more broadly in Australia.

What Should a System for Monitoring Levee Condition Entail?

OEH is working with NSW Public Works to develop guidance on visual levee auditing to support informed maintenance and emergency response decision making. The considerations in this paper will be finalised in guidance to be published by OEH.
A robust system for monitoring levee conditions could involve the following aspects:

- A program of regular and frequent visual inspections and audits to enable early identification of potential problems.

- A consistent methodology for undertaking visual levee audits and inspections, considering the significant variation in levee types and purposes. This can be supported by guidance on the type of problem, its importance and the course for corrective action.

- A template on levee condition to collect information in the field and track condition over time. This includes references to relevant reports, Work-as-executed drawings, operation and maintenance manuals, etc. This would feed information into levee condition reports to provide essential information to the levee owner for maintenance and rectification decisions.

- A template for tracking and reporting on visual levee audits and changes over time.

- An effective way of ensuring that up to date information on levee conditions, deficiencies and associated contingency planning, are available to those whose operations or decision making may be affected by any change in condition. This includes both the Council and State Government (in particular, the SES and OEH).

Visual Levee Monitoring Regime

Effective monitoring of the condition of a levee is essential to identify any issues that may need to be rectified or further investigated, so that the levee is able to fulfil its design function for its maximum economic life.

A risk-based, hierarchical approach is suggested to ensure that local government is supported to care and maintain for its levees to the fullest extent possible. Such an

approach aims to develop a robust visual levee monitoring regime. This is likely to involve establishment of a system that facilitates the ongoing systematic assessment of a levee. This entails not only reporting what is seen (good and bad) but interpreting it, highlighting problems and issues and recommending a course of action (which may include the need to seek additional advice or undertake additional investigations). The hierarchical approach allows the best use of skilled resources in the most appropriate locations. It means that when access to an appropriate skill set and rigorous approach is required, this decision will have been based on good judgement as well as knowledge of the context of the potential consequences of a flood to the community and how the flood and levee system interact.

Key features of a successful monitoring regime are likely to include the following components:

1. **Visual Inspection of the levee:** A regular inspection on all levees is advisable to enable the identification of potential problems in a timely manner. These would normally be undertaken on a minimum of an annual basis to ensure that any emerging problems are identified and rectified early. A visual inspection could also serve as a trigger for requiring a full visual levee audit if a need was identified.

   While it would be ideal for the inspector to have civil or geotechnical engineering qualifications, this does not always have to be the case. Nor is it considered essential to have those qualifications. However, it is desirable if the inspector has experience in civil construction works in the fields of earthworks, concrete works, pipe laying, pumping (and sheet piling or other type construction where different levee types are used).

   If a regime of visual levee audits has been in place, the annual visual inspection reporting can include any changes that have occurred since then, as well as progress made in implementing rectification actions.

   At regular, but less frequent intervals, including after trigger events occur, it is suggested that a fuller visual levee audit process be useful. Such triggers may include the aftermath of a major flood event, or during a prolonged drought when ground conditions have changed. Site specific triggers may also apply and result in a more or less frequent audit regime, based on risk-based factors (such as exposure and vulnerability) relating to the levee.

   It is also anticipated that a feedback process would be in place such that the inspections inform the audit, and vice versa so there is a cycle of continuous knowledge about the condition and any improvements required.

The less, frequent, more detailed assessment would typically have two components:

2. **Survey of the levee crest and key levee features:** This would typically be undertaken when there has been obvious deterioration in levee condition, or when trigger conditions as outlined above have occurred, or the level of risk the levee is exposed to suggest a more detailed examination of levee condition was warranted. The survey should complement the detailed visual levee audit, and be undertaken in advance so it can be used to inform the audit. The survey should be undertaken by a qualified surveyor or survey technician with access to the work-as-executed plans and any subsequent levee crest surveys so that changes can be identified. Surveys should be included with the relevant visual levee audit.

3. **Visual Audit of the levee:** The visual audit of the levee would be informed by any past audits, the survey of condition, any rectification works undertaken and by the visual levee inspections. The audit would normally be undertaken by a professional engineer with civil or geotechnical engineering qualifications and appropriate civil engineering, earthworks, concrete works, pipe laying and pumping experience. No geotechnical investigation or other types of investigations are intended to be part of this visual audit methodology. However, the need for more detailed investigations may be a recommendation from a levee audit where identified problems warrant further intrusive investigations.

The State Government, sometimes in partnership with the Commonwealth, have assisted with funding for crest surveys and visual audits of levees built with State and Commonwealth Government assistance in the past through various funding programs.

It is likely that at any stage (i.e. the inspection, survey or visual levee audit), actions requiring rectification may be identified. Therefore, inclusion of a rectification action plan as part of the visual levee audit is considered prudent. Progress on implementing the rectification actions would be reported through the inspection process.

In addition to the dedicated inspection, survey and audit functions outlined above, the maintenance of levees involves a number of ongoing tasks. These include:

4. **Contingency planning:** The owner of the levee is responsible for developing plans to rectify deficiencies in the levee. Where these deficiencies are significant and could be expected take some time to rectify they would also be responsible for developing contingency plans to deal with these deficiencies in the advent of a flood prior to their rectification.

5. **Maintaining Information:** Ensuring that information on levee operation and maintenance, and condition, and any associated contingency plans is kept up to date and available.

6. **Communicating information:** Ensuring that relevant staff and agencies have up to date information on levee operation and maintenance, and condition and are aware of any contingency plans to deal with significant deficiencies.

Support for a Visual Levee Monitoring Regime

Support for a visual levee monitoring regime is important to providing up to date information on the condition of the levee and any associated maintenance and structural issues so that these can be investigated further and rectified in a timely manner. To support and effective, efficient and informative monitoring regime, the following support may be beneficial:

- An understanding of limitations of inspections.
- Information on the levee and the flood situation
- An understanding of the key issues that need to be considered in levee zones
- A rating system for problems

- A list of inspection equipment
- A methodology for visual inspections
- Guide notes for inspections
- Reporting templates
- Availability of documentation and communication of outcomes

Some considerations concerning these aspects are outlined below.

Assessment Limitations

Any levee inspection, and particularly a visual levee inspection, is limited in its potential to assess issues as outlined below:

- Limited by background information available, often scarce or anecdotal (i.e. not Dr Who - cannot go back in time to when levee originally constructed). However, councils can assist by making the effort to find the information outlined below. If this is done once it should be scanned and linked to the operational and maintenance manual and audit template so it can be readily available for future audits.
- We do not have x-ray vision – (i.e. not Superman – limited to what can be seen above ground).
- Cannot economically look under every blade of grass and find every potential risk / issue (i.e. not Sherlock Holmes)

Information on the Levee and Flood Situation

To be most effective, this regime should be supported by documentation on the levee. This should exist within council and would need to be gathered together (from all sources) to ensure that the levee and its operation is understood to inform the audit. This documentation may include:

- Relevant reports – flood studies, floodplain risk management studies and plans, particularly those that relate to the design of the levee or examine its performance.
- Investigation reports for the levee and its final design criteria.
- Work-as-executed drawings of the levee and its key supporting features.
- Information on the infrastructure and community protected by particular portions of the levee system which may act independently and therefore fail in isolation.
- Operation and maintenance manuals for the levee.
- Previously completed surveys and inspection and audit reports.

Levee Zones and Priority Issues within Zones

A hierarchy of zones on or adjacent to a levee can be used so that attention during an inspection / audit is directed towards the most important areas.

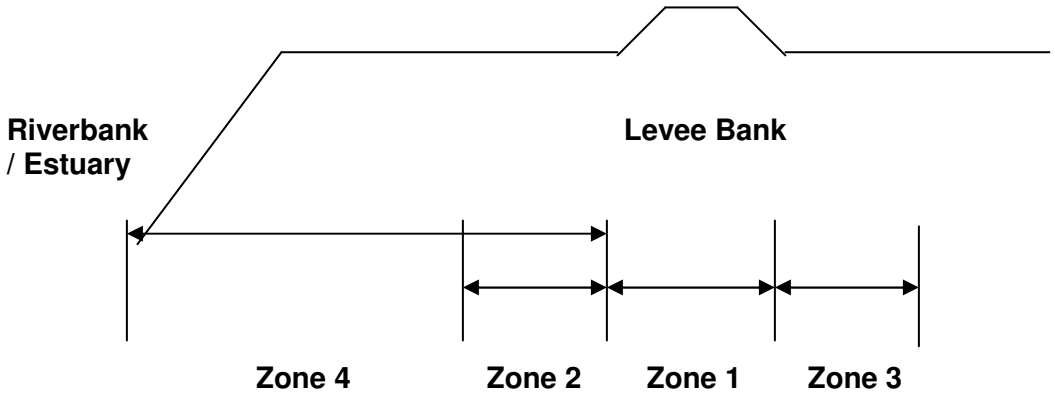

Figure 1: Levee Zones

Zone 1 Levee Footprint (including any footings for concrete levees).

Risks may be critical (could affect the structural integrity of the levee bank).

Zone 2 4 - 5m from the levee toe / levee footing toe on the water side of levee.

Zone 3 4 - 5m from the levee toe / levee footing toe on the town side of levee.

Risks in Zones 2 and 3 are of next importance (water can easily weaken/collapse structures adjacent to the levee bank which can adversely affect the structural integrity of the levee bank. Works on inside of levee bank e.g. house developments, can also adversely affect the structural integrity of the levee bank). Zone 3 is considered to include stormwater pump stations whose operation needs to be considered as part of the audit.

Zone 4 Riverbank / Waterway Frontage (within 50m of the toe of the levee).

Issues more difficult to deal with and likely to be more long term risks (e.g. long term riverbank erosion). Erosion both during events and long term can place the levee at risk.

Monitoring Rating System

To effectively monitor a levee, appropriate rating criteria can be established. For example, a simple four (4) tier rating system can describe the type of risks identified with each issue that may arise on a levee bank. These are:-

✓	**Acceptable**	If an item is rated as acceptable, no action is required.
±	**Marginal**	If an item is rated as marginal, an action is required to remediate the issue. These issues do not affect the structural integrity of the levee.
✖	**Unacceptable**	If an item is rated as unacceptable, an action is required to remediate the issue. These issues do affect the structural integrity or the functionality of the levee but do not pose an imminent threat in the event of a flood.
☠	**Imminent Threat**	If an item is rated as an imminent threat, an action is required to remediate the issue. These issues mean that they do not meet the levee design criteria and pose an imminent threat to the structural integrity or functional intent of the levee in the event of a flood.

Inspection Equipment

Whilst, the inspection would be done on foot, the following equipment may be appropriate.

- Plan / map of levee alignment (with chainages) and crest survey levels and changes. This would also ideally show design flood extents or another map be available to provide this information.
- Camera (date stamp printed on photo, GPS coordinates would be useful);
- Tape measure (with a peg / pin if inspecting alone) and/or measuring wheel to accurately locate risk / issue (where GPS camera not available).
- Inclinometer (instrument to measure batter slope);
- Notepad / notebook (with clipboard) with copy of Monitoring Report Template;
- A probe (any stiff light stick or rod with a blunt tip of sufficient strength to penetrate soil). The probe can provide information on conditions below the surface of the levee such as the depth and softness of a loose/saturated area.
- Appropriate guidance (which could include examples of problems to refer to in reporting). Officers undertaking the inspection/audit should have read any available guidance and have a reasonable understanding of the methodology and its purpose.

Inspection Methodology

An effective means of conducting the inspection is to treat each levee segment as an individual element, inspect it thoroughly, and record all relevant information and

observations prior to moving on to the next segment. These observations should be checked against information in the guide note to identify the type of issue and to understand its seriousness. A possible sequence for inspection of each levee segment is as follows:-

a. **The crest**: walk along the top of the levee from one end to the other and look for erosion, puddles, settlements, cracks in the paved or unpaved surface or animal burrows, etc.

b. **The waterside embankment:** walk along the waterside of the levee down to and including observations of the riverbank in a zigzag, top to bottom fashion and to the water's edge and observe erosion, puddles or wet areas, slumps, woody vegetation or animal burrows.

c. **The townside embankment:** walk along the townside face of the levee in a zigzag, top to bottom fashion to observe any erosion, puddles or wet areas, slumps, woody vegetation or animal burrows.

d. **Stormwater pipes** / **gate valves** / **pump stations:** Observe the condition of the inlet/outlet culverts on the waterside and townside headwalls. Check the condition of the pipes and gates/flaps to note any blockage or cracks. Check the condition of the outside and inside of the gate valves, identify rust, cracks, spalling, deterioration, etc. Check the condition of any pump stations for signs of rust and wear. Where possible, test run the pump and confirm operation of all gates and valves over their full range.

e. **Observe the condition of any flood gates:** Check gates to ensure they are functioning properly.

In the experience of NSW Public Works, it has been found that an efficient way to undertake the above inspection is to walk along the top as well as one batter in a zigzag pattern. At the end of the segment, return to the starting point by walking along the top and the other batter in a similar zigzag pattern.

Guidance

It is anticipated that this project will result in the development of appropriate guidance material that will be provided as part of this methodology in the final project report. This guidance will describe common potential risks to levees identified in past audits. It is expected to provide guidance on the ranking of the seriousness of issues and whether monitoring or additional advice may be required. This may assist in prioritising maintenance works for rectification and developing contingency plans if a flood occurs ahead of timely rectification.

Information likely to be covered in any guidance material may include:

- A brief description of the various types of defects and potential threats to the structural adequacy of levees that may be discovered by visual audit. Where possible these issues are illustrated with photographs, sketches and/or drawings as an example of the type of problem to look for.

- Guidance on how to assess the severity of the problem in the field or with the resources that could be reasonably expected to be available to a small Council with limited resources.
- The potential consequences of not dealing with the different types of identified problems, both short term issues as well as ultimate likely consequences.
- Guidance on when specific, more detailed investigations may be required.
- Guidance on monitoring programs for less serious problems that have the potential to further develop into more serious issues.
- Guidance on assessing the relative reliability of the levee to perform its design function until rectification work, if necessary, is undertaken.
- Guidance on the prioritisation of work determined based on predicted flood height and which risks / issues are felt to be the most urgent or riskiest at that time based on local site conditions (e.g. ones facing the full river flow more urgent than ones in backwater areas, larger scour areas more urgent than smaller scours). Priority list probably determined based on likelihood of inundation of risk area, velocity of water flow and magnitude of problem.
- Guidance on the format and contents of a visual levee audit report.

The guidance material will be updated when important new knowledge is gained from further audits. It has been said that "the number of different levee types is only limited by the designer's imagination". As such, guidance material cannot cover all situations. However, it is hoped that the principles and examples given will provide enough information for the inspector or auditor to make an informed and reasonable decision in those circumstances. But …"If in doubt, consult an expert".

Availability of Documentation and Communication of Outcomes

The outcomes of the audit or inspection provide up to date information on the levee conditions and any associated deficiencies. Where these deficiencies could take some time to rectify, the levee owner should consider developing contingency plans to deal with these deficiencies in the advent of a flood prior to rectification and ensuring relevant staff and agencies are aware of these plans.

It is important that relevant information on the operation, maintenance and performance of levees is available to those who need it. The type of information that is required includes the original design and construct plans including information about the design flood and freeboard, past inspections, surveys and audits undertaken. Other types of information required, and often generated as a result of those processes includes any rectification actions implemented or required and their status, ongoing maintenance requirements and communication of information to relevant authorities including the SES and OEH.

Conclusions and Recommendations

Levees are a key flood protection work for many communities. However, they are vulnerable to deterioration overtime. The speed of this deterioration will depend somewhat on their maintenance and climatic conditions.

An effective monitoring regime is essential to tracking our understanding of the vulnerability of individual levees to failure and identifying key rectification and maintenance works needed to maintain their design protection of protecting the community from the design event for their full design life.

OEH is working with NSW Public Works to develop guidance on visual levee auditing to support informed maintenance and emergency response decision making. The project is continuing to develop and test the guidance to support this methodology. This guidance will be made available to councils and other levee owners at the completion of the project.

Knowledge of the condition of the levee and any contingency planning to deal with flood events prior to timely rectification of deficiencies is essential across council so responsibilities are understood and able to be fulfilled. Agencies such as the SES and OEH should also be made aware of any significant levee deficiencies and any contingency plans so this can be factored into emergency response planning for floods.

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