Study into River Bank Collapsing - Lower River Murray

INSPECTION REPORT

- Final
- 17 February 2010

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Sinclair Knight Merz
ABN 37 001 024 095
590 Orrong Road, Armadale 3143
PO Box 2500
Malvern VIC 3144 Australia
Tel: +61 3 9248 3100
Fax: +61 3 9500 1182
Web: www.skmconsulting.com

Contents

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The contents of the Report are confidential and may not be duplicated or disclosed under any circumstances to any other person without SKM's prior consent. The sole purpose of this report is to present the findings of a study into river bank collapsing carried out by Sinclair Knight Merz ("SKM") for DWLBC in connection with the Lower River Murray. This report was produced in accordance with and is limited to the scope of services set out in the contract between SKM and DWLBC. That scope of services, as described in this report, was developed with DWLBC.

The scope of services was not intended to provide a definitive or quantitative investigation of the environmental impacts, performance and compliance of the subject sites. Environmental conditions may exist at the sites that are beyond the scope of our investigations and this report.

In preparing this report, SKM has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by DWLBC and/or from other sources. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

SKM derived the data in this report from visual site inspections, information sourced from DWLBC and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

SKM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by SKM for use of any part of this report in any other context.

Our field investigations have been limited to four days of visual land based site inspections of river banks along an extensive reach of the Lower River Murray from Nildottie to Wellington which have been selected by DWLBC.

All reports and conclusions that deal with sub-surface conditions are based on interpretation and judgement and as a result have uncertainty attached to them. You should be aware that this report contains interpretations and conclusions which are uncertain, due to the nature of the investigations. No study can completely eliminate risk, and even a rigorous assessment and/or sampling programme may not detect all problem areas within a site.

This report is based on assumptions that the site conditions as revealed through visual site inspections are indicative of conditions throughout the site. The findings are the result of standard assessment techniques used in accordance with normal practices and standards, and (to the best of SKM's knowledge) they represent a reasonable interpretation of the current conditions on the site.

This report has been prepared on behalf of, and for the exclusive use of, DWLBC, and is subject to, and issued in accordance with, the provisions of the agreement between SKM and DWLBC. SKM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

This Report was prepared solely for DWLBC and the matters covered by our Report and the emphasis placed on them may not necessarily address all or any specific concerns, purposes, requirements or interests of any third party. Our instructions were provided solely by DWLBC and may be different from those a third party would have provided. Third party interests and needs may be different to those of DWLBC. In particular, our Report does not cover all matters that a third party may wish to investigate and that there may be matters of interest to third parties which have not been considered to be material for the Report or investigated to the extent required.

The Report is strictly limited to the matters stated in it and does not extend by implication to any other matter. A third party should make an independent assessment of the matters which do not fall within the scope of our Report and, in relation to matters which fall within the scope of our Report, third parties should determine for themselves whether those matters require further enquiry. Where DWLBC proposes to release the whole or any part of the Report to any third party DWLBC shall include appropriate limitations and disclaimers releasing SKM from any liability arising from any use or reliance by such third party

1. Introduction

1.1. Study scope

Sinclair Knight Merz (SKM) was engaged by the Department of Water, Land and Biodiversity (DWLBC) to undertake a *Study into River Bank Collapsing – Lower River Murray*. The study area is the 209 km reach of the Lower River Murray between Blanchetown (Lock 1) and Lake Alexandrina.

The purpose of the study is to establish an understanding of river bank collapsing issues arising from current and anticipated ongoing low and lowering water levels in the lower pool. DWLBC will use the management recommendations from the study to assist it with its response to collapsing, and to form a policy position on options.

The study is being carried out in three phases:

- **Phase 1** – Initial services by individual contractual relationships between DWLBC and available selected consultants, site inspection in the Murray Bridge area (Caloote to Riverglen) and preliminary reports to March 2009. SKM's input to this phase was completed with submission of our letter of 20 March 2009.
- **Phase 2** – Investigation services by contract between DWLBC and SKM for a specialist river geomorphological and geotechnical study into slope stability and land slips along the lower pool and in the locations which have been selected by DWLBC, in order to provide management recommendations to DWLBC on high risk/high consequence areas and further detailed and scientific geotechnical investigations into a few representative sites as determined with DWLBC.
- **Phase 3** - Services, in addition to and beyond the Phase 2 study. The nature of the work and skill sets provided by SKM will depend on the findings and recommendations from Phase 2.

This report forms the output of **Phase 2** and documents the findings from four days of visual land based site inspections of river banks along an extensive reach of the Lower River Murray from Nildottie to Wellington which have been selected by DWLBC. The report provides an assessment of bank erosion problems, processes of bank erosion/failure and weakening factors contributing to erosion/cracking/failure. Recommendations for future management, further detailed investigations and monitoring requirements are also outlined in this report.

1.2. Study objectives

DWLBC identified the need for SKM to undertake a specialist geomorphological and geotechnical study into slope stability and land slips along the Lower River Murray. The objectives of the project are to:

- provide management recommendations on high risk/high consequence areas;
- inform further detailed scientific and geotechnical investigations at a number of sites selected by DWLBC;
- provide advice on monitoring requirements at assessed sites.

The main deliverable from **Phase 2** is a report which provides detailed recommendations for:

- undertaking further detailed site investigations that may be required to more fully understand collapses, or lack thereof, at sites of interest identified by DWLBC;
- management of river bank collapsing hazards along the Lower Murray including assets, trees and river banks over the next three years to end of 2012 or as may be qualified in the report;
- future monitoring of collapse-susceptible areas over the next three years from 2009/10 through to 2011/12 inclusive, or as may be qualified in the report, by non-geotechnical DWLBC, agency and local government staff, suitable for recording on a GIS Database maintained by DWLBC; and
- data to be added to DWLBC's website based on details in the SKM report in a format suitable for providing community information on river bank collapses, to be rewritten where necessary by DWLBC staff experienced in multi-media public releases, and subject to technical review by SKM personnel.

1.3. Document structure

Section 2 of this report provides a brief review of the river bank cracks and slope failure problem as it has developed along the Lower River Murray and previous investigations into this problem.

Section 3 describes the approach to this study as determined by SKM and DWLBC and an outline of the method used to assess each of the sites.

Section 4 provides a summary of sites investigated and the nature of erosion problems experienced. The role of different erosion processes, failure mechanisms and weakening factors in contributing to bank erosion/failure are discussed. This is followed by **Section 5** which outlines recommendations for further investigations, management and monitoring.

The report concludes with a summary of the outcomes of this study.

2. Background

2.1. Development of an erosion problem

The lower River Murray between Blanchetown and Lake Alexandrina has been affected in the last 3 years by very low inflows as a result of drought. These inflows have been insufficient to replenish the large volumes of river water that evaporate from the lower lakes each summer season and to provide unrestricted irrigation and domestic water to local persons and off-take for distribution within the SA Water pipeline network. Accordingly, the pool level has been dropping in that period from a normal level of ≈+0.75 AHD to a current level of about ≈-1.05 m during late summer 2008-09. River level during the inspections reported herein was about -0.5 to -0.79 m AHD.

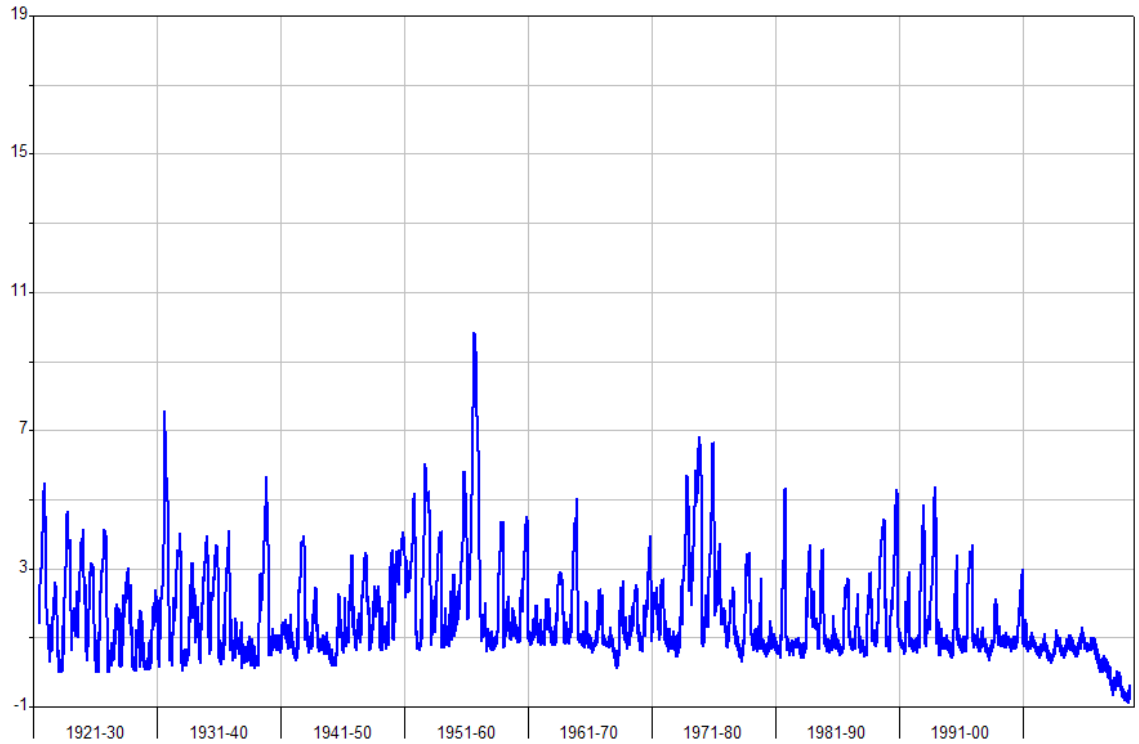
This level is lower than has ever been experienced previously in the pool, prior to and since barrage construction in the 1930s. Figure 2-1 shows historical water levels immediately downstream of Lock 1 from 1921 to present and Figure 2-2 from 2005 to present, showing the marked lowering in water level that has taken place since 2005. There has been a progressive step-wise decrease in water levels in the years 2006, 2007, 2008 and 2009, with water levels falling rapidly at ≈0.2 m/month through summer. Figure 2-3 shows water level history at Murray Bridge (Long Island), where water levels dropped to ≈1.05 m over late summer 2008-2009.

Pool levels are about 1.8 m lower than normal pool level and dropping. It is noted that wind seiche can vary water level locally in the lower Murray by up to +/- ≈0.4 m depending on wind direction. The next significant drop in water level is expected with the coming 2009/2010 summer.

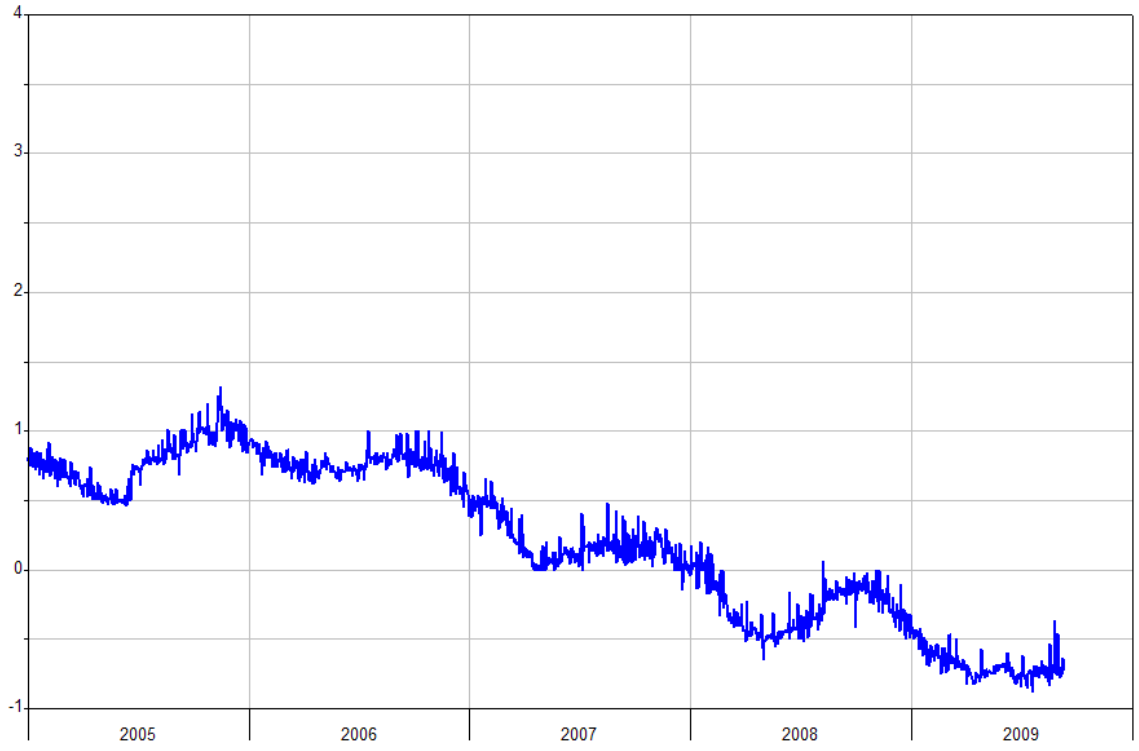
Dropping of water level of 1.8 m causes an increase in surcharge of ≈18 kPa or 1.8 tonnes per square metre to be applied to the river banks and adjoining flats for the length of the pool. This increase in surcharge potentially could favour bank failure. The dropping of water level and increase in bank surcharge acts to destabilise the bank. The nature of the failure depends on the height and profile geometry of the bank, stratigraphy and geomorphological properties of the bank materials.

Under the scenario where bank failure is triggered by lowering water levels resulting in increasing bank surcharge and development of tension cracks along the crest of the slope, we would predict that failures are likely to be in areas where thicker filling has been placed on the banks (e.g. in levees and paved areas), where the river channel is deepest, the toe of the existing slopes slumped/eroded into the river or a soft layer with an alignment toward the river is present within the soil profile.

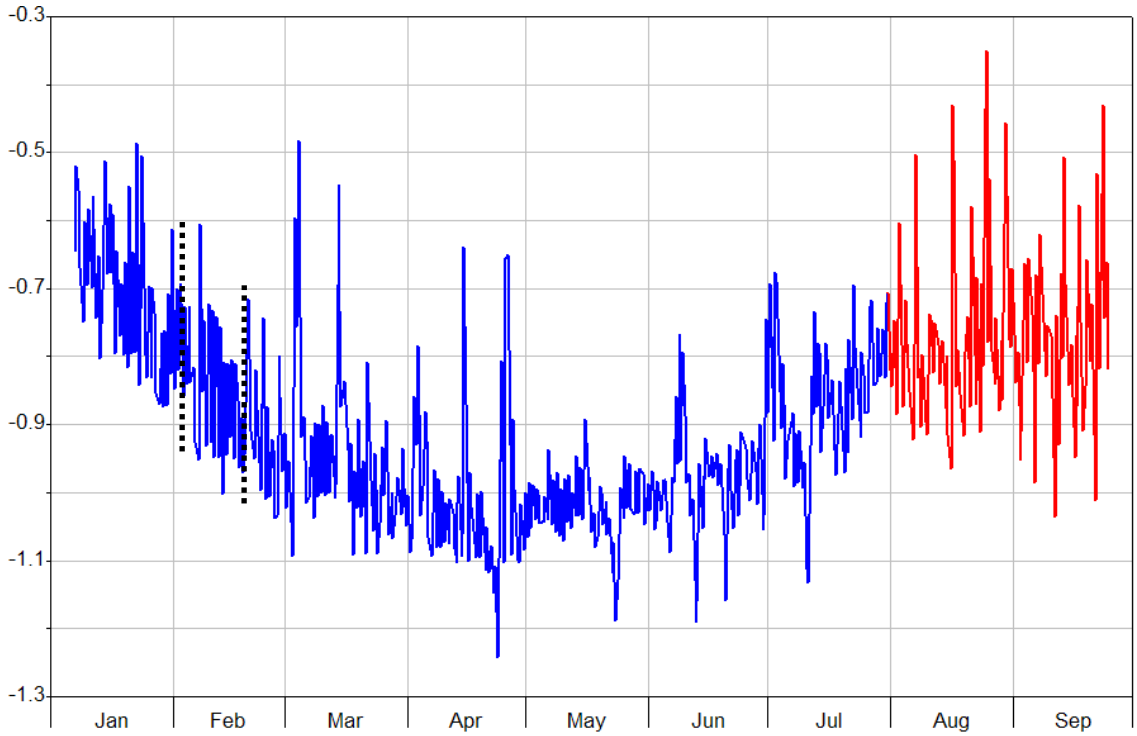
The timing of collapses alongside lowering of water level supports the theory that water level lowering is triggering bank failure. As pool levels lowered, collapses began to occur in succession from about 4 February 2009. Major slips were documented at Long Island Marina, Riverglen, Woodlane and Bells Reserve (Table 2-1).



- **Figure 2-1 River Murray at Lock 1 Downstream (A4260903) - Historical record of daily water levels (m AHD) from 1921 to present.**



- **Figure 2-2 River Murray at Lock 1 Downstream (A4260903) - Daily water levels (m AHD) for past 5 years from 2005 to present.**



- **Figure 2-3 River Murray at Murray Bridge (Long Island) - Daily water levels (m AHD) from January 2009 to present. Dashed lines indicate timing of major failures at Long Island Marina (4 and 20 February 2009).**

- **Table 2-1 Major incidents recorded in incident register.**

Date	Location	Incident
4 February 2009	Long Island Marina	20 x 6 metre section slumped that resulted in three cars falling into the river, only one of which was recovered. A number of historical River Red Gums were also lost.
14 February 2009	Riverglen	An area of approximately 25 x 4 metres slumped. While a boat was temporarily lost, there was no property damage.
20 February 2009	Long Island Marina	Further collapse at the site. Approximately 10 metres were lost with a number of historic River Red Gums. 10-15 metres collapsed at the same site of the 1st slumping.
Late February 2009	Woodlane Reserve	A large section of river bank slumped, damaging a pumping station.
Early March 2009	Long Island Marina	10 -15 metres collapsed at the same site of the 1st slumping.
7 March 2009	Woodlane Reserve	Further slumping occurred, enlarging the slumped area of the first collapse. The pumping station was lost.
9/10 March 2009	Long Island Marina	Remainder of bank at the northern end of the property collapsed.
10 March 2009	Woodlane Reserve	Further slumping at this site resulted in a nearby stobbie pole collapsing.
30 March 2009	Bells Reserve	River bank subsiding about 1000 sqm on Bells Reserve. Extensive crack in willow area about 5 feet deep and 2 feet wide. Concealed by vegetation.

2.2. Previous investigations

In July-August 2008, DWLBC engaged Arup to investigate and report on river bank slumping / collapsing that was beginning to manifest in the lower River Murray. Arup engaged Lyn Sanders through Golder Associates to undertake the investigation with them and produced a report in two parts (ARUP, 2008a; ARUP, 2008b); based on a site inspection conducted by Houseboat along most of the river, where draft permitted, from Lock 1 at Blanchetown to Lake Alexandrina. A third report, relating to an investigation of the Long Island Marina Bank Slump was also produced by Arup in February 2009. These studies reported in general terms on the distress of the river banks, levee banks and the wider valley infrastructure.

An inspection was carried out of the river banks in the Murray Bridge region on the 13 March 2009 by Daryll Pain (SKM), Alan Moon (Coffey Geotechnics), Rob Frazer of Murray Bridge, Robert Shipp (Murray Bridge Council) and Damian Vears (DWLBC). A summary of preliminary findings from this inspection were outlined in the proposal for this study (SKM, 2009). Areas inspected were chosen because of the examples of river bank slumping and cracking that existed at each of the sites. Examples of cracking and slumping ranged from:

- descriptions of sudden changes to river bed profiles just offshore from the waterline,
- to cracks onshore parallel to and near the water line,
- to wide cracks around trees and stumps on overhanging high points;
- to tree and bank collapses along swamps;
- to major slips at Woodlane where a pump station, trees and a stobie pole were carried into the river; and
- and at Long Island Marina where the major slips occurred;
- as well as an adjacent major slip that threatened a SA Water sewer rising main.

Some of the major slips were noted as occurring as a series of slips with the landside face of the slip progressing landwards. Cracks and slips were noted where levees and roadworks had been built on the bank and where levees existed 20 m and more inshore from the bank and where no levees existed at all. Crack locations were observed as much as 15-25 m landside of the shoreline.

Rob Frazer provided specific slip circle analyses examples of the slumped river bank adjacent to the marina at Long Island. Low undrained shear strength in soft clays at the low end of the range ~10-20 kPa resulted in factors of safety just less than unity with classic slip circle geometry and failure mode fitting observed bathymetry at the slips.

Cracks represent the back face of slip circles and the Long Island models show that the toe of the slip can be well out into the river channel. Channel depth is a prime driver of crack position on the bank, in that deeper channel implies greater offset of the crack landside of shoreline.

Slumping can occur at any time but anecdotal evidence is that slips occur often at night. River bank assets such as personal jetties and “beaches’ are prevalent in residential areas along the river bank, many of which are at risk of destruction with river bank slumping. Slips can occur in channel sides underwater, and can be associated with release of gases as bubbles of (most likely) methane and or hydrogen sulphide. The bubbles are therefore potential indicators of slips and imminent bank slumping.

It was observed that large trees have collapsed into the river channel creating navigation and recreational hazards. Also trees are splitting and collapsing where branches and foliage, normally supported in and on the water surface, become unsupported as pool level drops. Potential issues were recognised with oncoming winter rainfall, with trees breaking branches as mass of foliage becomes heavier with wetting; and water finding its way into cracks, lubricating slip surfaces and potentially promoting further movement.

Onshore and offshore hazards associated with slumping were outlined and a series of actions were recommended to reduce the risks associated with these hazards. These inspections and further correspondence between SKM and DWLBC provided the basis for formulating the proposal for the present study.

3. Study approach and methodology

3.1. Study approach

SKM's approach to **Phase 2** was to obtain an overview of existing physical conditions along the whole length of the lower pool, concentrating on;

- Understanding, by specialised observation and review of conditions that lead to existing river bank collapses from the river GIS database and existing incident reports;
- Identifying other locations along the pool where high collapse potential conditions may exist;
- Undertaking site inspections of typical high collapse potential areas representing the whole length of the lower pool, including a selection by DWLBC of possibly up to 10 (of about 20) existing reported incident sites;
- With DWLBC, identifying high consequence areas of high collapse potential where collapse has not yet occurred or been reported;
- Risk ranking high consequence areas of concern with DWLBC;
- Reporting where possible the future stability of high consequence areas which have failed, possibly including recommendations for site specific geotechnical investigations.

The study takes into account a reduction of water level to minus 1.5 metres AHD commencing early summer 2009 and continuing for three years.

3.2. Site selection

Following a review of the GIS Datapack prepared by DWLBC, previous investigations and specific bank collapse incidents provided by DWLBC, a number of sites were identified by SKM for inspection as outlined in Table 3-1.

- **Table 3-1 Sites identified by SKM for assessment and rationale for choosing them.**

Incident Number	Site	Rationale
3	Placid Estates, Riverview	Rotational failures with obvious macro and micro failures.
1	Long Island Marina	Rotational and planar/slab failures impacting on Marina Development, moorings and potential for collapses impacting on properties further upstream.
4	Riverglen	25m by 4m collapse which has reportedly dispersed. Close proximity to houses.
-	Jaensch Property	50m section of bank 4m wide has slumped 1m. Noted in Arup Report.
23	Murrawong Access Road	Tension cracks along access track, failure and erosion may result in loss of road to properties
51	Sturt Reserve	Identified as high risk by Robert Frazer. Soft organic clays.
47	Wellington Marina	Large tension cracks – site of predicted failure by Robert Frazer.

DWLBC also identified a number of locations to be investigated in the field. These sites were updated into the GIS database as incident sites. Based on a review of SKM and DWLBC identified sites, a list was compiled for further investigation in the field as outlined in Table 3-2. The priority ranking assigned to each site is taken directly from the DWLBC register of river bank collapsing database.

3.3. Method of site assessment

Site assessments were carried out by a Senior Geomorphologist, Senior Geotechnical Engineer and Graduate Environmental Engineer from SKM and DWLBC staff members. Staff used bank assessment record sheets developed by Thorne *et. al*. (1996) to appraise bank erosion problems at each of the sites. These assessment sheets are useful for recording direct observations needed to undertake an assessment of a bank problem. The process of assessing a site is broken down into six stages, dealing with the following aspects in turn:

1. Scope and purpose of bank assessment;
2. Channel site map;
3. Bank survey;
4. Identification of bank erosion and/or instability problem;
5. Examination of toe-sediment balance of the bank;
6. Bank map and profiles.

At the conclusion of these site assessments, and following discussion between the assessors, information on each site was reviewed, and any site specific recommendations for further investigations, management and monitoring were documented. Photographs of key features (tension cracks, bank condition etc) were also taken and the GPS location of these photographs recorded. At some of the sites investigated, issues were considered of sufficiently low priority not to warrant a full bank assessment in the form outlined above. In this case, photographs were taken to provide a record of the site and any issues noted.

- **Table 3-2 Final list of sites to be investigated in the field. Priority, incident number, incident name and description taken directly from DWLBC register of River bank collapsing. Asterisk notes instances where a doubling up of incident numbers for two different locations was noted in the database.**

Priority	Incident Number	Incident Name	Description
No Priority	29*	No Name	Between Swan reach and Blanchetown. Western side of river, coming from Swan Reach End when driving up dirt road and pumping station between swan reach and Blanchtown, there is a little dirt road, just before the pumping station to the river - drive down to river and walk upstream approx 60 m, there is a large crack in the bank.
High	32	Punyelroo	Road cracking on road at Punyelroo (site near white bus). Owner of shack David Harmann states he has had to prop up his shack on stumps as it is dropping into the river.
High	24	Young Husband	Eastfront Road, Younghusband – 21 km from Mannum on East Front Road on riverside, there is a crack in soil on river bank, about 1m, between the river bank of the road, 50m past "Lawson" sign which is on a harness cart wheel next to pumping equipment.
Moderate	9	Lake Carlett	Channel on the upside is falling. Upstream from Mannum. Mannum side just near Stone Wall and Greenings Landing.
Moderate	34	Mannum	T Junction on the Eastern side at Mannum Caravan Park and Ferry near the boat building yard
No Priority	27	Bolto Reserve, Mannum	River bank slumping at Bolto Reserve, manmade structure affected.
Moderate	28*	Baseby Reserve, Private Property	River bank cracking and moving upstream from Baseby Reserve on Private Property.
High	26	Pompoota	Thurbridge Irrigation area (otherwise known as Bilk Flat Irrigation area). Slumping of levy area where pipes are, causing pipes to break. Levy bank is tilting.
High	7	Woodlane Reserve, Mypolonga	A large section of river bank slumped, damaging a pumping station. Further slumping occurred, enlarging the slumped area of the first collapse. The pumping station was lost. Further slumping at this site resulted in a nearby stobbie pole collapsing.
High	23	Murrawong Road	Cracking occurring on Murrawong Rd between council reserve and the shacks. This is the only access to and from the 15+ shacks.
No Priority	51	Sturt Reserve	
High	1	Long Island Marina	Collapsed 12 months ago, 20 x 6 m section slumped, 3 cars fell into the River, trees were lost. Further collapse at the site of the 2nd slumping, 10 metres lost, 10 -15 m collapsed at the same site of the 1st slumping.
High	20	Monteith	River bank subsiding about 1000sqm on Bells Reserve. Extensive crack in willow area about 5 feet deep and 2 feet wide. Concealed by vegetation. Adjacent to boat ramp on upstream side.
High	30	River Bank behind Willow Point wines.	Land bank slumping near 6 shacks at river bank behind willow point wines.
High	4	Riverglen (White Sands)	25 x 4 m slumped, boat temporarily lost, no property damage.
Moderate	21	Lot 112 Princes Hwy Tailem Bend	150 m of river bank cracking.
High	3	Riverview	A 50 m section of river bank collapse, half way along the Murrayview Community Recreation Reserve. An aluminium boat was lost.
High	6	Washpool (near Tailem Bend)	Slumping occurred in two areas of this private property, below the garage and at the base of the boat ramp.
Moderate	36	Jervois Rd, Wellington	4 cm-15 cm cracks a minimum of 30 feet long behind a willow approx 6 feet back from the water's edge.
No Priority	15	Lot 653 Jervois Rd, Wellington	A section of cliff on this private property collapsed. The area was only recently landscaped and this property loss has been recorded.

3.4. Information on summary sheets

Following field assessments and subsequent discussions between SKM and the DWLBC, site information recorded in our bank assessments was reviewed. A summary sheet was prepared for each site where bank assessment sheets were filled in. An explanation of these sheets is given in this section.

3.4.1. Overview of feature

Each site was described according to the main geomorphological and geotechnical features and processes documented. Co-ordinates and the date the site was inspected are recorded. Water level on the day of inspection is also recorded. Photographs of banks and impacted areas are also shown.

3.4.2. Description of bank erosion problem

Changes that have taken place to the site as documented in incident reports, discussions with community members and observed directly in the field are documented.

3.4.3. Bank characteristics

The form and features of the river bank are described in terms of bank characteristics (including bank material properties and layering, profile geometry, presence of cracks), bank structures and bank vegetation.

3.4.4. Erosion processes, failure mechanisms and weakening factors

The location, extent and severity of a particular problem are described with reference to bank erosion processes, failure mechanisms and weakening factors. The role that lowering of water level has in weakening bank materials is considered.

3.4.5. Likelihood of continued erosion/failure

The likelihood of continued erosion/failure at each site was assessed. The likelihood assigned is based on a continuation of lowering water levels, approaching -1.5 M AHD. A definition of each of the likelihoods assigned is presented in Table 3-3.

Table 3-3 Likelihood and probability of erosion/failure.

L	Category	Description	Probability Range
1	Rare	Rare that erosion/failure will occur in the planning horizon	< 5%
2	Unlikely	Unlikely that erosion/failure will occur in the planning horizon	5-10%
3	Moderate	Moderate likelihood that erosion/failure will occur in the planning horizon	10 to 50%
4	Likely	Likely that erosion/failure will occur in the planning horizon	50 to 80%
5	Almost certain	Almost certain that erosion/failure will occur in the planning horizon	>80%

3.4.6. Consequences of continued erosion/failure

The consequences of continued erosion/failure at each site was assessed in relation to the following two types of assets:

1. Social (ie. Health and Safety)
2. Economic (i.e Damage to property, roads, houses etc)

For these two types of assets, the level of consequence that may be associated with not addressing erosion/failure is explained in Table 3-4.

Table 3-4 Consequences of erosion/failure.

C	Consequences	Social asset threatened	Economic asset threatened[1]
1	Insignificant	Local treatment with short recovery – minor short term health effects	No significant infrastructure assets
2	Minor	Medical treatment required or short term acute health effects	Asset of minor value ($10,000) (e.g. fencing)
3	Moderate	Lost time injury (off work recovery required) or short /medium term injury	Asset of medium value ($100,000) (e.g. road bridge)
4	Major	Extensive injuries or chronic health issues	Asset of major value ($100,000 to $500,000) (e.g. house)
5	Catastrophic	Single fatality or permanent disability	Asset of high value ($1 million) (e.g. series of houses)

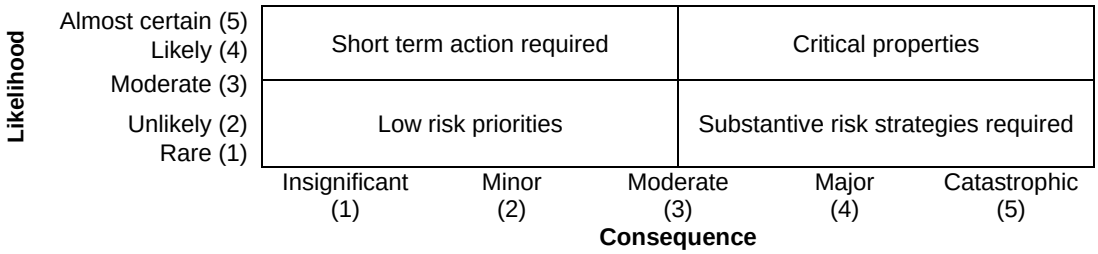
[1] The value of land has not been factored into consequence ratings for economic assets. This is meant only to provide a simple scaled estimate of the value of economic asset threatened.

3.4.7. Recommendations and priority

Recommendations to reduce the exposure to risks associated with bank erosion problems are outlined. These fall into three main categories:

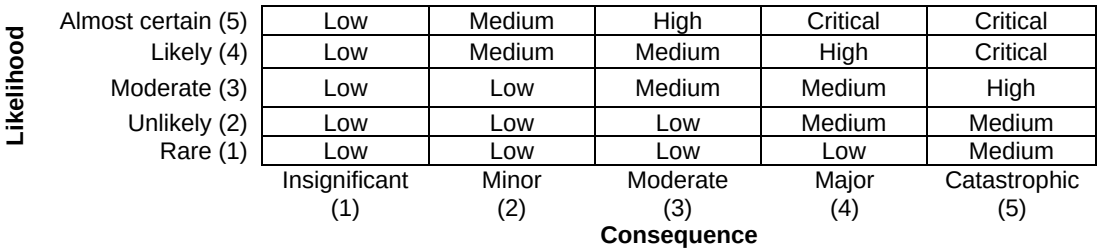
1) Recommendations for further investigations to clarify the stability of the river banks and the conditions in which failure is likely to occur.
2) Management recommendations to reduce risks that bank erosion problems pose to the public.
3) Monitoring recommendations detailing features which should be monitored.

The priority for implementing recommendations was determined by considering the likelihood and consequence of erosion/failure. Our assessment of priority is based on the risk assessment matrix presented in Figure 3-1 (after *Risk Management Standard AS/NZS 4360:1999*). Although framed in qualitative terms, the matrix shown in Figure 3-1 allows a quick and transparent way to rank issues.



- **Figure 3-1 Risk assessment matrix.**

We have refined this risk assessment matrix, so that priority can be broken down into four levels: critical, high, medium and low. The priorities for each combination of consequence and likelihood scores are highlighted in Figure 3-2.



- **Figure 3-2 Risk assessment matrix for determining the priority for completing works and additional management recommendations.**

A description of the implications of each of the management priorities listed in Figure 3-2 is given below in Table 3-2.

- **Table 3-5 Description of priorities given in Figure 3-2.**

Low	Medium	High	Critical
Low risk that does not necessarily require intervention	Moderate risk that with intervention may reduced to more acceptable levels	High risk requiring intervention to reduce risk to an acceptable level	High risk that should be addressed through management actions

Our risk assessment considers the risk of future erosion/failure given the present condition of the site. In this light, we are assessing the likelihood and consequence of erosion/failure if recommendations are not carried out.

This then provides the basis for an assessment of the priority for undertaking recommended further investigations, management actions and monitoring.

4. Summary of Site Assessments

4.1. Overview of sites

The intention of this chapter is to provide a summary of sites assessed in the field and the nature of erosion problems documented. Table 4-1 provides a breakdown of the number of incident sites that were inspected in the field and those not inspected.

Essentially, sites where more detailed assessments were carried out were in areas where bank erosion problems were of particular concern to DWLBC and the community. Sites where a brief assessment was completed generally were areas where incidents had been reported but upon our inspection were considered not to be of high enough priority to warrant a more detailed assessment.

A number of incident sites were not inspected in the field. Similarly to the sites where a brief assessment was carried out, these sites were considered on the basis of discussions with DWLBC to be of low priority.

- **Table 4-1 Summary of incident site assessments. Asterisk notes instances where a doubling up of incident numbers for two different locations was noted in the database.**

Sites Inspected				Sites Not Inspected	
Detailed Assessment [1]		Brief Assessment [2]			
IC No	Incident Name	IC No	Incident Name	IC No	Incident Name
32	South Punyelroo	47*	Wellington Marina	29	No name
50	Ngaut Nguat	-	Kia Marina	9	Lake Carlett
24	East Front Road	-	Thiele Reserve	34	Mannum
27	Bolto Reserve	47*	Wellington Ferry	28	Baseby Reserve
37	Caloote	13	Placid Estates	26	Pompoota
7	Woodlane Reserve			21	Lot 112 Princes Hwy Tailem Bend
23	Murrawong Road			3	Riverview
51	Sturt Reserve			36	Jervois Rd, Wellington
1	Long Island Marina			15	Lot 653 Jervois Rd, Wellington
20	Bells Reserve (Monteith)				
30 & 4	Riverglen (White Sands)				
6	Washpool (Tailem Bend)				
47*	Wellington Marina				

[1] Summary sheet of each site is provided in Appendix A, and overall summary documented in Table 4-2.
[2] Photograph only taken at this site, refer to GIS layer.
[3] These sites were not inspected as considered a low priority.

The following sections provide a summary of erosion problems documented along the lower River Murray, and what can be interpreted to be the main processes and contributing factors leading to erosion/failure. Table 4-1 over the page also provides a summary of recommendations and level of priority associated with these recommendations (location of sites shown in Figure 4-1).

- **Table 4-2 Table summarises outcomes of risk assessment, management recommendations, future investigations, monitoring requirements and prioritisation. For more detailed information on individual sites refer to Appendix A.**

IC No	Incident Name	Overview of feature	Likelihood of continued erosion/failure	Consequences of failure		Recommendations			Priority
				Social Assets	Economic Assets	Further Investigations	Management	Monitoring	
32	South Punyelroo	Tension cracks and ground movement	Almost certain	Catastrophic	Major	Boreholes and survey	No immediate management actions	Movement of ground and houses, measure tension cracks.	Critical
50	Ngaut Nguat	Tension cracks	Almost certain	Catastrophic	Minor	Review of past report and drilling results	Install buoys/mooring bollards for large cruise vessels to tie off to	Measure tension cracks	Critical
24	East Front Road	Tension cracks along road	Almost certain	Catastrophic	Moderate	Boreholes and review of road history	Replace section of road, remove trees along bank	Measure tension cracks	Critical
27	Bolto Reserve	Movement of jetties	Likely	Moderate	Minor	No further investigations advised at this time	No immediate management actions	Investigate on site specific basis	Low
37	Caloote	Tension cracks and slumping	Almost certain	Catastrophic	Catastrophic	Boreholes and survey	Vacate houses downstream of boat ramp, no mooring of boats	Measure tension cracks, repeat survey	Critical
7	Woodlane Reserve	Rotational slip, toppling and tension cracks	Almost certain	Catastrophic	Moderate	Boreholes and survey	No mooring at the site, fence off failure area	Measure tension cracks	Critical
23	Murrawong Road	Rotational slip/slab failure and tension cracks	Almost certain	Catastrophic	Moderate	No further investigations advised at this time	Advise people road is no longer safe, no mooring of boats	Measure tension cracks, repeat survey	Critical
51	Sturt Reserve	Tension cracks and shallow slide	Almost certain	Catastrophic	Catastrophic	Boreholes and survey	Fence of Sturt Reserve, advise residents to vacate premises	Measure tension cracks, repeat survey	Critical
1	Long Island Marina	Rotational slip, tension cracks and toppling	Almost certain	Catastrophic	Moderate	Borehole and survey	Prevent pedestrian access	Measure tension cracks in areas surrounding past failures	Critical
20	Bells Reserve (Monteith)	Tension cracks and slumping	Almost certain	Catastrophic	Minor	Borehole and survey	Prevent pedestrian and vehicle access to areas where slipping and cracking has occurred	Measure tension cracks	Critical
30 & 4	Riverglen (White Sands)	Tension cracks and toppling	Almost certain	Catastrophic	Minor	No further investigations advised at this time	No immediate management actions	Landowners to measure tension cracks	Critical
6	Washpool (Tailem Bend)	Tension cracks and subsidence	Almost certain	Catastrophic	Major	No further investigations advised at this time	Prevent pedestrian access to picnic area and concrete walkway, rebuild platform adjacent to rowing club	Measure tension cracks	Critical
47	Wellington Marina	Tension cracks	Almost certain	Catastrophic	Major	No further investigations advised at this time	Prevent pedestrian and vehicle access , no mooring of boats	Measure tension cracks in surrounding area	Critical

■ **Figure 4-1 Sites inspected where a detailed site assessment was completed.**

4.2. Nature of erosion problems

Sites inspected were found to show signs of active river bank slumping and cracking which pose a threat to social and economic assets that are located within close vicinity of the river banks. The severity of risks associated with these erosion problems is directly related to the degree in which assets and members of the community are located within the vicinity of the river banks and frequency at which they occupy these areas.

Based on our inspections it is apparent that bank slumping and cracking poses a major threat to the following:

- ***Properties with river frontage***, in particular the areas of South Punyelroo (IC 32), Caloote (IC37), Sturt Reserve (IC 51) and Riverglen (IC 30 & 4). Tension cracks were documented as far back as 80 m from the shore line at South Punyelroo (IC 32).
- ***Roads, car park areas and associated traffic***, notably Murrawong Road (IC 23) and East Front Road (IC 24). Continued bank retreat threatens Kittelty Road at Woodlane Reserve (IC 7).
- ***Riverside reserves***. Waterfront reserves form areas where public congregate. Tension cracks were documented at a number of reserves inspected along the Lower River Murray: Woodlane Reserve (IC 7); Sturt Reserve (IC 51); Bells Reserve (IC 20).
- ***Mooring areas and navigation along waterways***. The ability to moor boats at a number of marinas has been impacted by lowering water levels and problems of bank slumping and cracking: Long Island Marina (IC 1) and Wellington Marina (IC 47). Some bank areas are no longer safe to moor against (i.e. South Punyelroo, Caloote, Sturt Reserve) and river passage is impeded as a result of past failures (such as around Long Island). Ground subsidence and movement has also impacted on integrity of jetties (Bolto Reserve, IC 27).
- ***Areas of historical and cultural significance***. Cracking at the base of the limestone cliffs at Ngaut Ngaut threatens deposits in rock shelter which are known for their extensive faunal remains, artefacts and human burials. This site is considered of national significance (Department of Environment and Heritage, 2008).

There are also two other issues which arose out of the inspections, which need to be carefully considered when assessing the impacts that river bank slumping and cracking are having on assets adjacent to the River Murray. These are:

1. The extent to which natural hazards have been considered in approving development in close vicinity to the river and below limestone cliffs, in particular the property at Caloote below a limestone overhang.
2. Queries regarding the quality of construction and material used, with reference to sections of East Front Road and jetties along Bolto Reserve (IC 27).

4.3. Erosion processes, failure mechanisms and weakening factors

Bank erosion problems rarely are the result of a single process or mechanism of instability, but rather are usually the result of complex interactions between a number of processes and mechanisms that may operate on the bank either simultaneously or sequentially (Thorne et al., 1996). These can be grouped into three broad categories:

1) **Erosion processes** which detach, entrain and transport individual particles or assemblages of particles away from the toe of the face of the retreating bank;
2) **Failure mechanisms** which lead to collapse of all or part of the bank;
3) **Weakening processes** which operate on and within the bank to increase its erodibility and to reduce its geotechnical stability.

The following sections deal in turn with erosion processes, failure mechanisms and processes of weakening and consider the role that each of these has in accounting for the problems of bank erosion along the Lower River Murray.

4.3.1. Erosion processes

Seven categories of bank erosion are recognised in the literature (Thorne et al., 1996):

- **Parallel flow (fluvial entrainment)** – Sediment is detached and carried away by flow parallel to the bank;
- **Impinging flow (fluvial entrainment)** – Sediment is carried by flow striking the bank at an angle to the long-stream direction;
- **Boatwash** – Sediment is carried away by waves and currents generated by passing boats;
- **Wind-waves** - Sediment is carried away by waves and currents generated by the wind;
- **Rills and gullies** – Banks are eroded by concentrated surface runoff draining across the bankline;
- **Piping** – Subsurface erosion by water draining through the bank; and
- **Freeze/thaw** – Particles and aggregates are loosened by freezing and fall of the bank face during flow or boat wash.

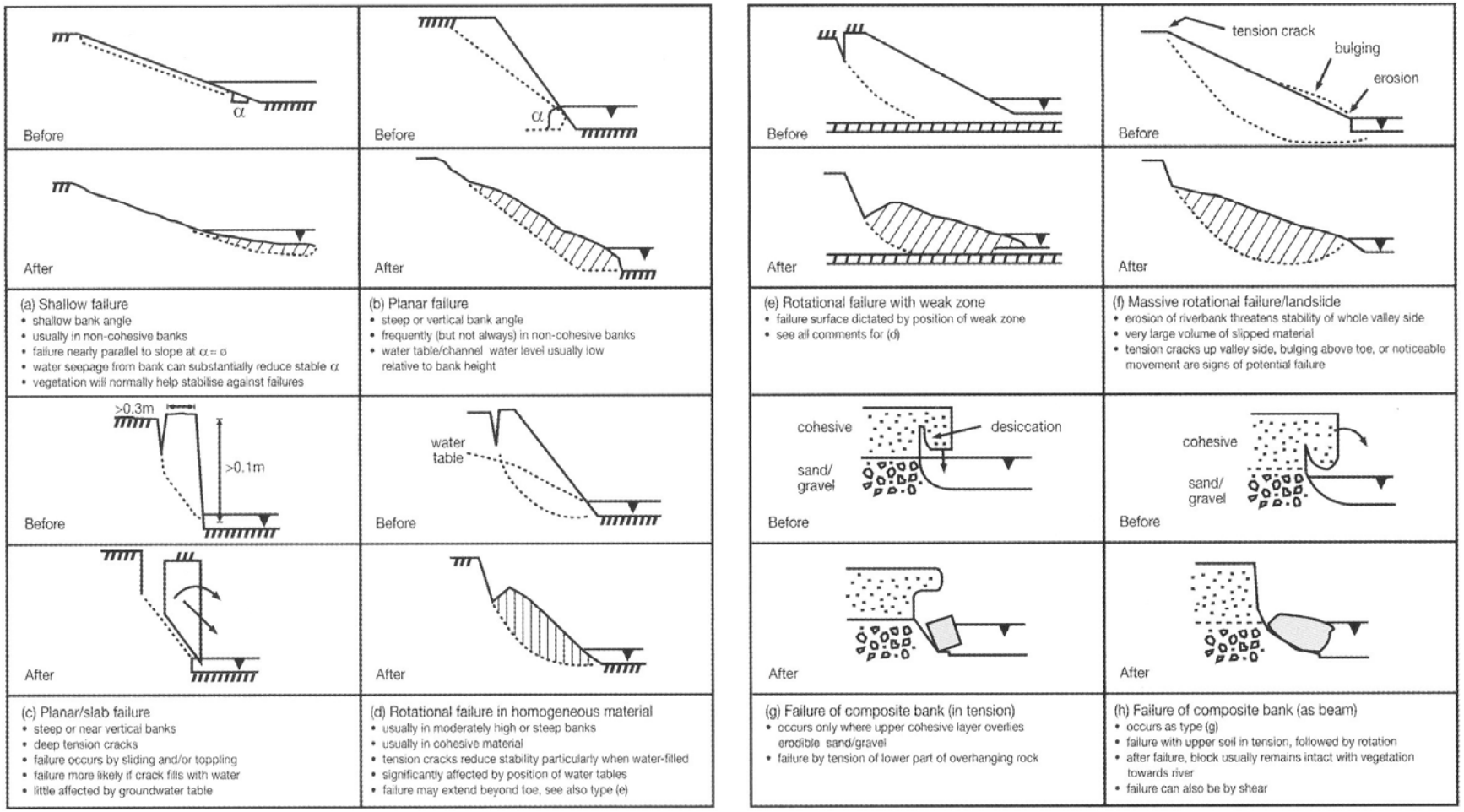
Because of the regulated nature of the Lower Murray, the channel is generally characterised by a low energy flow regime with low shear stresses and cohesive clay banks. Under these circumstances, the potential for fluvial entrainment is limited. There was also a lack of field evidence such as scour and undercutting to suggest otherwise. However, fluctuations in water levels as a result of weir operations, boat wash and wind-waves appears to be effective in washing away imported sand material from the channel margins. The removal of sand material at these artificial beaches and exposure of underlying clays was noted at a number of locations.

4.3.2. Failure mechanisms

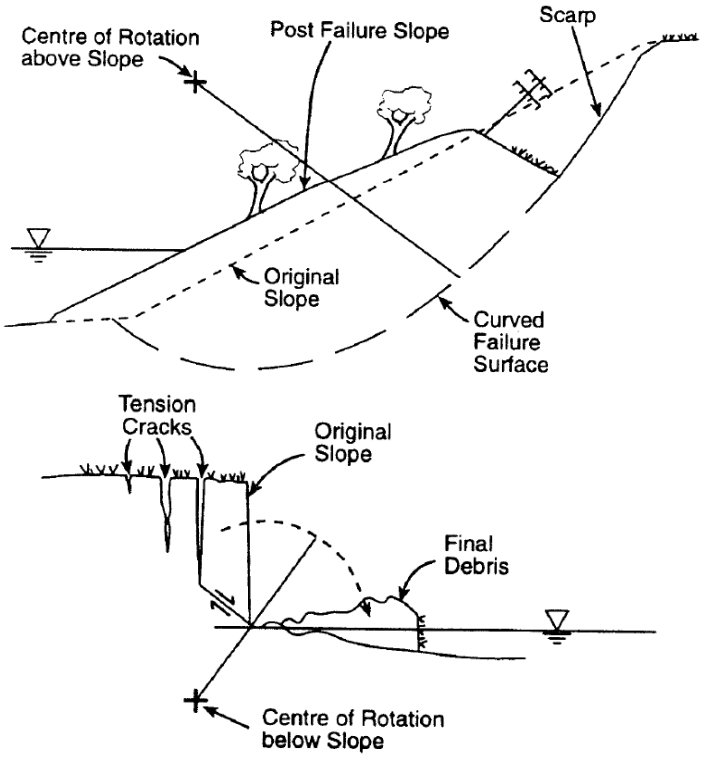
Seven categories of mechanism responsible for bank collapse may be identified (Thorne et al., 1996):

- **Shallow slide** – Shallow seated failure along a shear plane parallel to and just below the bank surface, typically occurs in weakly cohesive soils. See also Figure 4-2 (a) shallow failure and (b) planar failure;
- **Rotational slip** – This is a deep seated movement of all or part of the bank profile in which a block of soil slips along a curved surface. This is a severe type of failure that involves the movement of a large volume of material and generates serious bankline retreat. See also Figure 4-2 (e) rotational failure with weak zone, (f) massive rotational failure/landslide, (d) rotational failure in homogenous material and Figure 4-3;
- **Slab failure** – Blocks or columns of soil topple forward into the channel, often with deep tension cracks separating the failure blocks from the intact bank. Similarly to rotational slips, this represents a severe type of failure involving the movement of large volumes of material and serious bankline retreat. See also Figure 4-2 (c) planar/slab failure and Figure 4-3;
- **Cantilever failure** – Overhanging blocks of soil collapse into the channel by shear, beam or tensile failure. Overhangs are found in layered banks where a resistant, cohesive or root-bound layer overlies an erodible, non-cohesive layer. See also Figure 4-2 (g) failure of composite bank (in tension) and (h) failure of composite bank (as beam);
- **Soil fall** – Soil falls directly into the channel from near-vertical or undermined, cohesive bank face. This often follow weakening by desiccation, saturation or frost action on an unvegetated surface;
- **Dry granular flow** – Avalanching of dry, granular bank material down the upper part of a non cohesive bank. When this occurs in lower bank this can cause instability of upper bank and bankline retreat; and
- **Wet earth flow** – Liquefaction and flow of section of bank due to saturation and high port water pressures. This can result in rapid bankline retreat in zones of strong seepage and poor drainage.

Of these bank failure modes outlined, deep rotational slips and slab failures would appear to be the main mechanisms causing the large failures and retreat of banklines at sites inspected along the Lower Murray. These two modes of failure can also occur together sequentially, with a large rotational slip forming a steep face that then continues to retreat through slab failures. This would appear to be the case for Long Island Marina (IC 1) and Woodlane Reserve (IC 7). These represent the most severe form of bank failure modes. They are a sign of serious instability, deep below the rooting zone for riparian vegetation. Heavy engineering intervention through re-profiling and improved drainage to increase bank stability will be necessary if the bankline can not be allowed to retreat.



- **Figure 4-2 Bank failure modes (from Hey et al., 1991).**



- **Figure 4-3 Failure mechanisms typical of over-steepened and over-heightened banks: rotational slip (above) and slab failure (below) (from Thorne, 1999).**

4.3.3. Weakening factors

Six categories of factor responsible for decreasing the erosion resistance and mechanical stability of a river bank are broadly identified in the literature (Thorne et al., 1996):

- **Leaching** – Leads to a weakening of the bank through a reduction in cohesion that occurs when clay minerals are removed by solution in groundwater seeping through the bank.
- **Trampling** – Destruction of soil fabric by crushing under the weight of pedestrians or grazing animals.
- **Destruction of riparian vegetation** – Damage of destruction of riparian vegetation by a variety of natural processes and human actions.
- **Mechanical damage** – Damage of banks by boat mooring, stock access or angling practices.
- **Positive pore water pressures** – Occurs when drainage of water through the bank is restricted to allow a build up of seepage pressure. By reducing the effective strength of the bank material they weaken the bank, increasing the probability of block failure or in extreme cases, leading to liquefaction and wet earth flow.
- **Desiccation** – Cracking and crumbling of soil due to intense drying that breaks electro-chemical bonds. This loosens soil crumbs on exposed bank surface during hot summers.

In the case of the Lower River Murray, a number of additional factors are noted which are considered significant in decreasing the erosion resistance and mechanical stability of the river banks:

- **Development on banks** – plastic properties of wet clays and their compaction when under load can cause subsidence and consolidation (i.e. construction of jetties, roads, houses).
- **Fluctuation of water levels** – changes in moisture status associated with fluctuating water levels can cause expansion and shrinking of clays.
- **Consistent lowering of water levels** – reduced flows/drought causing increased desiccation of banks and formation of tension cracks, increased surcharge of banks associated with lowered water levels.

This discussion has been limited by available information and visual site inspection of a number of sites. Further geotechnical investigations are recommended to quantify the role of relevant weakening factors, material properties and bank parameters. This is necessary before any firm conclusions can be drawn regarding the cause of failures and is a precursor to considering the scope for stabilisation.

5. Recommendations

5.1. Future Investigations

A series of recommendations for future investigations have been made for sites assessed in the field. These recommendations are recorded within the summary sheet of each site as outlined within Appendix A. These recommendations are also outlined in brief in Table 4-2.

It is recommended the following site inspections/investigation be undertaken in DWLBC nominated high risk/high consequence areas:

- Preparation of the OH&S documents for the site investigation;
- Geological mapping of the failure area;
- Survey of the cracks, existing features in vicinity of the problem and cross sections of the slopes including both land and the river bed;
- Drilling of boreholes to identify the material, consistency and alignment of the soil profile;
- Sampling and in-situ testings within the soil profile;
- In-situ CPTu tests;
- A laboratory test program on the selected samples for the soil index and strength parameters;
- Preparation of the factual report.

Following the site investigation, slope stability analyses for selected cross sections will be undertaken to assess the soil parameters and stability of the slopes which will be used for future risk assessment and management decision makings.

It is recommended that the knowledge of river bank collapsing gained from the present study and subsequent detailed geotechnical investigations is used to develop a map of risk of collapsing potential for the entire length of the Lower River Murray. This map can then be used to identify the distribution of high risk/high consequence areas and form the basis for prioritising management actions and monitoring.

5.2. Management

DWLBC were initially advised of SKM's recommendations for management verbally in a meeting on the 24 October 2009 at the conclusion of our four day site assessments (21-24 October 2009) and in writing on the 25 October 2009. We understand that DWLBC promptly acted on these management actions.

As was emphasised in earlier correspondence, the situation as it relates to cracking and bank slumping is so serious that the timeframe is critical and the recommended actions should be undertaken as a matter of priority immediately.

Due to the nature of the possible failures and uncertainties involved in the engineering judgement on site by visual inspection (as highlighted in our limitation statement at the front of this report), we recommend that the residents of properties in high risk areas and public who have access to the high risk reserves should be advised about possible injury and fatality risks before further investigation and detailed assessments are completed.

We recommend for the private properties and residential dwellings being advised of high risk that they should vacate these premises until detailed assessment is completed due to the potential consequences continued erosion/failure may have on health and safety. Access to high risk reserves should be fenced off to stop all pedestrian and vehicle traffic. A fast and urgent response is needed for the East Front Road section as tension cracks leading to collapse are evident.

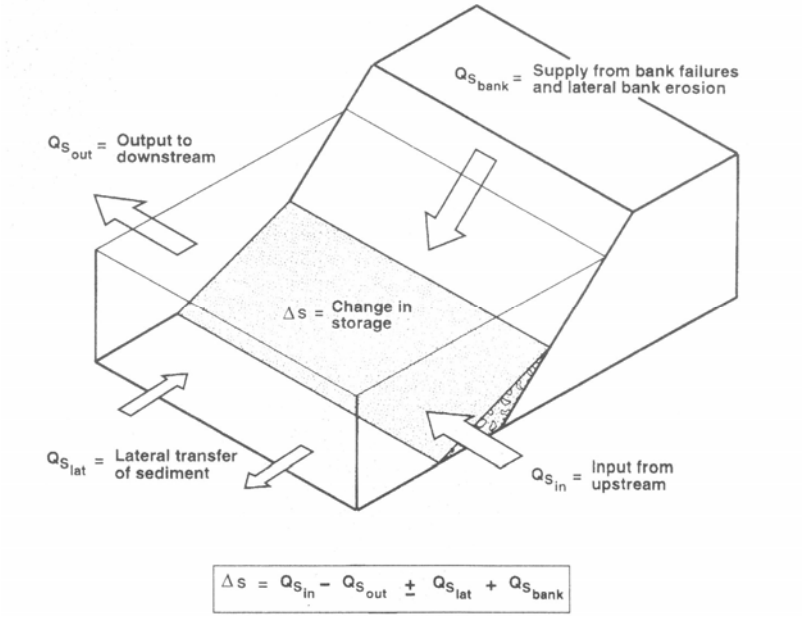
A series of site specific management recommendations were made for areas inspected in the field. These management recommendations are recorded within the summary sheet of each site as outlined within Appendix A. These management actions are also outlined in brief in Table 4-2.

Specific comments are reserved to two issues: the issue of dredging and removal of failure material from the channel margins; and removal of vegetation (willows) on river banks. We are not aware of plans to dredge particular sections of the channel at this time. However, it needs to be stressed that there is a risk that dredging and removal of failed material/debris may have the affect of destabilising the adjacent bank and initiate further failures.

The concept of basal endpoint control is used to demonstrate the linkages between different bank processes with reference to Figure 5-1. Bank failure involves the movement of material directly from the intact bank to the basal area. The removal of material from the basal area depends on its entrainment by flow as shown in Figure 5-1. However, dredging activities may also result in removal of material from the basal area directly or indirectly as a result of removal from mid-channel areas, which in turn impact on lateral transfer of sediments.

The amount and duration of basal sediment storage depends on the balance between the rates of supply from bank processes and removal (entrainment and dredging). The accumulation and or erosion of material from this basal zone exerts an important influence on bank stability. The accumulation of material at the base of bank, has the effect of decreasing bank angle and height, increasing bank stability.

Pressure to dredge areas of channel, particularly around marinas is likely to increase in future. Further geotechnical studies are recommended in the planning stage of any proposed dredging project to demonstrate that removal of material and debris will not impact on bank stability and cause an increase in rates of bank erosion.



- **Figure 5-1 Basal endpoint control showing role of sediment fluxes to and from river bank basal zone (from Thorne and Osman, 1988).**

The additional weight or surcharge of trees on river banks is often cited as a contributing to bank failure. The removal of vegetation and in particular willows for the purpose of reducing surcharge has been a practice used along the Lower River Murray. However, as far we can ascertain, the extent to which it is a significant factor in decreasing bank stability has not been investigated.

Studies completed in of slump blocks along the LaTrobe River in Gippsland, Victoria show that trees represented as little as 4% of total saturated slump mass (Abernethy and Rutherfurd, 2000). This is small in comparison to other destabilising factors and considered secondary. Consideration also needs to be given to how far the roots penetrate into the banks. If the roots go beyond the shear plane, the reinforcement effect of roots is likely to exert a considerable influence over any failure process.

Some further investigations are recommended to guide the practice of vegetation removal from banks and clarify if it is significant in reducing surcharge and the extent to which vegetation removal impacts on bank stability.

5.3. Monitoring

As part of this study DWLBC have requested advice on future monitoring of collapse-susceptible areas over the next three years from 2009/10 through to 2011/12 inclusive. A series of monitoring recommendations have been made for sites inspected in the field and these are included in summary sheets in Appendix A. Monitoring recommendations are also outlined in brief in Table 4-2.

The following are the principles of a *General Operational Monitoring Plan* that is recommended for areas that are identified as susceptible to cracking and bank collapsing:

- Erosion extent – Map out the limits of the erosion problem. A suitably scaled map showing the position of bank line should be developed and location of features such as tension cracks should be developed.
- Rate of bank retreat – the rate of bank retreat can be recorded on-site from surveys taken over time, i.e keeping a record of distances from bank line to known point (house, pole etc).
- Tension cracks - The presence of tension cracks indicate that the bank has already failed and may be close to collapse. The position of tension cracks, their length, width and depth should be monitored.
- Photographic record – Repeat photographs showing the same field of view are useful for documenting changes at a site.
- GIS Integration – Monitoring and Incident Reports should be integrated into GIS environment, with position of locations of features recorded as GPS coordinates.

It is recommended that this general operational monitoring plan is implemented at weekly intervals. A feature survey by a qualified surveyor would be of assistance in setting out each of the sites for monitoring. Bank lines, tension cracks and bench marks could be recorded at this time, providing a more accurate base map for future monitoring.

Depending on the outcomes of further geotechnical investigations, it may be necessary to switch from a *General Operational Monitoring Plan* to a *Detailed Operational Monitoring Plan* in high risk areas, which will be characterised by more frequent and intensive monitoring. Where cracking and bank slumping has potential to impact on assets such as roads and houses, there may also be a need for precision survey techniques to achieve the level of accuracy required to monitor the development of tension cracks and slumping at these locations.

6. Summary

The Lower River Murray is experiencing significant problems of cracking and slumping of river banks which is a high risk to social and economic assets that lie within close proximity to the river. Field inspections carried out in this study indicated that bank erosion problems are largely driven by mass-failure mechanisms. Mass failure of river banks is occurring by the development of tension cracks, followed by deep rotational slips and continued bank retreat through slab failures. Tension cracks provide a warning of bank areas that have already failed and may be close to collapse.

Our inspections were completed at a time when water levels were -0.5 to -0.79 m AHD. Water levels are predicted to drop to -1.5 m AHD over the coming 2009/10 summer. As pools levels lower, the increase in bank surcharge will act to further destabilise the river banks with more failures predicted to occur. The result of our risk assessment completed here show that continued erosion/failure is almost certain to occur for the majority of sites inspected, with moderate to catastrophic consequences. Of greatest concern is the risk that these problems pose to Health and Safety. There is potential for loss of life to occur in the event that people are within the vicinity of the slip area at the time a bank collapse occurs.

In order to reduce risks to a more acceptable level, a series of recommendations for further investigations, immediate management actions and monitoring have been outlined. Further detailed geotechnical investigations have been recommended at a number of high risk sites to quantify the material properties, weakening factors and conditions under which collapse is likely to occur. These investigations will provide a greater level of certainty than can be ascertained from visual inspections undertaken to date around the risk of collapse for a water level of -1.5 m AHD. It is recommended that the knowledge of river bank collapsing gained from the present study and detailed geotechnical investigations planned is used to map of risk of collapsing for the entire length of the Lower River Murray. This map could be used to identify the distribution of high risk/high consequence areas and form the basis for prioritising management actions and monitoring.

We recommend that residents of properties in high risk areas and public who have access to high risk reserves are advised about possible injury and fatality risks before further investigations and detailed assessments are completed. Residents of private properties and residential dwellings being advised of high risk should vacate these premises until detailed assessment is completed. Access to high risk reserves should be fenced off to stop all pedestrian and vehicle traffic. A fast and urgent response is needed for the East Front Road section as tension cracks leading to collapse are evident. We recommend a strategy of risk avoidance and separation, where measures are taken to avoid exposure of the public to the hazard, such as limiting access to the river banks.

The principles of a General Operational Monitoring Plan along the Lower River Murray at areas identified as susceptible to cracking and bank collapsing have been outlined. It is recommended that this monitoring is implemented at weekly intervals. It is important this monitoring is linked to management actions, with appropriate measures implemented to minimise the exposure of any new risks to the public (i.e. new incidence of cracking and slumping). Depending on the outcomes of future detailed investigations and assessments it may be necessary to switch from a General Operational Monitoring Plan to a Detailed Operational Monitoring Plan in high risk areas, which will be characterised by more frequent and intensive monitoring.

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Appendix A Site Assessments

Summary Sheet

Incident Name: South Punyelroo **Incident Number: 32**

Overview of feature				
Tension cracks and ground movement	Easting	Northing	Date inspected	Water Level
	372788	6169365	21/09/2009	-0.742 m AHD

Grey sandy clay with tension cracks.

Tension cracks in road leading to houses.

Description of bank erosion problem

- Tension cracks noted in sandy clay exposed along shoreline [Photo ID 232 & 233]. Cracking also along road at back of houses [Photo ID 235, 236 & 237]. Road is located c.80 m from shoreline.
- Lateral movement of earth around house foundations [Photo ID 239], with movement in the direction of the river (c.2 cm). Slumping of ground (c. 4cm) also noted within the vicinity of paving tiles [Photo ID 240].

Bank characteristics

- Low angle shoreline comprised of grey sandy clay with thin drape of pale sand forming veneer over the lower toe and upper bank [Photo ID 232]. Tension cracks c.2 cm in width and c.5 cm deep [Photo ID 233].
- Small jetties along shoreline were originally constructed here in the 1980s and show no obvious signs of movement.

Erosion processes, failure mechanisms and weakening factors

- Desiccation of exposed sandy clay along the shoreline with tension cracks [Photo ID 233]. Recent evidence of ground movement impacting on area between road and water line. Tension cracks on road 3 to 5 m in length [Photo ID 235, 236 & 237].
- Lowering of water level has contributed to desiccation of sandy clay material along shoreline.
- Anticipate slow slumping at this location. Failure and movement may be related to soft sandy clay material moving over a layer of harder material.

Likelihood of continued erosion/failure

- Almost certain that area will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure could result in property damages and potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	Moderate (3)	**Major (4)**	Catastrophic (5)

Recommendations	Priority
Future Investigations	**Critical**

▪ Three boreholes in area, two along road that runs behind houses and one at shoreline. ▪ Survey of area in conjunction with boreholes. ***Management actions*** ▪ No immediate management action required, however, this is classified as a high risk area as houses lie within area of movement. Given the high risk to occupants of the houses, further monitoring of tension cracks and movement to houses is recommended. ***Monitoring*** ▪ Repeat surveying of area to monitor movement of house. ▪ Repeat measurements of the depth, length and width of tension cracks along road.	

Summary Sheet

Incident Name: Ngaut Nguat **Incident Number: 50**

Overview of feature				
Tension cracks	Easting	Northing	Date inspected	Water Level
	372945	6160746	24/9/2009	-0.497 m AHD

Boat mooring and degradation of bank.

Tension crack at base of limestone cliffs.

Description of erosion problem

- Concerns expressed from Aboriginal custodian regarding cracking at the base of the limestone cliffs. These pass through deposits in a rock shelter at the base of the cliff which is known for its extensive faunal remains, artefacts and human burials. The shelter provides significant insight into the prehistory of human occupation in Australia and is of national significance (Department of Environment and Heritage, 2008).

Bank characteristics

- The river banks are comprised of silty fine sand and clay sediments. Alluvial deposits from a bench which tapers up to vertical limestone cliffs. Boats presently moor at the bank and disembark directly on the river bank. A series of walkways and boardwalks provide pedestrian access along the base of the limestone cliffs.

Erosion processes, failure mechanisms and weakening factors

- Erosion of the banks is evident at the location where boats pull in and tie off [Photo ID 81]. Banks are undercut, the action of boat waves against the banks, wetting and drying of banks leads to cracking and crumbling.
- The limestone cliffs are prone to failure. A number of large tension cracks could be observed in the cliff face, running from the base of the cliff to the top [Photo ID 82 & 89]. This is a natural process, which presents a high background risk to people walking along the pathways.
- In the sheltered area, tension cracks have appeared in the fluvial deposits at the base of the cliff in the past couple of months and these have continued to open up [Photo ID 85].
- Cause of tension cracking in alluvial deposits may be related to lowering of water level, increasing surcharge of banks.

Likelihood of continued erosion/failure

- Almost certain that further erosion of the banks and continued cracking at the base of the cliff will occur. Likely that further cracking of the limestone cliffs will occur.

Rare	Unlikely	Moderate	Likely	**Almost certain**

(1)	(2)	(3)	(4)	**(5)**
Consequences of continued erosion/failure				
▪ Large rotational failure of the banks and/or failure of the limestone cliffs could result in potential injury and fatality and damage to Aboriginal artefacts of national significance.				
Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	**Minor (2)**	Moderate (3)	Major (4)	Catastrophic (5)

Recommendations	**Priority**
Future Investigations	**Critical**
▪ Review Frazier report and past drilling/augering of rock shelter area. Nature of transition between limestone and fluvial deposits, presence or absence of limestone beneath deposits to be determined.	
Management actions	
▪ Install buoys/mooring bollards in river to eliminate need for large cruise vessels to tie off on River Red Gums.	
Monitoring	
▪ Continue to monitor area for tension cracks. Measure depth, length and width of tension cracks.	

Summary Sheet

Incident Name: East Front Road (Young Husband) **Incident Number: 24**

Overview of feature				
Tension cracks along road	Easting	Northing	Date inspected	Water Level
	364107	6139306	21/09/2009	-0.726 M AHD

Tension cracking along East Frond road.

Location where tension crack arc has developed.

Description of erosion problem

- Numerous tension cracks (c. 4-7 cm in width and varying in length) along the length of East Front Road and in some instances there has been localised slumping of 2-3 cm [Photos ID 241-245, 248 & 249].
- Quality of road construction is questionable. Noted that there has been a long history of problems and maintenance along this road.
- At one location, tension crack form an arc across road in the vicinity of two trees on banks [Photo ID 248 & 249].

Bank characteristics

- River banks are layered and comprised of sand/silt, with overlying grey clay and upper sand.

Erosion processes, failure mechanisms and weakening factors

- Road embankment considered to be comprised of poor construction materials. Settlement over time had lead to formation of tension cracks and slumping.
- Drop in water level may be significant factor in contributing to failure at bend in road where tension crack arc has developed [Photo ID 248 & 249]. Water level at present c.4-5 m below road surface. Role of trees on banks uncertain, shallow roots may contribute to failure whereas deep roots are not likely to contribute to failure.

Likelihood of continued erosion/failure

- Almost certain that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure could result in damages to property, Government infrastructure and potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	**Moderate (3)**	Major (4)	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ Pavement Dipping to determine integrity of road base – Three boreholes in cracked area and two in non cracked area to 1 m in	**Critical**

depth. Nuclear gauge insitu test for compaction at dipping sites. ▪ Need to review history of road for whole alignment – materials, survey and cross-sections. ***Management actions*** ▪ Section of road where tension crack arc has developed needs to be replaced. Trees along bank will need to be removed when this section of road is replaced [Photo ID 248 & 249]. ***Monitoring*** ▪ Continue to monitor road for tension cracks. Repeat measurements of the depth, length and width of tension cracks along road.	

Summary Sheet

Site Name: Bolto Reserve **Incident Number: 27**

Overview of feature				
Movement of jetties	Easting	Northing	Date inspected	Water Level
	346218	6135143	22/09/2009	-0.763 M AHD

Subsidence of land adjacent to platform.

Subsidence of jetties at this location.

Description of erosion problem

- Subsidence of river banks and jetties that run along the edge of the river behind properties [Photo ID 1 & 3].

Bank characteristics

- Generally a low gradient bank comprised of clay material at base which is covered in parts by sand deposits. This sand material is imported material brought in to provide a beach along the edge of the river.

Erosion processes, failure mechanisms and weakening factors

- No tension cracks observed along river frontage. Jetty piles are footed in plastic clay.
- Suspect subsidence relates to:
  - plastic properties of wet clays and their compaction causing subsidence and consolidation when water is squeezed out under load (from construction of jetties and their use).
  - changes in moisture status associated with fluctuating water levels causing expansion and shrinking of clays.
  - quality of jetty construction and extent to which these structures were level at time they were built.

Likelihood of continued erosion/failure

- Likely that further bank subsidence will occur if water levels continue to lower.

Rare (1)	Unlikely (2)	Moderate (3)	**Likely (4)**	Almost certain (5)

Consequences of continued erosion/failure

- Further bank subsidence could result in damages to jetties and potential injury.

Social	Insignificant (1)	Minor (2)	**Moderate (3)**	Major (4)	Catastrophic (5)
Economic	Insignificant (1)	**Minor (2)**	Moderate (3)	Major (4)	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ No further investigations of this area are advised at this time. ***Management actions*** ▪ No management recommendations. Problems considered low priority and are	**Low**

to be managed by individual landowners. ▪ Advice to be provided to landowners of concerns over safety to members of public who may walk along jetties. ***Monitoring*** ▪ Respond to landowner concerns and investigate on a site specific basis.	

Summary Sheet

Incident Name: Caloote **Incident Number: 37**

Overview of feature				
Tension cracks and slumping	Easting	Northing	Date inspected	Water Level
	341571	6129751	22/09/2009	-0.763 m AHD

Limestone cliff overhang with tension cracks.

Tension cracks and slumping at front of house.

Description of erosion problem

- Problems first became apparent at this site over the summer of 2008. For the purposes of this assessment the site is divided into three areas:
  1. Area A – Upstream of boat ramp. Tension cracks up to 5 cm in width and 1 m deep along footpath upstream from houses. Tension cracks also appearing in road below houses [Photo ID 4].
  2. Area B – Boat ramp and parking lot. No tension cracks observed.
  3. Area C – Downstream of boat ramp. Tension cracks through properties and slumping [Photo ID 5 & 9]. Also risk of toppling of blocks from limestone cliff behind two houses [Photo ID 7 & 8].

Bank characteristics

- No exposures of banks were observed at this site.

Erosion processes, failure mechanisms and weakening factors

- Number of houses in Area C lie beneath limestone cliffs. Tension cracks developed in these cliffs and nature of overhangs, mean that toppling/cantilever failure will result in blocks landing on houses [Photo ID 7 & 8].
- Tension cracks are continuing to open up in Area C with notable changes in the size of cracks noted over the past two weeks [Photo ID 5]. Tension cracks and slumping indicate formation of large rotational slip adjacent to river. Failures may be related to a number of factors including:
  - water level drop in adjacent river and the effect that this has in increasing bank surcharge.
  - clearing of vegetation and construction of houses within close proximity of river.

Likelihood of continued erosion/failure

- Almost certain that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure could result in property damages and potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**

Recommendations	Priority
Future Investigations ▪ Two boreholes in area, one in Area A and B. ▪ Survey of two areas in conjunction with boreholes. ▪ No further investigations proposed at this time for Area C. ***Management actions*** ▪ Area C to be vacated and fenced off to stop all pedestrian and vehicle traffic. No mooring of boats to be allowed. ***Monitoring*** ▪ Monitor depth, length and width of tension cracks in Area A and Area C. Repeat surveying of three areas to monitor roads, houses and public access areas.	**Critical**

Summary Sheet

Incident Name: Woodlane Reserve **Incident Number: 7**

Overview of feature				
Rotational slip, toppling and tension cracks	Easting	Northing	Date inspected	Water Level
	348216	6126137	22/09/2009	-0.763 m AHD

Site of past failure at Woodlane Reserve.

Position of tension crack where tape is located.

Description of erosion problem

- A large section of river bank slumped in area within vicinity of area where road runs close to river bank [Photo ID 15]. Initial slump damaged pumping station at site. Further slumping occurred, enlarging the slumped area of the first collapse, the loss of the pumping station and stobbie pole.

Bank characteristics

- Vertical banks at failure location c. 2.5 m in height and comprised of lower grey sand/silt/clay (1.5 to 2 m thick) covered with sand fill (0.5 m thickness). Edge of failed bank 5-10 m away from edge of road.

Erosion processes, failure mechanisms and weakening factors

- Large rotational slip at this location. Continued toppling and bank retreat within the vicinity of failure location is expected [Photo ID 15].
- Cause of failure not known. Constructed road, 1.5 m high passes close to river within vicinity of failure location.
- Tension cracks noted in reserve area upstream of failure around tree as shown in above photo and Photo ID 12.

Likelihood of continued erosion/failure

- Likely that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure could result in potential injury and fatality (if someone is in the vicinity of the bank when failure occurs).

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	**Moderate (3)**	Major (4)	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ Boreholes and survey: two in area upstream from failure location on road below houses, one on road adjacent to failed area and one in reserve	**Critical**

downstream. ***Management actions*** ▪ No boats to be moored at this site. Fence off area where failure has occurred to stop pedestrian traffic. ▪ Should bank retreat continue at this location it may be necessary to change the alignment of the road so that it is set back further from the river. ***Monitoring*** ▪ Repeat measurements of the depth, length and width of tension cracks. ▪ Continue to monitor road for tension cracks, particularly within the vicinity of rotational failure and monitor retreat of bank.	

Summary Sheet

Incident Name: Murrawong Road **Incident Number: 23**

Overview of feature				
Rotational slip/slab failure and tension cracks	Easting	Northing	Date inspected	Water Level
	348415	6119876	22/09/2009	-0.794 m AHD

Cracking and subsidence along Murrawong Road.

Slumping in reserve below houses.

Description of erosion problem

- Cracking reported along Murrawong Road. This is the only access to and from residential area.

Bank characteristics

- Lack of clear bank exposures from which to describe bank characteristics. Silt/clay material at base of bank (1 m thick) with overlying sand material (1.5 m thick). Willows lining banks adjacent to entrance to residential area.

Erosion processes, failure mechanisms and weakening factors

- Cracking and subsidence in road noted at entrance to residential area [Photo ID 16] and along the river bank in grassed reserve [Photo ID 17 & 18].
- Slumping of road and tension cracks may be attributed in part to drop in water level and effect this has in increasing surcharge. There is also very little setback from the river to the road at this location (c.5-10 m).
- It is not known the extent to which willows lining the banks have in increasing surcharge.

Likelihood of continued erosion/failure

- Almost certain that will experience continued subsidence and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure and continued erosion could result in potential injury and fatality. Road provides the only access point to the area.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	**Moderate (3)**	Major (4)	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ Not advised at this time.	**Critical**

Management actions ▪ People to be advised that road is no longer safe. ▪ No boats to be moored at this site. ***Monitoring*** ▪ Continue to monitor road and grassed bank areas for tension cracks. Repeat measurements of the depth, length and width of tension cracks. ▪ Repeat surveying of area to monitor movement of road and houses.	

Summary Sheet

Incident Name: Sturt Reserve **Incident Number: 51**

Overview of feature				
Tension cracks and shallow slide	Easting	Northing	Date inspected	Water Level
	343974	6111940	22/09/2009	-0.715 m AHD

Mooring of boat within high risk area.

Tension crack running along back of property.

Description of erosion problem

- Tension cracks originally noted by council in SE corner of reserve and signs and bunting were subsequently erected. Council removed willows and vegetation along with a large amount of topsoil from the area, in an attempt to alleviate weight of the bank [Photo ID 42 & 45].

Bank characteristics

- Banks comprised of organic rich silt/clay (c.1.5 m thick) with overlying sand (c.1 m thick). Depth to bedrock unknown at this location, granite outcrop noted nearby so may only require shallow boreholes (<5 m depth). Occasional willows along the edge of the bank within the vicinity of properties.

Erosion processes, failure mechanisms and weakening factors

- Desiccation of lower banks where clay unit has been exposed as Water Level has dropped. Tensions cracks have formed, which weakens materials leading to shallow failures [Photo ID 46, 47 & 48].
- Tension cracks run along back of houses, 9 m from road with potential for development of large rotational slip [Photo ID 49]. Tension cracks also noted at boat ramp [Photo ID 43 & 44].
- Lowering of water level has contributed to desiccation of clays along shoreline and also increases in bank surcharge.
- Possibility of hydraulic gradient from wetland areas located west of Riverfront Road discharging groundwater to river, with seepage weakening bank materials.

Likelihood of continued erosion/failure

- Almost certain that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure could result in property damages and potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**

Recommendations	**Priority**

Future Investigations ▪ Three boreholes and survey along Riverfront Road. One of the boreholes to be drilled in area of tension crack located 9 m from road [Photo ID 49]. Monitoring of groundwater levels in boreholes to assess hydraulic gradient. Linear shrinkage tests will show how sensitive materials are to moisture changes. ***Management actions*** ▪ Fence off Sturt Reserve and properties located south east of Sturt Reserve along Riverfront Road to stop all pedestrian and vehicle traffic. Advise people living in locality to vacate their premises. No boats to be moored at this site. ***Monitoring*** ▪ Repeat surveying of area to monitor movement of road and houses. ▪ Repeat measurements of the depth, length and width of tension cracks in area.	**Critical**

Summary Sheet

Incident Name: Long Island Marina **Incident Number: 1**

Overview of feature				
Rotational slip, tension cracks and toppling	Easting	Northing	Date inspected	Water Level
	345375	6110823	22/09/2009	-0.794 m AHD

Area of rotational slip.

Slab failure with deep tension cracks

Description of erosion problem

- This section has experienced a number of large collapses. In the first instance, a 20 x 6 metre section slumped that resulted in three cars falling into the river, only one of which was recovered. Subsequent collapses resulted in the loss of historic River Red Gums and bank retreat.

Bank characteristics

- Vertical banks c.3m in height comprised of silt/clay material at base and overlying sand material (fill?). Further information on history of site would be informative as background to understanding the characteristics of the bank materials where failure has occurred.

Erosion processes, failure mechanisms and weakening factors

- Series of deep-seated rotational slips in which blocks of soil have slipped along a curved surface. Large tension cracks are continuing to form and open up, driving further bank retreat and toppling failure [Photo ID 30].
- Condition of toe of bank is unknown, at some locations failed soil blocks lie where they have fallen forming a bench [Photo ID 23], but in other locations banks are vertical and it is not clear whether a toe has formed [Photo ID 26 & 29]. Concern that if failed material is removed through dredging this will initiate further bank instabilities.
- Possibly seepage through groundwater discharge into river. Very high water content in substrate noted in bore hole being drilled by Frazer at time of survey.

Likelihood of continued erosion/failure

- Almost certain that will experience continued movement and cracking and slumping.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Continued erosion will result in further damages to marina and potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	**Moderate (3)**	Major (4)	Catastrophic (5)

Recommendations	Priority
Future Investigations	**Critical**

▪ Bore hole and survey – One borehole below house just upstream of Marina and one in area of vacant land between Marina and House. ***Management actions*** ▪ Fence off area to stop all pedestrian access. Area is at high risk of continued failure of large sections of river bank. ***Monitoring*** ▪ No requirement for monitoring within close proximity to failures and tension cracks as areas unsafe. Continued monitoring of surrounding area for tension cracks. Should they appear, commence repeat measurements of depth, length and width of cracks.	

Summary Sheet

Incident Name: Bells Reserve (Monteith) **Incident Number: 20**

Overview of feature				
Tension cracks and slumping	Easting	Northing	Date inspected	Water Level
	346689	6106848	23/09/2009	-0.715 m AHD

Tension cracks in willow area [Photo ID 52]

Tensions cracks in reserve [Photo ID 54]

Description of erosion problem

- Extensive tension cracks and rotational slip in area of willows. Tensions cracks 0.5 to 1 m wide and 1 m deep with water noted at base [Photo ID 52]. No immediate danger posed to houses as they are set back a considerable distance from river bank.

Bank characteristics

- Banks comprised predominantly of clay. Sand forms upper layer of bank at some locations.

Erosion processes, failure mechanisms and weakening factors

- Deep circular failure of bank in area of willows, followed by secondary break up of material (slab/cantilever failure).
- Tension cracks noted in Bells Landing Reserve [Photo ID 54] upstream of willow area.
- Tension crack and failures likely to be caused by increased surcharge of banks caused by lowering of water level.

Likelihood of continued erosion/failure

- Almost certain that area will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Only minor impact as large set back to houses. Location is a public reserve so there is potential for injury and fatality if reserve is occupied when failure occurs.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**

Economic	Insignificant (1)	**Minor (2)**	Moderate (3)	Major (4)	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ Borehole and survey in recreation reserve to determine if rotational failure is likely to occur at this location. ***Management actions*** ▪ Area of willows where rotational slip has occurred and adjacent recreation reserve with tension cracks to be fenced off to stop all pedestrian and vehicle access. ***Monitoring*** ▪ Continue to monitor area for tension cracks. Measure depth, length and width of tension cracks.	**Critical**

Summary Sheet

Incident Name: Riverglen (White Sands) **Incident Number: 30 and 4**

Overview of feature				
Tension cracks and toppling	Easting	Northing	Date inspected	Water Level
	347534	6104588	21/09/2009	-0.780 m AHD

Section where February 2009 failure occurred.

Tension crack adjacent to bank.

Description of erosion problem

- An area of approximately 25 x 4 metres slumped on 14 February 2009. A boat was temporarily lost, but no property damage was reported. Reported by locals that material at toe of bank has dispersed so that there is now a deep drop-off at river bank.

Bank characteristics

- Banks comprised of sandy organic clay (c.1.5 m thick) with overlying sand (c.0.5 m thick). Where failures have occurred there is a steep drop off-to water. Unable to determine from visual inspection if failed material has settled below water level and formed a toe or if material has dispersed.

Erosion processes, failure mechanisms and weakening factors

- Area has experienced large primary rotational failure. Continued retreat of banks is occurring through secondary toppling/cantilever failures. Active undercutting highlights weak and erodible characteristics of clay materials in bank profile [Photo ID 35].
- Changes in moisture status associated with fluctuating water levels cause expansion and shrinking of clays, formation of tension cracks [Photo ID 36] which weakens bank materials and increases their susceptibility to failure.

Likelihood of continued erosion/failure

- Likely that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Large rotational failure or toppling failure could result in property damages and potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	**Minor (2)**	Moderate (3)	Major (4)	Catastrophic (5)

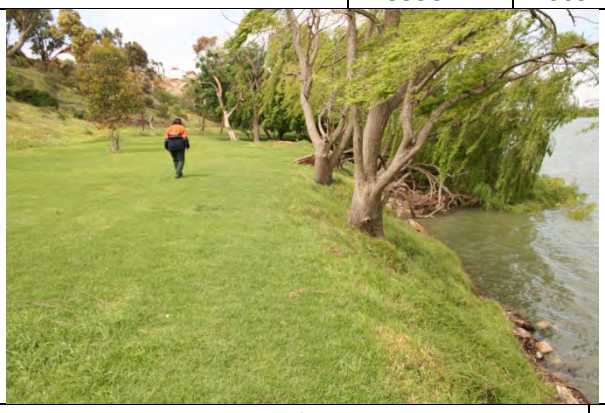
Recommendations	Priority
Future Investigations ▪ Not advised at this time. ***Management actions***	**Critical**

▪ No management recommendations at this time. ***Monitoring*** ▪ Ask residents to monitor their land and houses for movement. Landowners to measure depth, length and width of tension cracks.	

Summary Sheet

Incident Name: Walshpool (Tailem Bend) **Incident Number: 6**

Overview of feature				
Tension cracks and subsidence	Easting	Northing	Date inspected	Water Level
	359374	6097344	23/09/2009	-0.664 m AHD



Picnic area downstream from rowing club. Tension cracks 2-4 m from top of bank.

Possible slumping of rock beaching around steel supports. Subsidence & cracking of concrete.

Description of erosion problem

- Slumping and cracking reported along pedestrian walkway situated on top of river bank and area around rowing club.

Bank characteristics

- No clear bank exposures, silt/clay material. Gabion rock nets and steel supports underlie pedestrian walkway [Photo ID 57]. Rock beaching lines the river bank supporting concrete foot path.

Erosion processes, failure mechanisms and weakening factors

- A number of tension cracks have formed 2-4 m from bank downstream of rowing club in grassed recreation reserve, below picnic benches [Photo ID 56]. The position of these tension cracks are obscured by grass cover.
- Cracking and subsidence of pedestrian walkway along the top of the river bank. Rock beaching appears to have slumped below rowing club [Photo ID 59]. Further information on site history is required to confirm this is the case.
- Lowering of water level may be cause of tension crack and bank failures.

Likelihood of continued erosion/failure

- Likely that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Continued erosion could result in property damages (in particular the rowing club), potential injury and fatality.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	Moderate (3)	**Major (4)**	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ Not advised at this time.	**Critical**

Management actions ▪ Fence off picnic area and concrete walkway to stop pedestrian access. ▪ Rebuild platform adjacent to rowing club. ***Monitoring*** ▪ Repeat measurements of the depth, length and width of tension cracks.	

Summary Sheet

Incident Name: Wellington Marina **Incident Number: 47**

Overview of feature				
Tension cracks	Easting	Northing	Date inspected	Water Level
	343974	6111940	23/9/2009	-0.664 m AHD

Embankment with 50-60 m long tension cracks.

Tension cracks c.15 cm wide.

Description of erosion problem

- Tension cracks noted along this c.10m wide embankment that separates the river from marina. This embankment presently provides access to boats moored outside and inside the marina [Photo ID 73 & 74].

Bank characteristics

- Embankment comprised of soft organic clays. Embankment has a height of c.2.5 m and width of 10 m.

Erosion processes, failure mechanisms and weakening factors

- Large tension cracks run along the length of the embankment and reach lengths of 50 to 60 m, with widths of c.15 cm and depths > 1.5 m. Rotational failures likely with material slumping into the Marina [Photo ID 70, 71 & 72].
- Changes in moisture status associated with fluctuating water levels causing expansion and shrinking of clays, lowering of water level results in increased surcharge of banks, weakening the strength of clay materials triggering failure of embankment.

Likelihood of continued erosion/failure

- Likely that will experience continued movement and cracking.

Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	**Almost certain (5)**

Consequences of continued erosion/failure

- Potential for damage to cars driving on embankment and houseboats moored in the marina.

Social	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	**Catastrophic (5)**
Economic	Insignificant (1)	Minor (2)	**Moderate (3)**	**Major (4)**	Catastrophic (5)

Recommendations	Priority
Future Investigations ▪ Not advised at this time. ***Management actions*** ▪ Fence of embankment to stop vehicle and pedestrian access.	**Critical**

▪ Area to be fenced off to sop pedestrian and vehicle traffic along embankment. ▪ No boats to be moored on the inside of the marina along this embankment. ***Monitoring*** ▪ No requirement for monitoring within close proximity to failures and tension cracks as areas unsafe. Continued monitoring of surrounding area for tension cracks. Should they appear commence repeat measurements of depth, length and width of cracks.	