Goulburn River Constraints – Levee Risk Assessment and Risk Mitigation Strategy

January 2016

GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

DOCUMENT STATUS

Version	Doc type	Reviewed by	Approved by	Distributed to	Date issued
v01	Draft	Warwick Bishop	Warwick Bishop	Geoff Earl	10/11/2015
v02	Draft	Warwick Bishop	Warwick Bishop	Geoff Earl	26/11/2015
v03	Final	Warwick Bishop	Warwick Bishop	Geoff Earl	06/01/2016
v04	Final	Warwick Bishop	Warwick Bishop	Geoff Earl	18/01/2016

PROJECT DETAILS

Project Name	Goulburn River Constraints – Levee Risk Assessment & Strategy
Client	Goulburn Broken CMA
Client Project Manager	Geoff Earl
Water Technology Project Manager	Ben Tate
Report Authors	Ben Tate
Job Number	4146-01
Report Number	R01
Document Name	4146-01R01v04_FINAL_GoulburnLeveeRiskAssessment.docx

Cover Photo: Lower Goulburn River levee, *Rural Levees Assessment* (Water Technology, 2013)

15 Business Park Drive
Notting Hill VIC 3168

Telephone (03) 8526 0800
Fax (03) 9558 9365

ACN No. 093 377 283
ABN No. 60 093 377 283

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Project Background

Water Technology completed a Rural Levee Assessment of strategic levees on the lower Goulburn River and along the Victorian side of the Murray River for Goulburn Broken CMA during 2013 in partnership with Think Spatial. The *Goulburn Broken CMA Rural Levees Assessment* (Water Technology, 2013) produced highly detailed information regarding crest levels and points of weakness of the levees and presented results in a fairly generic and easily digestible format, common across projects completed for Goulburn Broken, North Central and North East CMA projects.

This project provides Goulburn Broken CMA with a detailed Levee Risk Assessment and Risk Management Strategy for the lower Goulburn River to support possible overbank environmental flows. It draws on the Rural Levees Assessment project and extensive new detailed flood mapping, completed by Water Technology in a concurrent project.

1.2 Project Scope

This report reviews the levees along the lower Goulburn River downstream of Shepparton near Loch Garry to the Murray River. The crest height of the levee and the condition of the levee have been examined in detail, assessing the risk of failure of the levee system during possible overbank environmental flow deliveries.

During this project the existing risk matrix developed for North Central CMA was used. A detailed assessment of consequence and likelihood of failure was undertaken based on flows of 40,000 and 55,000 ML/d as the design crest level.

This adopted risk management framework is compatible with the Goulburn Broken CMA's Risk Management Policy Procedure document and is consistent with the requirements of AS/NZS ISO 31000:2009 Risk Management Principles and Guidelines. Consequences were based on a water surface elevation equivalent to the modelled 40,000 or 55,000 ML/d flow, and assessing the water level against the natural topography and considering what the impact would be if the levee was to fail in a specific location. Land use and the location of dwellings and infrastructure was taken into account in the assessment. The assessment of likelihood used the surveyed point of weakness type, threat level and the depth of inundation against the levee in a 40,000 or 55,000 ML/d flow to determine a likelihood of failure. Note that this study only considered the risk to failure of a managed environmental watering event, not for larger unregulated natural floods.

The report proposes a series of priority works to upgrade the levee to a consistent standard including indicative costs using standard rates from flood mitigation design and recent levee construction costs supplied by GMW.

1.3 Study Area

The study area encompasses the lower Goulburn River from near Loch Garry through to the Murray River near Echuca, including levees on both sides of the river. Figure 1-1 shows the study area including the location of the levees and the 55,000 ML/d inundation depths used in this investigation.

The lower Goulburn River below Shepparton has been highly modified for agricultural purposes. The Goulburn River capacity reduces downstream with overbank flooding occurring frequently in natural conditions. The river has been leveed on both sides of the river from roughly Loch Garry to the Murray River, protecting extensive areas of farmland from these frequent flood events. The Goulburn River levee system has failed on numerous occasions in the past during large natural flood events.

There are 5 structures on the right bank of the river which allow flows north of the river through the levee system at different river levels. Loch Garry, the largest, is situated on the right bank of the river at the upstream end of the levee system. GMW operate the structure under an agreed set of operating rules, with the structure progressively opened once the river reaches 10.36 metres on the gauge at Shepparton (41,400 ML/day). This regulating structure protects land holders along Deep Creek from low to moderate Goulburn River floods. Other structures flow at the same or lower river levels. For this study, it is assumed that all these structures are modified to stay closed during possible environmental flow releases at up to 55,000 ML/d.

Despite the highly modified state of the lower Goulburn River floodplain, the river corridor supports high value natural ecosystems and requires regular flow events to maintain its environmental health.

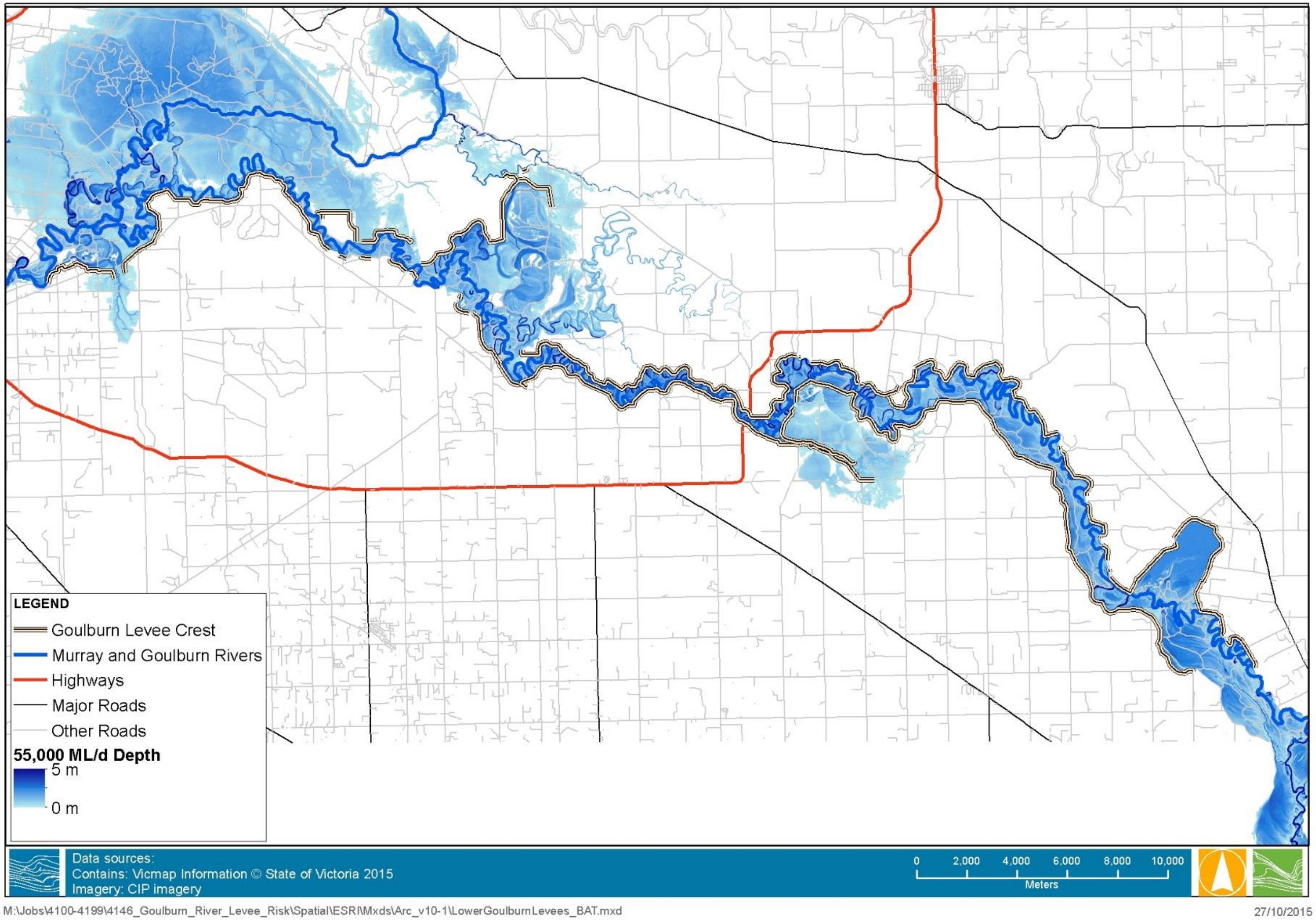


Figure 1-1 Study Area Overview

2. SURVEY

Survey of the levees was undertaken for the *Goulburn Broken CMA Rural Levees Assessment* (Water Technology, 2013). The survey was completed between January and June 2012. The survey predominantly used Real-Time-Kinematic Global Navigation Satellite System (RTK GNSS) receiving corrections in real time from Victoria's Continually Operating Reference Station (CORS) network. In areas with no mobile reception and hence no link to the CORS network, Think Spatial set up its own RTK base station providing corrections via radio link. In areas of dense tree cover, where GNSS reception was not possible, the surveyors used a Total Station method.

Teams of surveyors worked independently, but within close proximity, walking along the levees. One surveyed the levee cross-section and longitudinal-section points (i.e. the levee geometry), whilst the second surveyed points and lines of weakness.

The surveyor collecting levee geometry would pace approximate distances between longitudinal-section points consisting of a levee crest and riverside levee toe and natural surface. Generally, longitudinal-section points were collected at least every 50 m along the levee, or where the levee changed direction or if the crest changed height significantly.

Cross-sections were collected at least every 500 m or where the levee significantly changed shape. As a minimum, the levee crest and the natural surface, toe, bank sides and bank shoulders on both sides of the levee were surveyed.

Real-time survey data used AusGeoid09 (see note below) to provide vertical adjustment from Ellipsoidal Height to Australian Height Datum (AHD). More accurate local AHD was achieved by surveying and adjusting survey to local permanent survey marks every 5-10 km along the levee network. This ensured survey data fell within the 50 mm absolute vertical tolerance prescribed in the project brief. The majority of surveyed points are within a horizontal tolerance of 25 mm, with all data meeting the 0.5 m prescribed tolerance for the study.

Where total station survey was conducted, survey pegs were placed every 1-2 km in clear sky areas, surveyed using 10-15 minutes of static observations with GNSS. This procedure ensured horizontal and vertical accuracies to within similar tolerances as achieved with GNSS for the scope of the project.

2.1 Points of weakness data capture

The capture of the points of weakness (POW) was undertaken during the survey of the levee geometry by the second surveyor trained in identifying and surveying these features. Further details about the POW are provided in Section 4.

Where the weakness could be defined as a discrete location, it was surveyed as a point. In some cases, a line better represented the weakness (for example a line of trees or a length of levee affected by wheel ruts). Most POW were attributed with a code denoting its relative importance in describing the threat of the weakness and another code describing the position relative to the levee bank.

Where the geometry of the bank resulted in a perceived reduction in the bank's structural integrity, a cross-section was surveyed.

Geo-tagged photographs were taken of each POW to provide assistance for engineers assessing the levee condition.

2.2 Outputs

The outputs from the survey components included plans prepared in AutoCAD and delivered as DWG and Adobe PDF formats.

A drawing set was produced for each of the following themes including a locality plan as the first sheet:

- **Topographic Features** - including points of weakness, running distances of river and levee, and Vicmap base data; and
- **Sections** - containing cross-sections of the levee including POW cross-sections and longitudinal sections.

Plans were produced for the above themes for each levee section.

GIS datasets were provided for the development of hydraulic models as well as further engineering assessment of the condition of the levees. The GIS data includes the 3D survey data of all cross-sections, longitudinal sections, points and lines of weakness, geo-tagged and hyperlinked photos. A polygon layer representing the on-ground 'footprints' for all plans was also supplied with live hyperlinks to the DWG and PDF plans.

2.3 Re-establishment of geodatabase

The ESRI geodatabase was re-established and overlayed with the latest Floodplains LiDAR, aerial imagery and latest flood modelling results for steady-state flows of 25,000, 30,000, 35,000, 40,000, 45,000 and 55,000 ML/d. The geodatabase was sent to CMA and GMW in September 2015 for review.

The risk assessment carried out during this study was different to the previous 2013 assessment with the current assessment based on lower design flood levels associated with 55,000 ML/d flows rather than an assumption that water levels were at the top of the levee crest. The current flood modelling was significantly improved. The lowest flood assessed in the 2013 assessment was the 20% AEP flood from the Lower Goulburn Floodplain Rehabilitation Scheme (Water Technology, 2006). The 20% AEP flood was associated with a 10.75 m level at the Shepparton gauge with a flow of around 57,000 ML/d. The previous 20% AEP flood levels were around 400 mm higher than the latest 55,000 ML/d modelled results around Loch Garry, with results around Kotupna within 100 mm.

The comparison between the old and new flood modelling results was made along the entire river and it was noticed that while there was general agreement, the difference in levels did fluctuate between higher and lower, with the newer modelling picking up more detail of some channels, roads, flood runners and other floodplain features, as well as some differences in the assumptions at outlet structures in the levee system.

The new modelling assumed these outlet structures were closed. It also stamped in a more extensive series of unofficial levees including channel banks, some roads and some small farm scale private banks. Some of these unofficial structures that act like a levee need to be considered in the wider context of the levee system through the constraints management business case. It is noted that some of these structures were not picked up in the modelling but were identified during the analysis phase, some areas of inundation shown in figures in this report may be overestimated due to the crest levels of these features not being stamped into the model topography. The analysis generally showed that these unofficial features acting like levees were above the 40,000 and 55,000 ML/d water surface elevations. No allowances have been made for repairs to these unofficial structures, and if repairs are required through further investigation during detailed design, the cost of this would likely be easily covered by the contingencies allowed for across the rest of the levee system. The strategic levee audit did include some levees along Wells Creek, however it was found that these levees extended further than that identified by the levee audit. Additional cost for repairing the Wells Creek levees was included as this will be a necessary component of the levee system and it comprised a significant length of levee.

It is important to note that there is no feature survey, photos or points of weakness survey captured for these unofficial structures so assumptions will be required to be made for the treatment options in the next stage.

3. LEVELS OF PROTECTION

3.1 Methodology

The extensive levee crest survey of the lower Goulburn River rural levee system was compared with detailed flood modelling of a 40,000 and 55,000 ML/d flow. Using the levee crest survey, points were interpolated every 1 m along the levee crest, developing a detailed representation of the levee crest height. At each point, the maximum water surface elevation from the 40,000 and 55,000 ML/d flow was inspected within a 25 m radius. This ensured that the 10 m model grid resolution didn't result in a levee crest point being shown as dry through a model grid resolution discrepancy.

Note that the surveyed levee crest elevations were captured approximately every 50 to 100 m (sometimes at larger intervals), so in running the comparison of levee crest and water level at 1 m increments along the levee, the levee crest level was interpolated between points. Some of these interpolated points where found to be lower than that suggested by the LiDAR. So in the preliminary results presented early in the project, a number of small sections of levee were showing crest levels below the design height. On closer inspection using the detailed LiDAR information a number of these locations were removed as it was clear from the LiDAR that the levee crest is higher than the 55,000 ML/d design level.

Flood modelling was calibrated to available gauge rating curves along the river and were closely reviewed by Goulburn Broken CMA. A number of locations where informal levees were not captured in the levee survey and not included in the model were identified, with Water Technology using detailed LiDAR to estimate the levee crest and stamp it into the model. As discussed earlier there were a number of locations where these features were not identified until after the modelling was complete.

3.2 Results

To aid the review of the levee risk assessment, Water Technology produced an ArcGIS online database detailing flood extents, levee alignments, low levee crest points, levee points of weakness, and areas of priority works. An example of the map is provided in Figure 3-1.

Figure 3-1 ArcGIS Online example map showing low crest heights (preliminary results prior to detailed review)

Figure 3-2 below shows the series of flood inundation maps available through the recent modelling work. Figure 3-3 below shows a map of the levee crest elevation comparison to the modelled 40,000 and 55,000 ML/d water levels, including a summary table. It can be seen that just under 3.7 km of levee is below the design standard of the 55,000 ML/d water level, this is only 2.5% of the total 144 km levee system. This is a significant reduction from the preliminary estimate. It was found that in a number of locations the detailed LiDAR revealed no indication of low points in the levee and it is thought the interpolation between levee survey points may have underestimated levee crests in these locations.

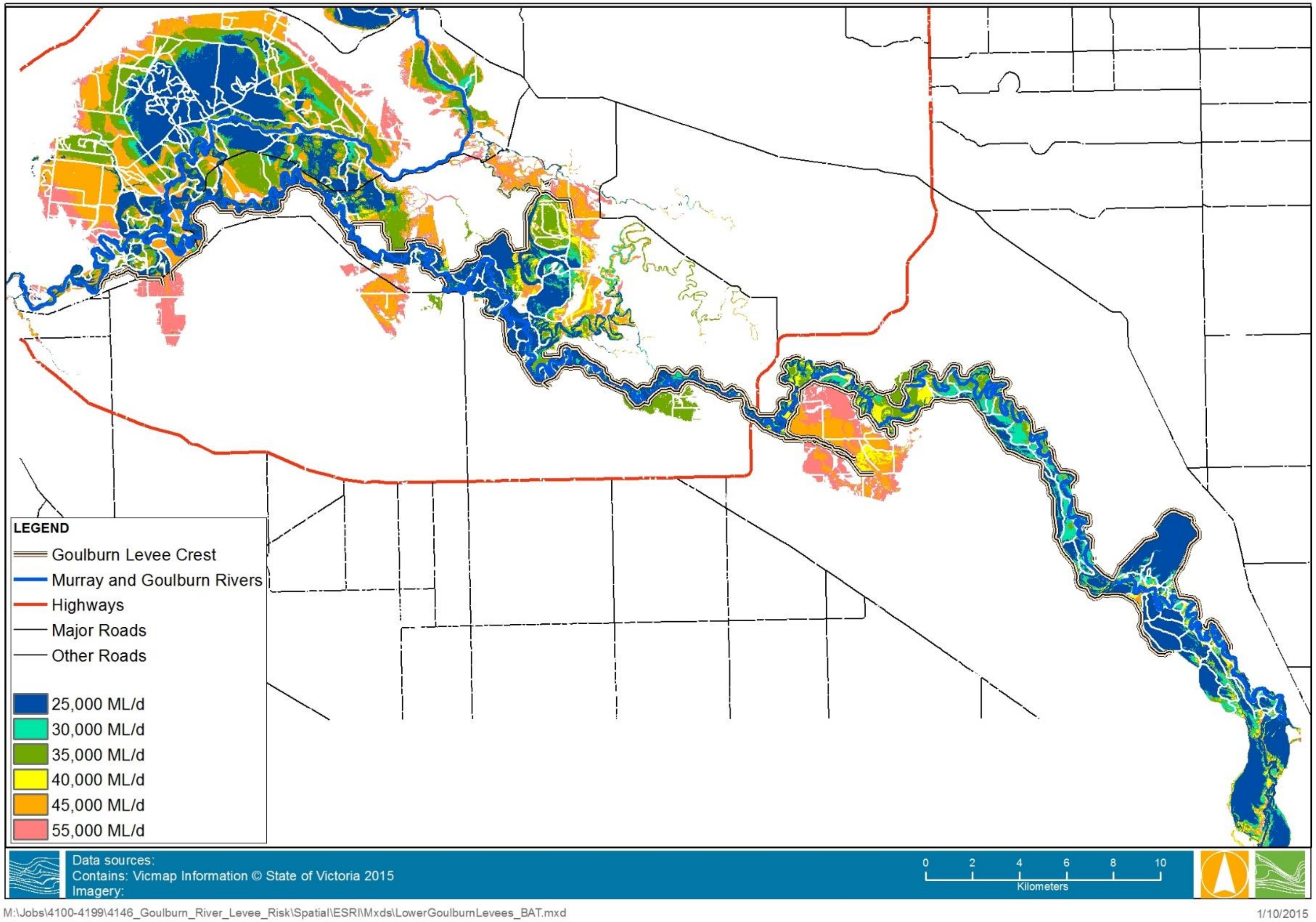


Figure 3-2 Lower Goulburn River Flood Modelling Results

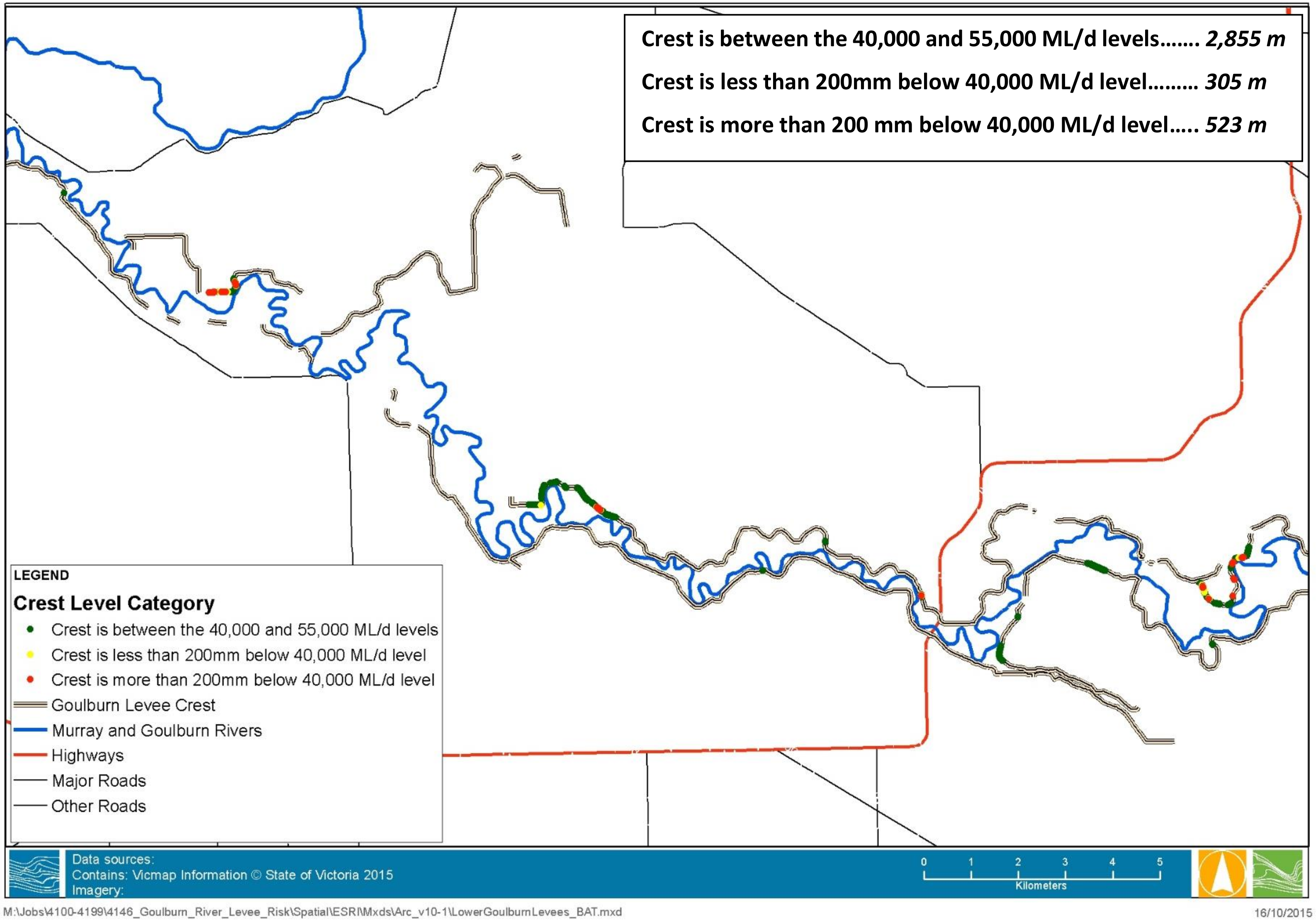


Figure 3-3 Level of protection of levee crest height

4. POINTS OF WEAKNESS

Points of weakness (POW) are defined locations along the levee that do not offer the same level of protection or represent the general condition of the levee. They are visible features affecting the structure or shape of the levee that may reduce the protection or performance of the levee. Points of weakness may be the observed effects of natural processes such as erosion and proximity to the river; they may relate to man-made activities or infrastructure such as tracks and pipes traversing the levee; or biological impacts such as saplings and tree regeneration, rabbit burrows and wear by larger animals (cattle or horses for example).

4.1 Prioritisation Methodology

4.1.1 Points of Weakness data

POW were identified in the field and captured as either point or linear features. This data formed the basis of the levee condition assessment. In addition to the location of the feature, the POW type was captured with a threat code, survey information, photograph and physical survey. The weakness types and threats that were identified in the field are listed in Table 4-1 and Table 4-2.

Table 4-1 Point of weakness types

Type	Feature
Crest	Narrow Crest
Culvert	Culvert
Other	No Vegetation Overtopping
River Bank	Inside Outside Straight Undercutting
Hole	Erosion Fallen tree Rabbit Burrow Sink Hole Wheel Ruts
Trees	Mature in Bank Mature in Crest Sapling in Bank Sapling in Crest Stump in Bank Other (eg.Root)

Type	Feature
Low Crest	Road Crossing
Pipe	Pipe
Recent Works	Excavations Other
Other	No Vegetation Overtopping
Erosion	Ants Nest Cracks Poor Material Pugging Rilling

Table 4-2 Point of weakness threats

Minor to moderate potential	High current (current)
High to very high potential	Very high (current)
Moderate (current)	

4.1.2 Risk Assessment

A risk based approach is commonly used as a means of priority setting and planning of stream management programs and projects. Risk management is a term applied to a logical and systematic method of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating the risks associated with any activity, function or process in a way that will enable organisations to minimise losses and maximise opportunities (Standards Australia, 2004). Risk is identified by Standards Australia (2004) as the product of the likelihood and consequence of an event impacting on an asset or objective. As such, risk management is as much about identifying opportunities as avoiding and mitigating losses.

As this current investigation is associated with the condition of existing levees, a risk assessment process has been adopted to suit the requirements of the project. The following sections outline how a risk assessment based priority setting methodology has been applied. The risk assessment assists with the identification and analysis of priority issues and processes for future management.

4.1.3 Consequence of failure

Consequences of levee failure, were assigned in accordance with the ratings and descriptions provided in Table 4-3. The minor, moderate and major classes have been adopted and modified from the Bureau of Meteorology's flood warning definitions as the definition for various levee failure consequences. The consequence was assigned based on the assumption that the levee failed to the ground and in consideration of the infrastructure and land use in the interpreted inundated area caused by the failure. The inundated area and likely hazard encountered was determined from LiDAR and modelling of larger natural flood events.

The consequence of failure was revised from the 2013 assessment due to changes in assumptions. In the 2013 assessment the water level at the time of failure was assumed to be at crest level. For this current assessment the water level was assumed to be at the 40,000 and 55,000 ML/d water surface profiles. This in itself is conservative given that the peak flow of any environmental water delivered will be well below 40,000 ML/d. For the majority of the levee system this means that the assumed water level for the risk assessment is significantly lower than in the 2013 assessment, with an appropriate reduction in the consequence of a levee failure.

Conceptually, if a breach did develop, the lower river levels would lead to the breach developing slower with lower volumes flowing through the breach. The velocity and resulting depth outside of the levee would be lower as the river is perched and water drains away into the lower Goulburn River and to the Murray River. The lower river levees would thus lead to lower consequences outside of the levee system.

The 2013 consequence layer was used as the starting point and revised with the knowledge of the lower depth of flooding against the levee for the 40,000 and 55,000 ML/d flows. The consequences of levee failure in a 40,000 and a 55,000 ML/d flow event were determined to be similar, and the same consequence ratings were applied for both flow events. The assessment also made use of improved layers of buildings and roads within the floodplain.

A GIS data set was developed for consequence and all points of weakness were assigned a consequence rating. This data is presented in Figure 4-1.

Table 4-3 Consequence table

Rating	Class	Description
1	Insignificant	Causes no inconvenience
2	Minor	Causes inconvenience. Low-lying areas next to watercourses are inundated which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.
3	Moderate	In addition to the above, the evacuation of less than 5 houses may be required. Main traffic routes may be covered. The area of inundation is substantial in rural areas requiring the removal of stock and/or the length of inundation is substantial resulting in loss of income from agricultural land.
4	Major	In addition to the above, extensive rural areas and/or urban areas are inundated. Properties and towns are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood affected areas may be required. Flooding of buildings above floor level is likely.
5	Catastrophic	House/s within 50 m of levee where sudden and unexpected levee failure poses a risk to life.

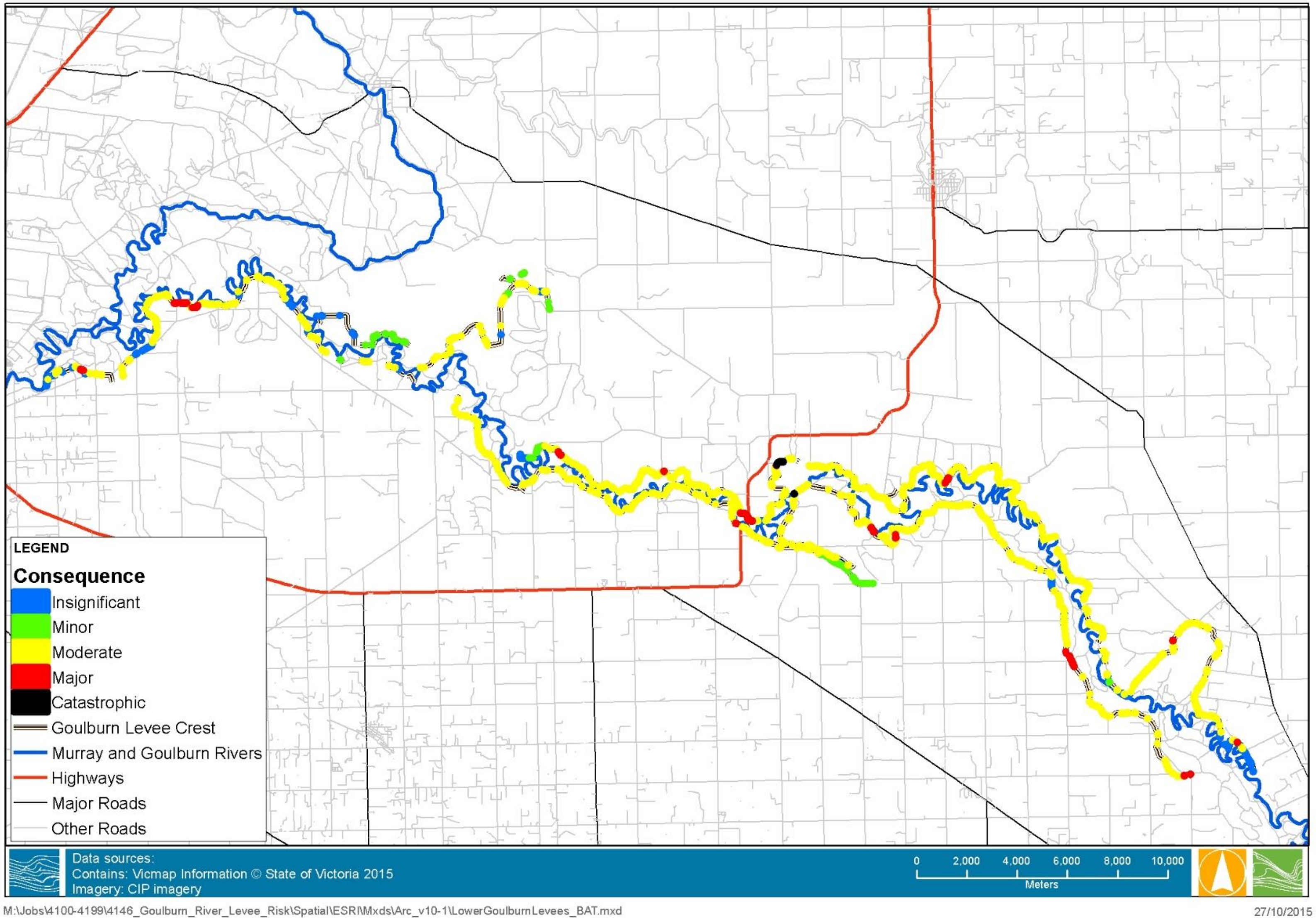


Figure 4-1 Consequence Ratings for the levee

4.1.4 Likelihood of failure

The likelihood of levee failure due to a point of weakness was assessed for each generic point of weakness feature and threat combination. Approximately 75 different point of weakness category/threat combinations resulted from the 1,779 surveyed points of weakness along the Goulburn levees. This allowed a standardised rapid assessment. Assessing the likelihood of failure due to a POW is a subjective analysis and can be influenced by an individual's bias. To counter this, an experienced Senior Engineer with skills in floodplain management, and civil works headed the risk assessment. This was reviewed by a Principal Engineer who also oversaw the development of the North Central CMA levee risk assessment project. The team of experienced engineers at Water Technology discussed the different modes of levee failure before assigning likelihoods to each POW type.

The relative likelihood of failure for each weakness/threat combination was determined in accordance with the ratings and descriptions provided in Table 4-4. It is also noted that reaches of levee without points of weakness are still considered to have a rare likelihood of failure. The likelihood of levee failure due to a point of weakness assumes the specified managed flood events occur within the planning horizon. In this study the planning horizon equates to the outlook of the business plan, which is in the order of the next 30 years. Further to the analysis of likelihoods of failure based on points of weakness, the depth of water that will be against the levee during a managed watering event was also considered. If points of weakness occur in areas of shallow depth, then the likelihood of failure is lower than an identical feature in reaches with a higher depth of water against the levee.

Table 4-4 Likelihood of levee failure table, assessed for each POW combination

Rating	Likelihood	Description
A	Almost certain	Almost certain that impact will occur in the planning horizon
B	Likely	Likely that impact will occur within the planning horizon
C	Possible	Possible that likelihood will occur within the planning horizon
D	Unlikely	Unlikely that the impact will occur within the planning horizon
E	Rare	Rare that impact will occur within the planning horizon.

This assessment is quite subjective as it requires a judgement on the likelihood of failure of a point of weakness. As such it is suggested that this assessment be used for relative priority-setting purposes rather than as an absolute measure of the likelihood of a particular POW feature failing. The assessment was reviewed by Goulburn Broken CMA, GMW and an independent reviewer.

Discussion on Likelihood of Levee Failure Posed by Vegetation

Vegetation in the levee system is a common feature, with points of weakness due to trees in the levee making up 32% of all points of weakness. This averages out to a point of weakness due to trees in the levee every 250 m for the Goulburn levees, much lower than the North Central CMA levees.

Although trees in the levee can lead to a piping failure mode should the tree die back and the roots decompose, the likelihood of levee failure due to trees in the levee has not been shown to be the primary cause of levee failure in Victoria. The trees are most likely to cause issues after a watering event when the levee is still wet and trees are more likely to fall over due to local storm events. Therefore our recommended mitigation measure would be to monitor these levee sections before and after a watering event and after a major storm event rather than completely replacing the levee, which is consistent with a low to medium risk. For these reasons the likelihood of varying types of vegetation causing a levee failure has either been classified as rare or unlikely as per Table 4-4 below. In areas where the consequence is major or catastrophic, the vegetation classified as unlikely will constitute a medium risk and will need to be addressed. Areas of lower consequence generally correlate to shallower depths of water against the levee, therefore the likelihood of vegetation causing levee failure will be lower also, constituting a low risk.

As the likelihood of failure is influenced by depth against the levee, the likelihood was assessed for the 55,000 ML/d water surface elevation and was then reduced when assessing the 40,000 ML/d event. The assigned likelihood of failure can be viewed on the online mapping described earlier.

4.1.5 Risk Matrix

Risk profiles were developed by assigning scores to the consequence and likelihood ratings. The risk profile was determined by applying the scores to a risk matrix as shown in Table 4-5. The definition of each risk profile is then summarised in Table 4-6.

This adopted risk management framework is compatible with the Goulburn Broken CMA's Risk Management Policy Procedure document and is consistent with the requirements of AS/NZS ISO 31000:2009 Risk Management Principles and Guidelines.

In discussion with GMW and Goulburn Broken CMA, it was decided that risk management treatments would be employed to reduce the risk of all points to low risk. In addition, low risk points of weakness with a consequence of failure of major were identified for repair works also.

Table 4-5 Risk Matrix

Likelihood of Failure due to POW	Consequence of Failure				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
A Almost certain	Low	Medium	High	Extreme	Extreme
B Likely	Low	Medium	Medium	High	Extreme
C Possible	Low	Low	Medium	Medium	High
D Unlikely	Low	Low	Low	Medium	Medium
E Rare	Low	Low	Low	Low	Medium

Note that any risk point above low, and low risk points with a major consequence, were considered for repair works.

Table 4-6 Risk profile definition

Risk Profile	Definition
Low	A level of risk that is low and can be managed.
Medium	As low as reasonably practical (actions are required to reduce risk).
High	Major risk requiring intervention to reduce risk.
Extreme	Intolerable risk requiring highest priority (immediate) attention.

Note that any risk point above low, and low risk points with a major consequence, were considered for repair works.

4.2 Results

The point of weakness risk assessment was loaded onto the same ArcGIS online database described earlier. The risk assessment is summarised in Figure 4-2.

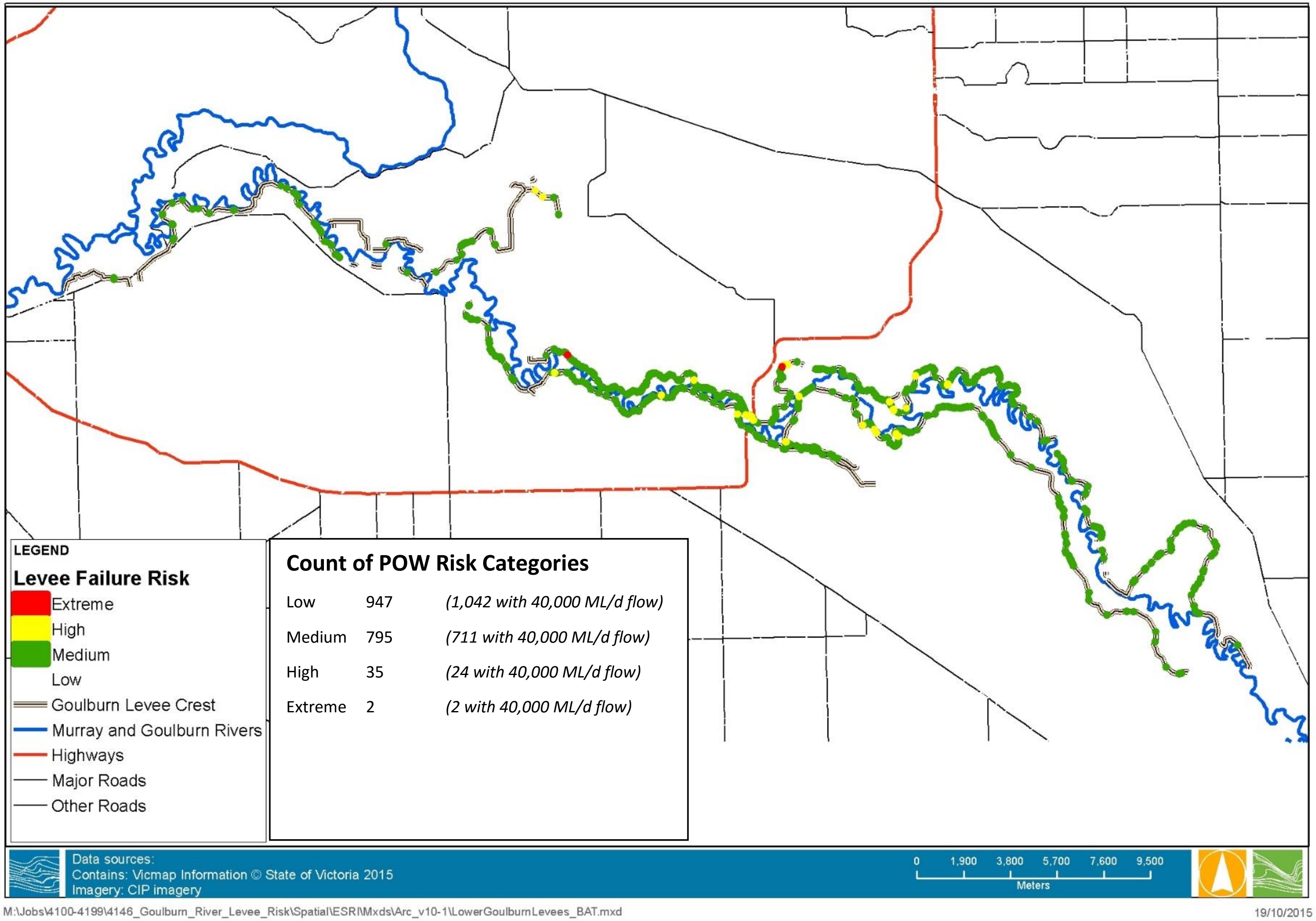


Figure 4-2 Risk ratings for the levee at 55,000 ML/d water surface elevation

5. STRUCTURAL LEVEE RISK TREATMENT

Broadly speaking any issues with the current levee can be treated by realigning the levee, replacing the levee, raising the levee or repairing the levee. The design crest height for the levee where it was being realigned or replaced was the higher of the water surface elevation during a flow of 55,000 ML/d or the existing levee crest height. A flow of 40,000 ML/d was also assessed for the levee crest level, with results presented throughout this report for both design options. In sections of the levee where the crest was being increased, the levee was topped up to the 40,000 or 55,000 ML/d height. These are the lowest sections of levee. The design crest heights equivalent of a 40,000 and 55,000 ML/d water level are still well above the design environmental water level that will be delivered during managed events. The design levee crest therefore includes a variable degree of freeboard, with the minimum freeboard likely to be between 0.5 to 1 m.

It is acknowledged that the Goulburn River has importance for local indigenous groups, and that cultural heritage values must be considered in any works along the river. Allowances for cultural heritage assessments have been made outside of this risk assessment and works cost estimation.

5.1 Priority Works - Levee Raising, Replacement & Realignment

The low points in the levee have been treated using all three treatment options, with the point of weakness largely being treated via repair. Treatment options were investigated for all sections of levee with a low crest and all points of weakness with a risk rating of medium, high or extreme, or low risk sections with major or catastrophic consequence. Goulburn Broken CMA also supplied a number of locations where the levee is sited close to the river on an outer bend, where it is estimated that the levee may be at risk of failure due to migrating of the river bend in the next 20-40 years. Realignment of these sections of levee has been included in the priority works. Where realignment or replacement levees have been proposed the levee has been designed behind the existing levee with a crest level set at the higher of the 40,000/55,000 ML/d water level or the existing levee crest height. This ensures that if the existing levee in front of the new levee is left to deteriorate with the new levee maintained, that the level of protection remains unchanged. In this way the standard of protection is not diminished for larger natural flood events. In general the sections of replacement levee were designed to the existing levee crest, which was usually higher than the 55,000 ML/d water level.

For costing purposes the following assumptions were made for each of the priority levee works:

- A total levee cost of $75/m^3, as supplied by GMW for recent Hattah levee works. This cost rate is for physical works only and was based on a contractors final delivery costs for the physical works items.
- It is assumed that appropriate grade fill will be available within 25 km of each site, if this is not the case the cost of fill may be higher.
- Minimum cost of works $25,000 for small volume jobs.
- Detailed design estimated at 10% of total capital cost.
- 50% contingency placed on capital cost and detailed design cost.
- Levees that required designing to be trafficable were designed with a 4 m crest width and 4 to 1 batter slopes, this was based on advice from GMW on previous works at Guttrum and Benwell Forests.
- Levees that were not trafficable were designed based on the Victorian Levee Guidelines, assuming a 2 m crest width, 3 to 1 batter slope on the inside of the levee and a 2 to 1 batter slope outside of the levee.

The 17 priority works locations identified for the Goulburn levees are shown below in Figure 5-1. Each of these locations are described further in Appendix 1.

For the design crest level associated with the 55,000 ML/d flow, the total cost estimated for the 17 identified priority levee works is **$11,500,000**, as summarised in Table 5-1.

For the design crest level associated with the 40,000 ML/d flow, there is no longer need for works at priority works locations 6, 9, 12, 13, 14, 15 and 16. At these sites only minor crest raising was required under the 55,000 ML/d design condition, and at 40,000 ML/d the existing levee crest is satisfactory. The total cost estimated for the 10 identified priority levee works locations with design crest level at the 40,000 ML/d level is **$10,900,000**.

Table 5-1 Summary of Levee Priority Works for 55,000 ML/d Design Crest Level

Priority Works ID	Description	Length (m)	Average Depth (m)	Volume (m^3)	Cost
1	Levee realignment	102	1.4	Road	$ 222,000
2	Levee realignment	237	1.2	Road	$ 405,000
3	Levee realignment	456	1.1	Road	$ 641,000
4	Major crack under pipe, needs short section of levee replaced	25	0.8	Standard	$ 41,000
5	Levee replacement and new section of levee	1147	1.2	Standard	$ 1,189,000
6	Raise crest 100-200mm	111	0.0	Standard	$ 41,000
7	Levee realignment	1158	1.2	Road	$ 2,143,000
8	New levee, 1km of it is road entrance to house	3163	1.2	Road	$ 5,115,000
9	Raise crest 100-200mm	36	0.0	Standard	$ 41,000
10	Raise crest 100-200mm	394	0.1	Standard	$ 41,000
11	Levee replacement	817	1.3	Standard	$ 973,000
12	Raise crest 100-200mm	22	0.0	Standard	$ 41,000
13	Raise crest 100-200mm	62	0.0	Road	$ 41,000
14	Raise crest 100-200mm	1084	0.4	Standard	$ 210,000
15	Raise crest 100-200mm	1420	0.2	Standard	$ 118,000
16	Raise crest 100-200mm	21	0.0	Standard	$ 41,000
17	Levee replacement	333	0.6	Standard	$ 168,000

See Appendix 1 for further details.

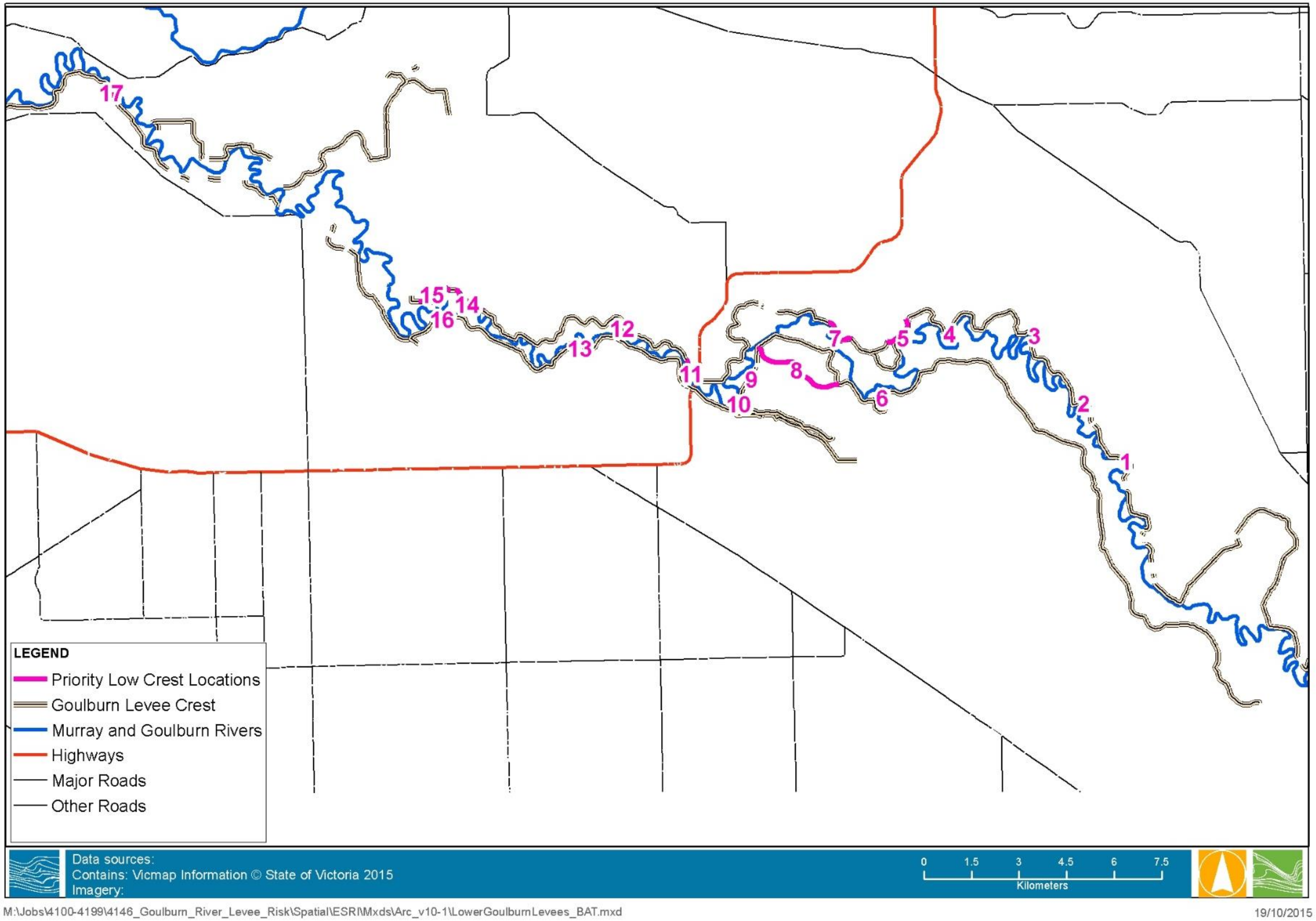


Figure 5-1 Lower Goulburn Levee Priority Work Locations

5.2 Point of Weakness Repair Works

In addition to the priority works identified above, there are many locations within the Goulburn levee system where points of weakness have been identified that have been attributed a risk of failure greater than low which require treatment. Points of weakness with a low risk but with a major or catastrophic consequence rating were also costed for repair. These are considered repair treatments, but given the uncertainty involved in the severity of the weakness and the extent of the treatment required, the costing for repair works has been conservative.

A number of the identified points of weakness were located in sections of the levee where priority works have been identified and documented above. It was assumed that these points of weakness would be repaired during the priority works phase and that these points of weakness did not require further cost allowances to be made for their repair.

Given the uncertainty in the required repair works at each of these locations a very simple method to estimate repair costs was adopted. For all medium and low risk points of weakness $5,000 per site was assumed, and for all high and extreme risk locations $25,000 per site was assumed. These were simply rough estimates based on judgement. It is likely that many superficial points of weakness may cost considerably less to treat, however it is equally likely that there will be some that turn into larger jobs than anticipated. In light of this uncertainty a generous 100% contingency cost was also applied.

A total repair cost for the points of weakness locations outside of the priority works locations and assuming a 55,000 ML/d design water level, was estimated at **$8,220,000.** This included 19 high and extreme risk points of weakness and 727 low and medium risk points of weakness. In addition to the surveyed points of weakness, the 2013 survey also identified a number of point of weakness lines. These were for lengths of levee that were in a less than ideal condition as opposed to individual points of weakness. In the areas outside of the priority works, the point of weakness lines requiring repair summed to a length of 7.7 km. At an estimated cost rate to repair of $100 per linear metre plus a 100% contingency given the unknown in relation to the repair works, this results in a cost of repair of **$1,540,000**. This cost rate estimate is thought to be conservative for generic superficial levee repairs. Estimates of preparatory work, reprofiling, spraying, topsoiling and grassing were summed from Rawlinsons Australian Cost Estimate Handbook and were well below the estimated linear metre cost rate with generous contingencies.

A levee system on both banks of the Wells Creek system is partially covered by the rural levee audit and has picked up some points of weakness. From a desktop review of LiDAR it appears as though the levee crest is clearly higher than the design crest level, so no wholesale upgrades are anticipated. It is likely that the Wells Creek levee system that has not been surveyed will have a similar level of points of weakness as compared to the rest of the Goulburn levee system. Therefore a cost estimate for these point of weakness repair works was made pro rata. Using the 55,000 ML/d and 100% contingency rate an estimated cost of repair for the unsurveyed Wells Creek levee system was estimated at **$380,000**.

Assuming a 40,000 ML/d design crest level, the cost of repair works of the points of weakness may be reduced to **$7,140,000**, the lines of weakness repair remains at **$1,540,000**, and the Wells Creek levees repair is reduced to **$338,000**. These costs are based on 659 low and medium risk, 11 high and extreme risk points of weakness, and 7.7 km of point of weakness lines.

5.3 Tree Health Risk

A risk which has not been quantified is that associated with poor tree health causing trees to fall over and damage the levee. Therefore a component of the initial project works could be to assess all levees and undertake vegetation management at that time which could include:

- Assessment of vegetation health by a qualified arborist to identify and address any medium to large trees considered in a condition or state that may significantly increase likelihood of levee failure. Trees located in high consequence reaches of levee would be removed as part of the initial structural levee works; and
- Removal of all immature saplings presently growing on or close to the levee to prevent them from become risks.

Given the points of weakness survey identify just over 30 km of levee impacted by trees, the initial work could be targeted in these areas. An inspection by an arborist may take three weeks to complete, marking trees for removal/pruning. Assuming a rate of $75/hr and a two person team, plus expenses, this initial assessment may cost approximately $20,000. The cost of removing and pruning these identified trees is currently unknown, and should be estimated after the inspection done as part of the detailed design.

It is thought that most trees will be in good health and that any removal/pruning could be part of a longer term maintenance program. As such the initial inspection has been allowed for, and any follow up work will become part of the maintenance program unless the inspection suggests otherwise.

5.4 Summary for Structural Works

Item	**55,000 ML/d Design Crest**	**40,000 ML/d Design Crest**
Priority Levee Works	$11,500,000 17 works locations	$10,900,000 10 works locations
Points of Weakness Repairs	$9,760,000	$8,680,000
Wells Creek Repairs	$380,000	$338,000
Tree Health Risk Inspections	$20,000 inspection plus an allowance for works	$20,000 inspection plus an allowance for works
Total Cost	**$21,660,000**	**$19,938,000**

The total cost allows for inspection of tree health risk to the levees but does not include any allowance for works required to reduce the risk from tree health damaging the levee. These works will be costed after the inspection completed during detailed design.

With the completion of these structural works the levee condition issues described above would be reduced to a low risk.

6. STRATEGIC LEVEE RISK MANAGEMENT STRATEGY

After completing the above structural works, an ongoing program of inspection, maintenance and repair is required to keep the low risk profile. The inspections and maintenance is required as it is likely that the levee will deteriorate and the risk of levee failure will increase. The following is an outline of what could be involved in such a program.

6.1 Structural Levee Maintenance

The approximate cost of annual maintenance for works to maintain the low risk profile of the upgraded levees has been costed based on a number of assumptions. It is assumed that 30 km of levee per year is inspected (discussed further below under monitoring), and 5% of that levee inspected has maintenance works completed. This will most likely include works to control vegetation and minor improvements to levee crest and erosion of banks. Assuming a cost rate of $100 per linear metre plus 100% contingencies for levee maintenance gives a total estimated cost of $300,000 for annual maintenance of the levee system.

6.2 Operational Risk Mitigation

6.2.1 Operational Levee Condition Monitoring

A levee condition monitoring program will be very important to ensure that the low levee risk profile is preserved. Monitoring should be undertaken at various levels of detail and at various frequencies appropriate to the level of risk. The proposed monitoring program must be realistic. There are approximately 144 km of rural levee, more if you include some of the levee features that were not surveyed in the Rural Levee Assessment, most of which would be required to be walked on foot.

Annual Inspections

It is assumed that the levees would be inundated every 2-3 years consistent with the requirements of watering Red Gums. At a flow of 40,000 ML/d approximately 110 km of levee has water against it. A rolling program to inspect approximately 30 km of levee per year should see most of the levee with water against it every 3 years. Bearing in mind that some 3 year periods may not see a flow as big as 40,000 ML/d in the lower Goulburn River. To inspect 30 km of levee it is estimated that this would require a 2 person team for OH&S issues and take approximately 1 week of field work plus 2 days in the office documenting the annual inspection. This inspection should include photo documentation (preferably georeferenced photos), and standard field sheets documenting any issues and general levee condition along sections of the levee.

The approximate cost to undertake these annual inspections would be approximately $12,000 assuming 5 days of field work for two people and 2 days of office work for 1 person at a rate of $120/hr. This assumes the inspection is done by CMA or GMW staff, cost may be higher if it is undertaken by a civil consultant.

Procedures must be put in place for what to do if an issue is found in the levee condition, who it should be reported to, how the inspections feed into the maintenance program, etc.

Event Based Monitoring

It is expected that during a watering event or a natural flood event CMA and others will be visiting the river to undertake ecological monitoring and monitoring of the performance of the levees will also be important. This may be possible through a combination of field based monitoring, aerial imagery captured via UAV or fixed wing aircraft, or satellite imagery. The purpose of the aerial/satellite imagery would be to identify any failures of the levee that may occur. This may not be required if landholders take an active role in monitoring the levees (or at least their adjacent land near the levees) throughout an event. This monitoring should also identify the occurrence of any trees falling during an event that cause damage to the levees. Should this occur, intervention during the event should be taken to repair the levee to reduce the risk of failure during current and future watering events.

This event based monitoring is considered more important for earlier watering events so as to identify any unforeseen issues or imminent failures that may arise. In subsequent watering events the frequency of the event based monitoring may be reduced. An approximate cost based on a 2 person team for say 10 days of monitoring work during an event may be around $20,000.

It is suggested that event based monitoring utilise time stamped georeferenced photographs to tie back to the nearest gauge. This will allow the flood modelling to be validated and an understanding of what certain flows mean for different landholders. Any areas that are of particular concern could have a gauge board installed that can be manually read and over time a relationship between the gauge board and the permanent gauging stations could be developed. This gauge board can then be used by the local landholder and inspection team for communicating current site specific water levels. These levels could also be referenced to the levee height also.

To further reduce the risk it is suggested that pre event inspections be undertaken to ensure that no damage to the levees has occurred since the last inspection. This pre-event inspection could be concentrated on the sections of levee that will have depths of water against them that pose an elevated risk of failure. This will vary across events depending on the forecasted flow that is to be experienced downstream of Shepparton. An approximate cost for this pre-event inspection based on a 2 person team for say 5 days of monitoring may be around $10,000.

Landholder Monitoring

It is assumed that all landholders will take an interest in how a watering event may impact them, it is therefore likely that they will monitor to some degree the levees adjacent to their private land. A communication plan should be put in place to capture this local knowledge and use it to supplement the annual and event based agency monitoring program. This will assist in developing a strong relationship between landholder and agency. This will require some degree of training/communicating with landholders regarding what information is required and why, with emphasis on what is in it for the landholder.

One way of perhaps incorporating this landholder monitoring into their everyday lives so as not to burden landholders would be to explore the possibility of landholders checking on the condition of the levees along the edge of their property boundaries at the same time as they do their routine fence inspections. Generally most landholders with stock will check the fence line after a storm to ensure no trees have come down on the fence. In similar events there is a risk that trees from the levees come down, so if landholders can monitor this at the same time as the fences it would be highly beneficial and cost efficient.

It is assumed that contacting each of the landholders may take approximately 5 days of time per year, with another 3 days in setting up and holding a workshop with landholders. This may cost $7,000 each year.

6.2.2 Operational Levee Failure Response

Immediately on identifying a levee breach the appropriate agencies should be informed through standard emergency management processes.

As levee failure is unpredictable and may occur through mechanisms not associated with the more predictable overtopping of a low crest, a process must be put in place to respond to a breach in the levee should it occur.

1. The most important aspect to reduce the consequences of a levee breach is an immediate response, as if left, the breach will enlarge and will become difficult to block, potentially

resulting in greater floodplain impact. As such early identification and communication is vital. All landholders should be made aware of the potential risks and what to do if a breach is identified (i.e. who to contact).

2. A levee breach can potentially be a hazardous environment if it is in a location where there is deep fast flowing water, as such safety must be a primary concern. Once a breach is identified a safety analysis should be performed which determines if it is safe to proceed with an attempt to block the breach.
3. The levee will need to be fully repaired after the water has subsided.
4. The breach site should be specifically monitored in future watering events.

6.2.3 Operational Communication System

Consideration should be given to a means of automatically notifying landholders should various events arise. Firstly all landholders should be notified in advance of a watering event or a natural flood event, making it very clear what type of event and hence what actions/responsibilities agencies have during these events and who landholders should communicate with.

During an event should a breach be observed a system should be in place whereby the consequence of that levee breach is considered and all impacted landholders are identified. This system could then contact each of the impacted landholders. VICSES work with sophisticated telephone automatic emergency communications systems and these systems could be used for this purpose, but in most instances the consequence is not likely to warrant this expenditure. A review of the number of landholders impacted by various levee breach scenarios will identify the level of sophistication of this communication/notification system.

It is important to have the messaging clear, and pre-constructed if possible, and reviewed prior to sending out any public messages. It cannot be assumed that once a message is sent that it is received or acted upon, so depending on the consequence further actions may be required like contacting VICSES and getting them involved in the emergency.

7. CONCLUSIONS

This assessment has considered the likely risk of levee failure from managed watering events on the lower Goulburn River. The assessment has included an analysis of levee crest elevations in comparison to managed flow events of 40,000 and 55,000 ML/d along the length of the levee system as well as considering a large number of discrete points of weakness.

Following an appropriate risk management process, the relative risk of each section of levee has been determined by considering the consequence and likelihood of levee failure given the current condition of the levees.

The cost estimates for repair and replacement of sections of the levee system have been made using the best available information. It is recommended that an engineer with geotechnical experience in levee or channel bank condition and repair, review this assessment as part of the early stages of detailed design. This review should include a field based component, assessing sections of levee covering the various points of weakness identified. Costing for repair works on the sections of levee visited could then be undertaken and compared to those completed in this assessment. This will allow increased confidence in the final cost estimates prior to progressing to design and construction phases.

For the river water levels associated with a 55,000 ML/day flow the assessment identified 17 priority works locations with the levee crest raised to the higher of the 55,000 ML/d or the existing crest level at an estimated cost of $11,500,000. Points of weakness with medium/high/extreme risk, those with low risk but major or catastrophic consequence, were assessed as requiring repair and were costed at $9,760,000. Added to this cost is another $380,000 for repair works along the Wells Creek levees and $20,000 for a tree health inspection. This gives a total structural works cost of **$21,660,000.**

For the river water levels associated with a 40,000 ML/day flow, the assessment identified 10 priority works locations with the levee crest raised to the higher of the 40,000 ML/d or the existing crest level at an estimated cost of $10,900,000. Points of weakness with medium/high/extreme risk, and those with low risk but major or catastrophic consequence, were assessed as requiring repair and were costed at $8,680,000. Added to this cost is another $338,000 for repair works along the Wells Creek levees and $20,000 for a tree health inspection. This gives a total structural works cost of **$19,938,000.**

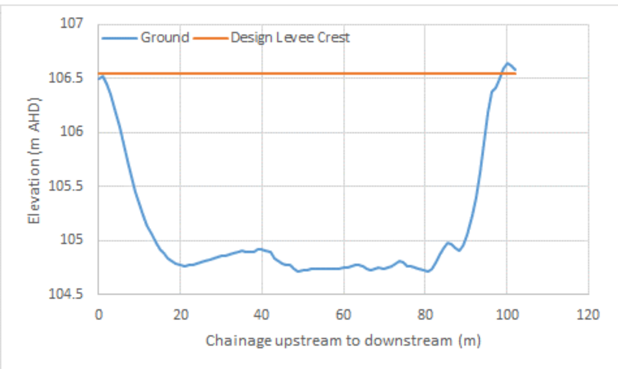
After completing the above structural works, an ongoing program of inspection, maintenance and repair to keep the low risk profile could cost in the order of $350,000 to $400,000 per year.

A number of further operational mitigation options have been identified and discussed. A robust operational communications plan/system should be put in place along with an emergency levee breach response plan.

APPENDIX 1 PRIORITY WORKS DETAILS FOR 55,000 ML/D DESIGN CREST LEVEL

Priority Works Location 1

Description: Existing levee is very close to the river bank on an outer bend and highly likely to fail in next 20-40 years with the bank collapsing into the river as the bend migrates. Realignment will straighten the levee, retreating back away from the bank. There appears to be a road providing farm access, so crest and batters require designing appropriately to cater for traffic.



Design Assumptions

Levee Length: 102 m

Average Depth: 1.4 m

Crest width: 4 m

Batter Slope: 4:1 on both sides

Cutoff Trench: 2 x 1 m (width x depth)

Total Volume Estimate: 1,798 m^3

Cost: $222,000

Priority Works Location 2

Description: Existing levee is very close to the river bank on an outer bend and highly likely to fail in next 20-40 years with the bank collapsing into the river as the bend migrates. Realignment will retreat back away from the bank. There appears to be a road providing farm access, so crest and batters require designing appropriately to cater for traffic.

<u>Design Assumptions</u>

Levee Length: 237 m

Average Depth: 1.2 m

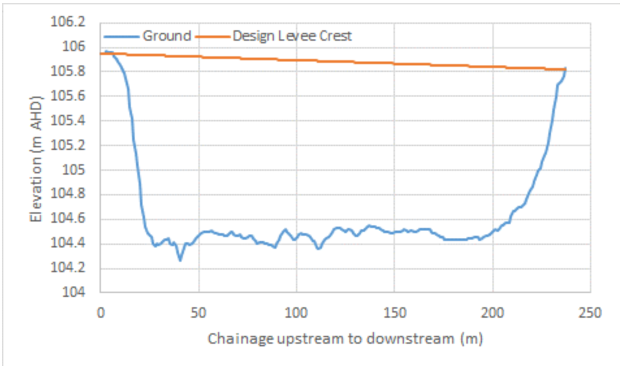
Crest width: 4 m

Batter Slope: 4:1 on both sides

Cutoff Trench: 2 x 1 m (width x depth)

Total Volume Estimate: 3,271 m^3

Cost: $405,000



Priority Works Location 3

Description: Existing levee is very close to the river bank on an outer bend and highly likely to fail in next 20-40 years with the bank collapsing into the river as the bend migrates. Realignment will straighten the levee, retreating back away from the bank. There appears to be a road providing farm access, so crest and batters require designing appropriately to cater for traffic.

Design Assumptions

Levee Length: 456 m

Average Depth: 1.1 m

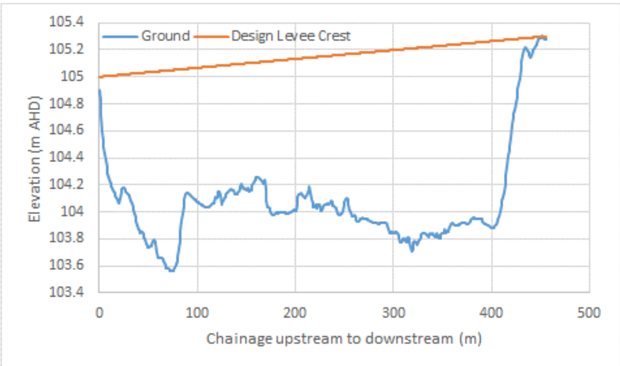
Crest width: 4 m

Batter Slope: 4:1 on both sides

Cutoff Trench: 2 x 1 m (width x depth)

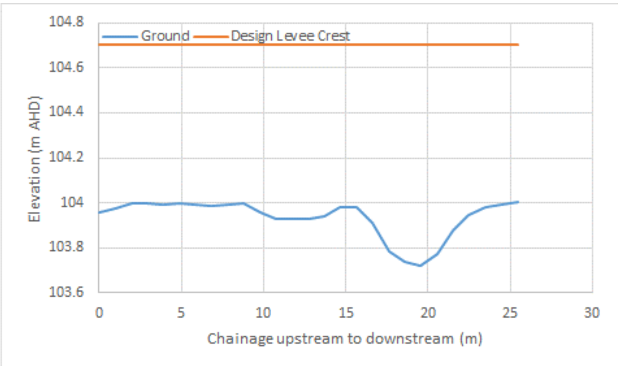
Total Volume Estimate: 5,183 m^3

Cost: $641,000



Priority Works Location 4

Description: There is a large pipe with pump located here, with the pipe sitting on top of the levee. The weight of the pipe and force from pumping looks to have cracked the levee under the pipe. The repair was costed as a new levee immediately behind the existing levee. In detail design it may be decided that the existing levee is repaired. The pipe could be reinstated to go over the levee but should be supported rather than bearing all its weight on the levee itself. Note that the existing levee height is approximately 400 mm higher than the 55,000 ML/d design crest height.



Design Assumptions

Levee Length: 25 m

Average Depth: 0.8 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: 2 x 1 m (width x depth)

Total Volume Estimate: 128 m^3

Cost: $41,000

Priority Works Location 5

Description: This section of levee includes a new section of levee at the upstream end to prevent a breakout that has occurred recently. This will offer a higher standard of protection to the local landholder. The remainder of the levee requires replacing and a lot of this levee is too low and is not in great condition. The completion of this levee and tying in with a downstream levee will make the river levee redundant. The existing river levee should remain and be allowed to deteriorate over time, or seek permission from the landholder to decommission it.

Design Assumptions

Levee Length: 1,147 m

Average Depth: 1.2 m

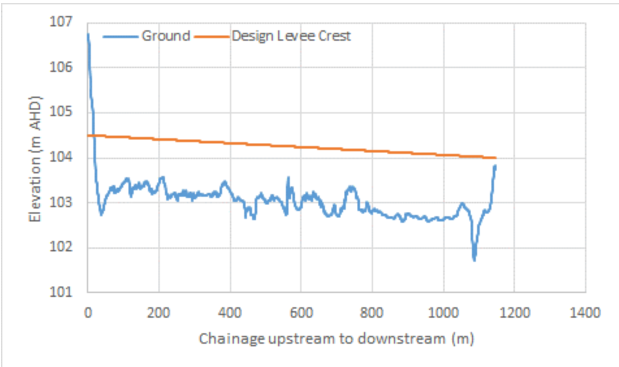
Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: 2 x 1 m (width x depth)

Total Volume Estimate: 9,611 m^3

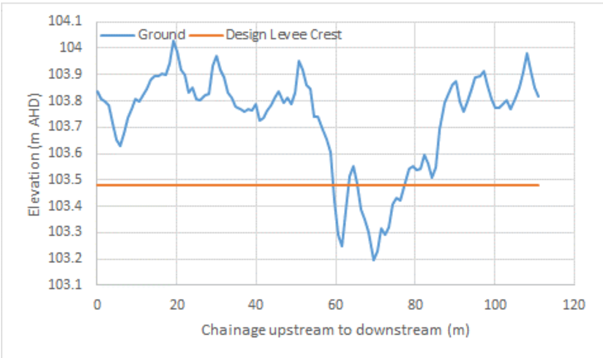
Cost: $1,189,000



Priority Works Location 6

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.

Design Assumptions



Levee Length: 111 m

Average Depth: <0.1 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: not required (just crest raising)

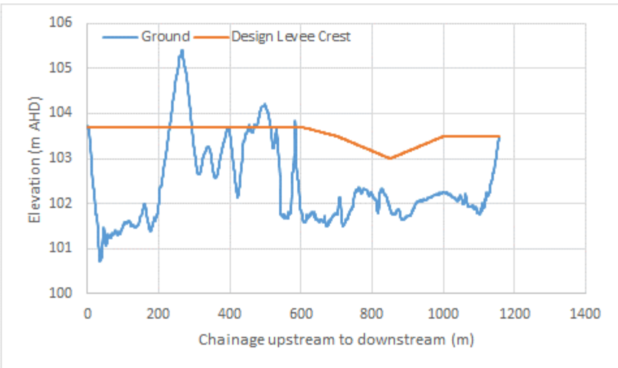
Total Volume Estimate: 5 m^3

Cost: $41,000

Priority Works Location 7

Description: The upstream section of this levee does not look like it is in good condition and is in need of replacement. The downstream section of the levee is very close to the river bank on an outside bend and should be realigned. The most suitable location for retreat would be along the existing road crest. It is recommended that the levee tie in with the existing road and the road act as a levee, providing a minimum level of protection of the 55,000 ML/d water level.

M:\Jobs\4100-4199\4146_Goulburn_River_Levee_Risk\Spatial\ESRI\Mxds\Arc_v10-1\LowerGoulburnLevees_BAT.mxd 19/10/2015



Design Assumptions

Levee Length: 1,158 m

Average Depth: 1.2 m

Crest width: 4 m

Batter Slope: 4:1 both sides

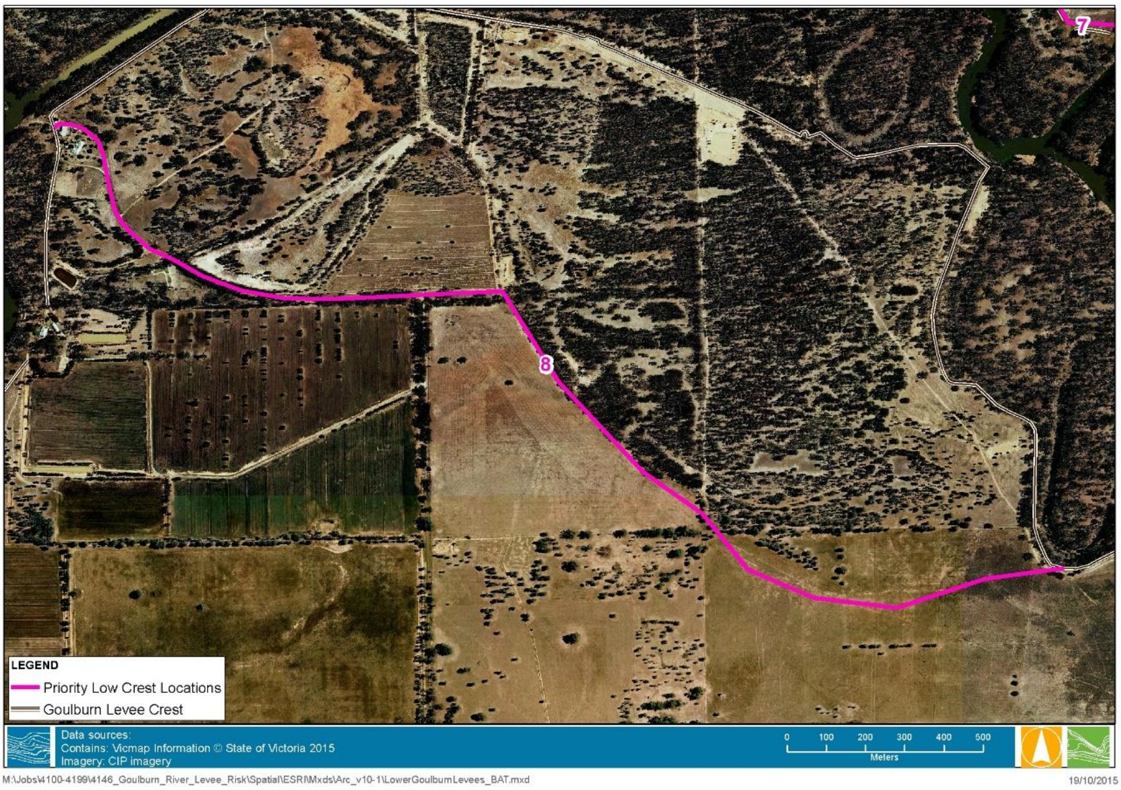
Cutoff Trench: 2 x 1 m (width x depth)

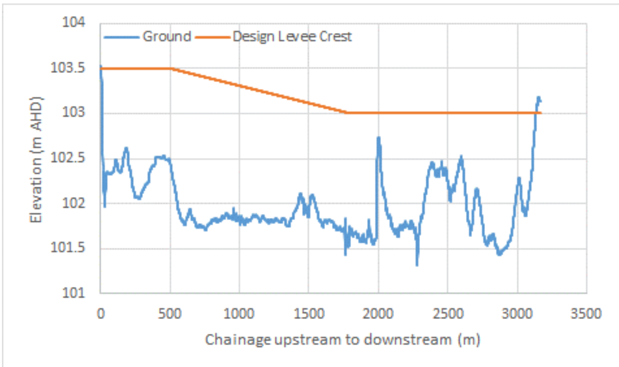
Total Volume Estimate: 17,316 m^3

Cost: $2,143,000

Priority Works Location 8

Description: The existing river levee to the north of the proposed site is known to have overtopped recently and is in poor condition. The realigned levee makes use of high ground and ties into the unsealed road that accesses the house at the western end of the levee. The road would be utilised as the levee. The road would pass the northern side of the house and key into the existing levee which runs to the south. The existing river levee would become redundant and could be left to degrade over time. Alternatively negotiations with the landholder may allow the existing levee to be decommissioned to facilitate more frequent flooding of the treed area inside the levee.





Design Assumptions

Levee Length: 3,163 m

Average Depth: 1.2 m

Crest width: 4 m

Batter Slope: 4:1 both sides

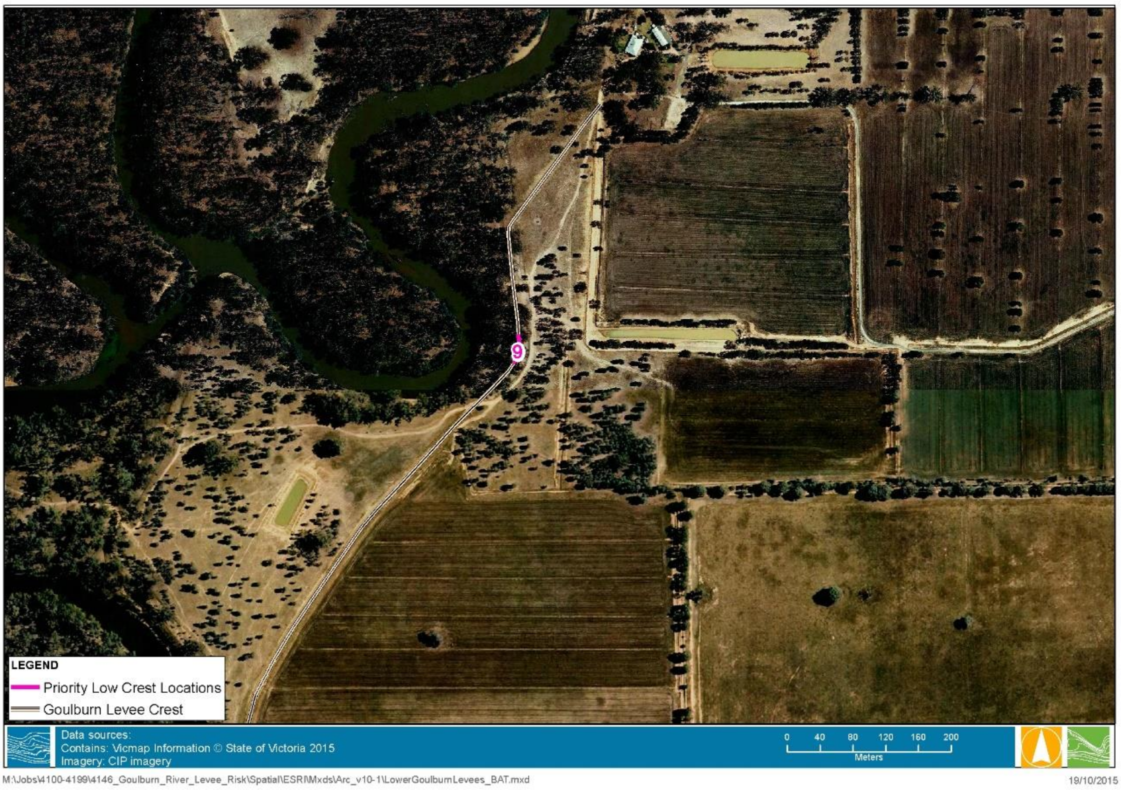
Cutoff Trench: 2 x 1 m (width x depth)

Total Volume Estimate: 41,330 m^3

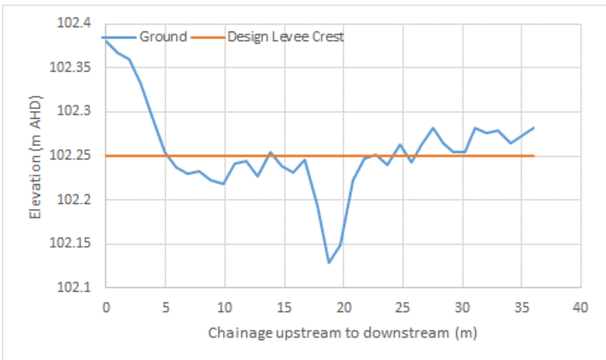
Cost: $5,115,000

Priority Works Location 9

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.



<u>Design Assumptions</u>



Levee Length: 36 m

Average Depth: <0.1 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: not required (just crest raising)

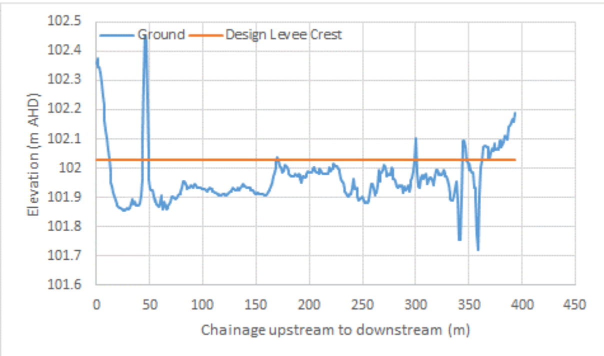
Total Volume Estimate: 1 m^3

Cost: $41,000

Priority Works Location 10

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.

Design Assumptions



Levee Length: 394 m

Average Depth: <0.1 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

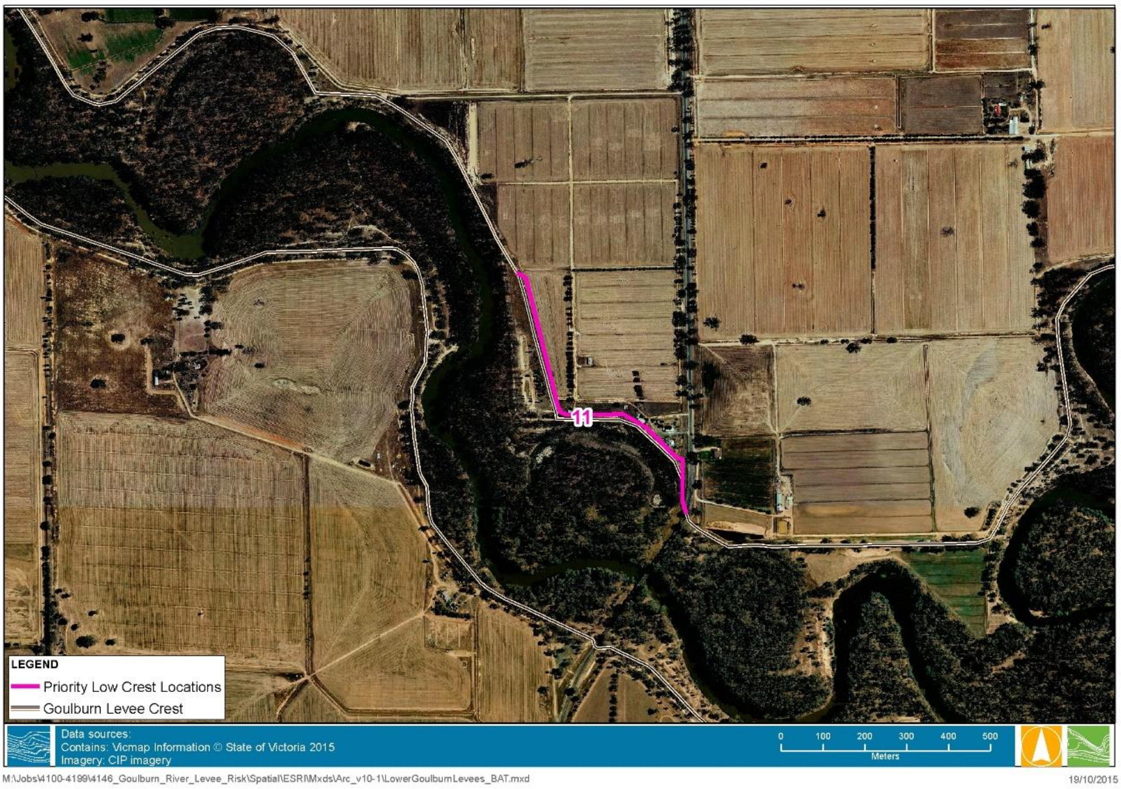
Cutoff Trench: not required (just crest raising)

Total Volume Estimate: 72 m^3

Cost: $41,000

Priority Works Location 11

Description: This levee is in a poor condition with many holes in the levee. Given the proximity to the house it is recommend to replace this levee behind the current levee. Given the close proximity to the house the alignment of the levee may require further consideration. The depth against the levee is approximately 1 m and with the proximity to the house this levee should be built to the highest standard of construction.



Design Assumptions

Levee Length: 817 m

Average Depth: 1.3 m

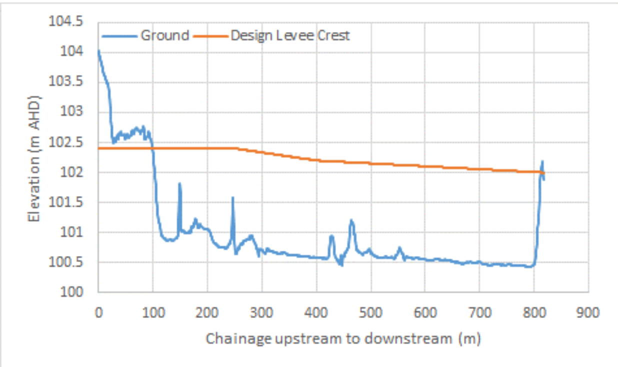
Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: 2 x 1 m (width x depth)

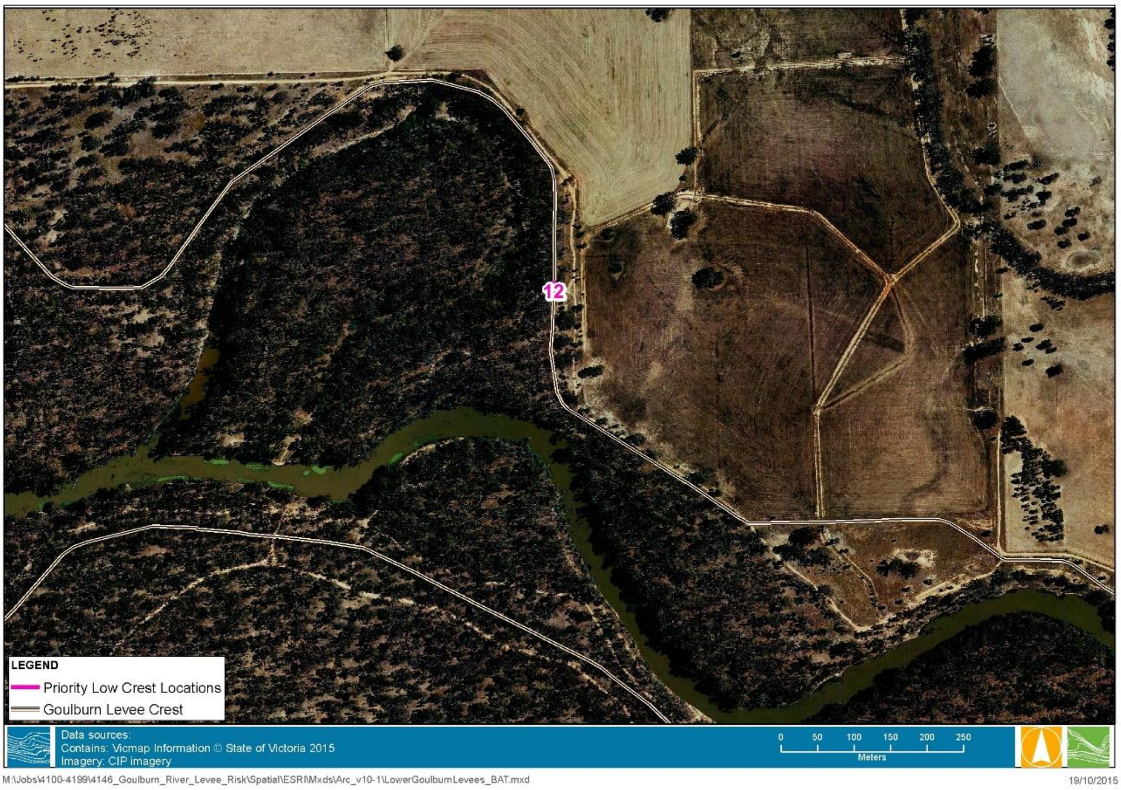
Total Volume Estimate: 7,863 m^3

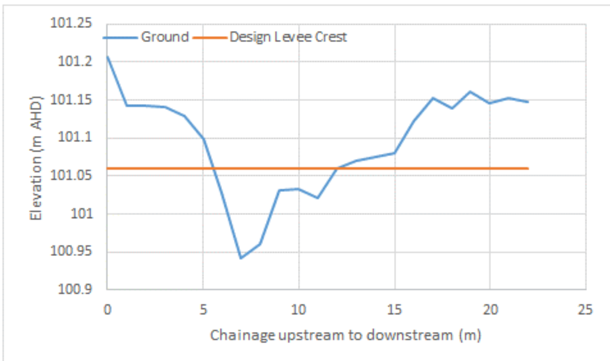
Cost: $973,000



Priority Works Location 12

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.





Design Assumptions

Levee Length: 22 m

Average Depth: <0.1 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

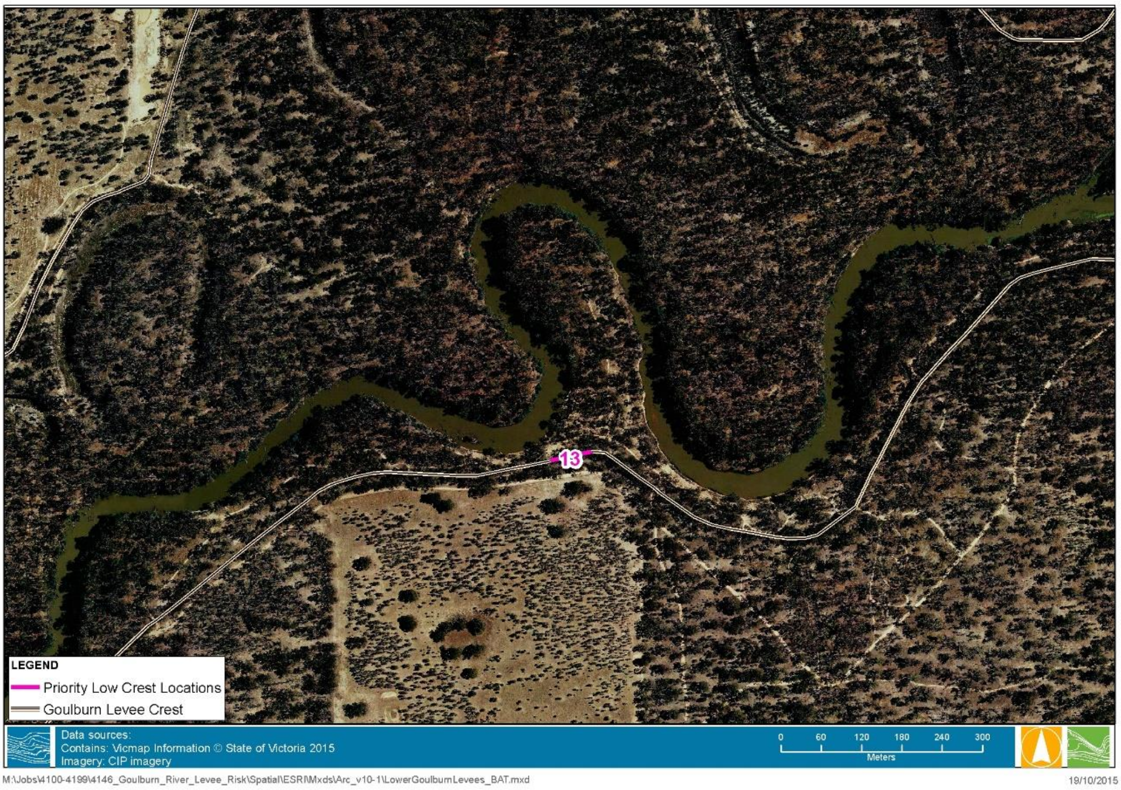
Cutoff Trench: not required (just crest raising)

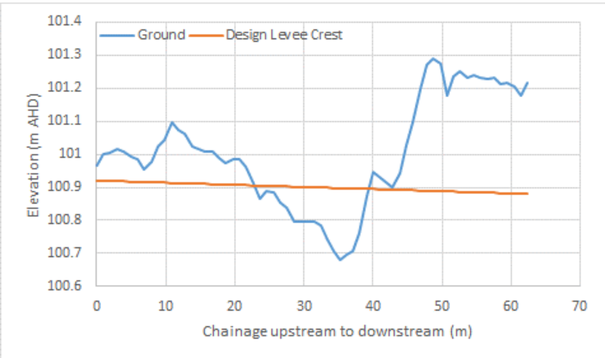
Total Volume Estimate: 1 m^3

Cost: $41,000

Priority Works Location 13

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.





Design Assumptions

Levee Length: 62 m

Average Depth: <0.1 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

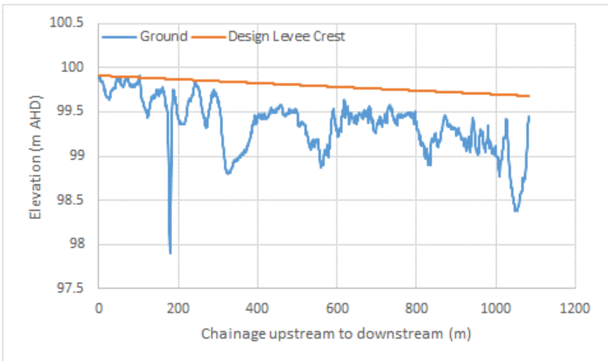
Cutoff Trench: not required (just crest raising)

Total Volume Estimate: 4 m^3

Cost: $41,000

Priority Works Location 14

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.



Design Assumptions

Levee Length: 1,084 m

Average Depth: 0.4 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: not required (just crest raising)

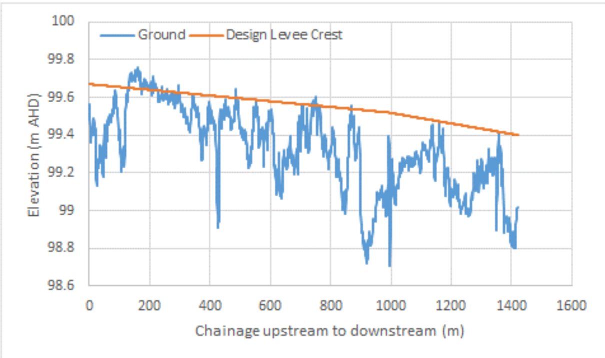
Total Volume Estimate: 1,694 m^3

Cost: $210,000

Priority Works Location 15

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.

Design Assumptions



Levee Length: 1,420 m

Average Depth: 0.2 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

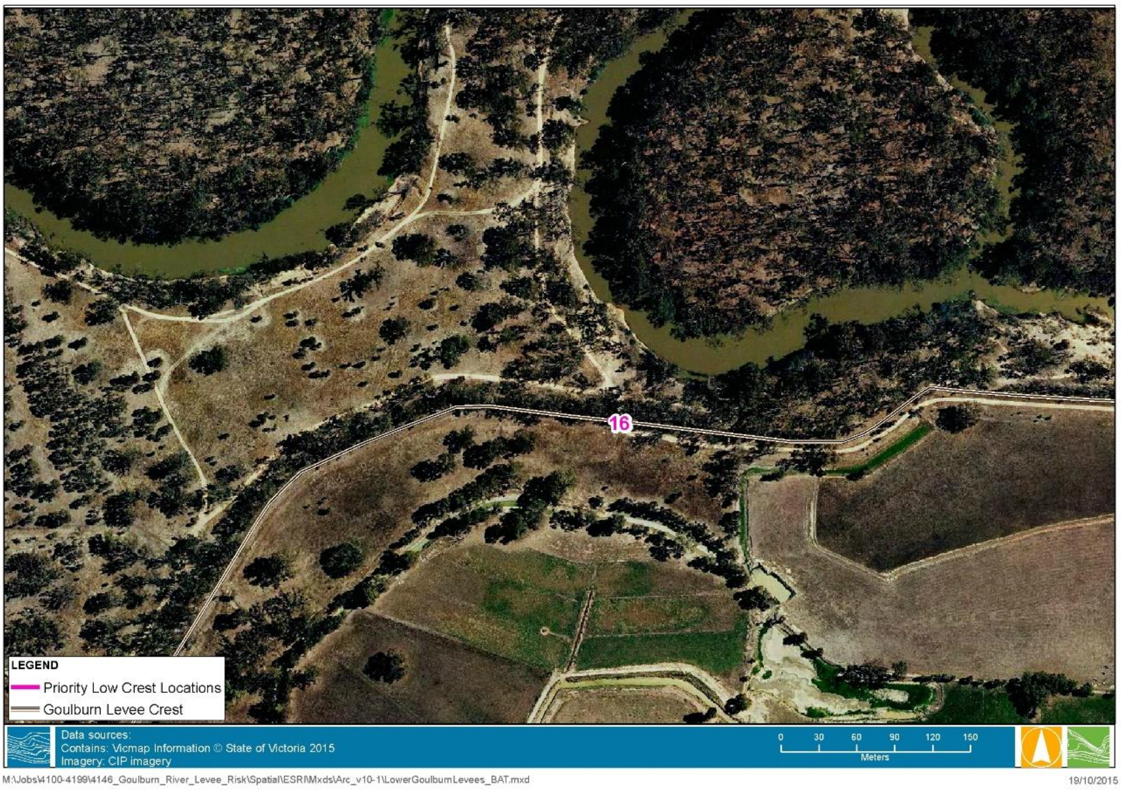
Cutoff Trench: not required (just crest raising)

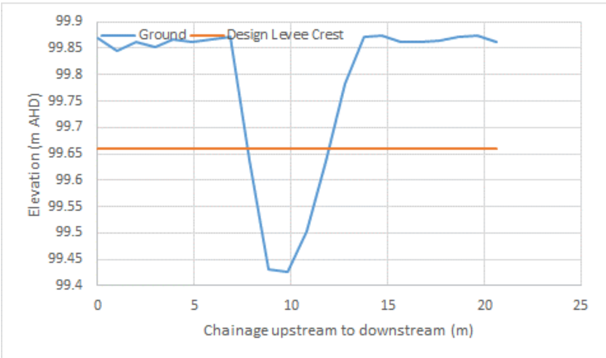
Total Volume Estimate: 951 m^3

Cost: $118,000

Priority Works Location 16

Description: This section of levee is slightly lower than the 55,000 ML/d design water level and requires 100 to 200 mm of crest raising.





Design Assumptions

Levee Length: 21 m

Average Depth: <0.1 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

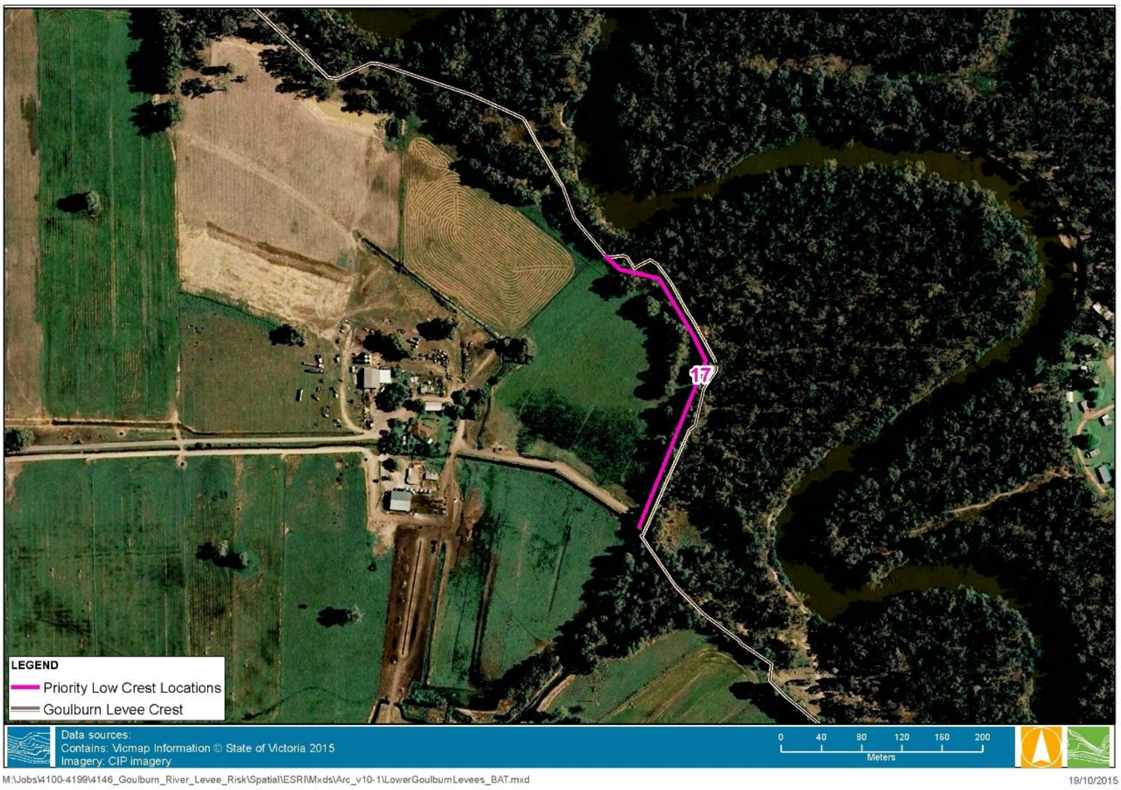
Cutoff Trench: not required (just crest raising)

Total Volume Estimate: 2 m^3

Cost: $41,000

Priority Works Location 17

Description: This levee is in a poor condition. Given the proximity to the house it is recommend to replace this levee behind the current levee.



Design Assumptions

Levee Length: 333 m

Average Depth: 0.6 m

Crest width: 2 m

Batter Slope: 3:1 inside, 2:1 outside

Cutoff Trench: 2 x 1 m (width x depth)

Total Volume Estimate: 1,356 m^3

Cost: $168,000