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Rural Levees Assessment
Final Report

January 2013

GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

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PROJECT DETAILS

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EXECUTIVE SUMMARY

The Rural Levees Assessment project was designed to meet the primary objective to improve the current state of knowledge, data and information of the strategic levees along the Goulburn River from Loch Garry to the Murray River and Murray River from Cobram to Barmah. This report documents the methodology and results for all tasks, with plans and data provided to GBCMA as electronic data and mapping files.

Survey

Survey of the levees was undertaken between January 2012 and June 2012 predominantly using corrected GPS with a vertical accuracy of at least 50 mm. The data captured included:

- Crest (Longitudinal) points were collected every 50 m along the levee, or where the levee changed direction or if the crest changed height significantly.
- Cross sections captured at least every 500 m and at all noticeable changes in levee geometry. As a minimum the cross sections included points for the levee crest and the natural surface, toe, bank sides and bank shoulders on both sides of the levee.
- Points of weakness data captured including coordinates for point or line features and linked photographs.

An assessment was undertaken to determine where the levees are located either within public land or privately owned land parcels. This task required an improvement of the cadastral data layer and included title searches and desk top re-establishment of the digital cadastre. This analysis found that along the Murray River levees 43 km (37%) is located in private land and for the Goulburn River levees 72 km (49%) is located in private land.

The following survey plans have been produced:

- Topographic Features, including points of weakness, running distances of river and levee, and Vicmap base data;
- Land Tenure, including parcels coloured according to whether they contain levee, running distances, and base data; and
- Sections, containing cross sections of the levee including weakness cross sections, and longitudinal sections.

In addition, GIS data has been produced from the survey including 3D cross sections, longitudinal sections, points and lines of weakness, linked photos and adjusted land parcels.

Level of protection

The surveyed levee crest levels and a Water Surface Elevation (WSE) for relevant flood events were compared with an allowance of 300 mm freeboard for modelled design events. Level of protection was assigned at 1 m intervals along the surveyed levees.

For the Goulburn River levees, the WSE were derived from the Lower Goulburn Floodplain Rehabilitation Scheme hydraulic modelling study. For the Murray River levees the WSE were derived from a number of sources. Upstream of the Barmah Forest, the Murray Regional Flood Study VFD contours were used. Downstream of the Barmah Forest, the Barmah-Millewa forest hydrodynamic modelling calibration models for the October 1993 and peak 2010 events were used. In addition, the 1975 flood contours sourced from the Victorian Flood Database were compared to the surveyed levee crest elevation for the entire length of the Murray River levees.

The total length of Murray River levees with a level of protection below the 1975 level is 67.5 km, representing 58% of the length of the Murray River levees surveyed. Works are required along 12.2 km of the Goulburn River levees to bring all levees up to a minimum standard level of

protection of a 5 year ARI flood event (8% of the levees). This analysis does not include consideration of the points of weakness data which has identified discrete points of lower levee crests and other potential points of weakness. Initial estimates of capital costs to provide a minimum level of protection are in excess of $9 million for the Murray levees and $6 million for the Goulburn River levees.

Points of weakness

Points of weakness (POW) are discrete locations along a 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, tree regeneration, rabbit burrows and wear by larger animals (cattle or horses for example). Over 3,000 features representing potential POW were captured and documented by the survey.

A risk based approach to identify priority points for works was developed using the input parameters of consequence and likelihood. The consequence of levee failure was assigned based on aerial photography interpretation of potential features as risk of inundation in the event of flooding.

The likelihood of levee failure due to a point of weakness was assessed for each point of weakness feature type. It was not possible to assess individual points of weakness due to the large number of points collected during the survey. The likelihood of failure assessment estimated the likelihood of failure of a POW classification rather than individual POW features, this allowed a standardised rapid assessment. 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.

The priority POW sites were selected as the sites with either an extreme or high risk rating. Sites identified with extreme or high risk generally correspond with areas where either a breach has occurred in the past and it has been repaired or where there is a discrete site with a low crest. Of the more than 3,000 POW sites identified in the field, 131 sites and approximately 1 km of linear features have been ranked as extreme or high risk:

- 48 sites for the Murray River levees
- 83 sites and 943 m for the Goulburn River levees

Costing

Indicative cost estimates were prepared for each of the prioritised sites and sections of levee. The cost estimates have been prepared within the context of this project's broad objectives and aims and have been derived from the survey information and photographs collected at the time of survey. Initial and annual maintenance costs are presented in Table 5-2 allowing for contingency and planning costs and annual maintenance for the works. An indicative cost for the priority works for the rural levees is $2.5 million comprising the Murray River levees ($416,000) and Goulburn River levees ($2,100,000).

Key findings

The survey and land tenure data provides a clear and accurate understanding of where the levee assets are located and the level of protection provided by the crest. However, the results show in general that the level of protection and condition of the levees both on the Goulburn and Murray Rivers is inconsistent along their length and it is clear that a large flood on the Goulburn River and/or River Murray would be likely to produce very uncertain results in terms of the performance of the levee system. Overtopping and failure due to levee breaching is likely to occur in an unpredictable fashion, leading to difficulties in flood response and management.

Whilst inconsistencies have been identified in the level of performance exhibited by the levees throughout the study area, it would be a significant undertaking to upgrade the system to achieve a uniform level of performance. A prioritised program of works to address the identified areas of significant weakness and greatest risk may be a more efficient use of any resources that may become available in the future. Further it may be desirable to develop a minimum standard of performance to avoid failure of some levees at a relatively low threshold compared to the rest of the system.

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1. INTRODUCTION

1.1 Project background

Levees have been constructed along the Goulburn and Murray Rivers on private and public land from the mid-1800s and early 1900s. The levees have been repaired and modified over time in response to damage caused by floods. With little or no regular maintenance many of the levees have fallen into a less than satisfactory condition. Whilst concurrently, development that has occurred within the communities that live on these floodplains has been a result of the protection, or perceived protection, afforded to them by the levees.

Recent flood events in Victoria have highlighted the need to assess the levees along the Goulburn and Murray River floodplains. The Lower Goulburn Floodplain Rehabilitation Scheme study (Water Technology 2005) noted that "…..*for floods equal to or larger than approximately a 10 year ARI flood however, the levees overtop and/or fail randomly along the river."*

Not only do we need to understand what the levee crest level is, but also what the condition of the levee is, where the levee is likely to breach, what is the magnitude/frequency of flooding that is likely to result in overtopping and who owns the levee and how is it going to be maintained.

1.2 Project scope

The Rural Levees Assessment project scope has been designed specifically to meet the primary objective to improve the current state of knowledge, data and information of the strategic levees along the Goulburn River from Loch Garry to the Murray River and Murray River from Cobram to Barmah. The specific requirements, as stated in the brief are to:

- Capture survey data of levee crests, levee toe/natural surface and cross-sections
- Identify points of weakness in the levees
- Establish land tenure
- Estimate the existing level of protection
- Develop a priority list of works to repair points of weakness to provide a more consistent standard of protection
- Estimate costs to carry out the required works
- Record all outputs into suitable GIS layers in accordance with Victorian Flood Database (VFD) formats.

The project has been undertaken as six distinct tasks:

- Land tenure,
- Levee survey
- Existing Level of Protection
- Points of Weakness analysis
- Priority works and costings
- Plan and data preparation.

This report documents the methodology and results for all tasks, with plans and data provided to GBCMA as electronic data and mapping files.

2. SURVEY

2.1 Survey capture methodology

Survey of the levees was performed predominantly using Real-Time-Kinematic (RTK) GPS receiving corrections in real time from Victoria's Continually Operating Reference Station (CORS) network. In areas of no mobile reception resulting in no link to the CORS network, ThinkSpatial set up its own RTK base station providing corrections via radio link.

A team of two surveyors worked independently, but within close proximity, walking or riding quad bikes along the levees. One surveyor surveyed the levee cross-section and longitudinal-section points (i.e. the levee geometry), whilst the second surveyor surveyed points 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-points were collected every 50 m along the levee, or where the levee changed direction or if the crest changed height significantly.

Cross sections were collected initially every 100 m and later, in order to improve efficiency, every 500 m. Cross sections captured all changes in levee geometry, but 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 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 ensures survey data falls within the 50 mm absolute vertical tolerance prescribed in the project brief. The majority of horizontal tolerances are within 25 mm of surveyed points, falling well within the 0.5 m prescribed tolerance.

2.2 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 0.

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), so these were surveyed as linear features. 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 banks structural integrity, a cross section was surveyed.

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

2.3 Land tenure

During field survey capture, fences were surveyed to assist in identifying land tenure, identifying the location of the levee as inside or outside each privately owned parcel.

The rest of the land tenure process was a "desktop re-establishment" exercise performed using AutoCAD.

Initially, the Department of Sustainability and Environment's Vicmap 'Parcel' layer was used and attempts were made to 'fit' the parcels to surveyed fencing (occupation). This was largely unsuccessful as the Vicmap parcel layer was found to be too inaccurate. Examples of inaccuracies include incorrect shape, relative distances differing from title by up to 40 m, different number of boundaries to title, and general inability to fit a Vicmap parcel in between surrounding titles, roads, or the river.

Next, starting with the most inaccurate parcels, several title plans were purchased and their dimensions keyed into AutoCAD. These titles were positioned and rotated to fit surveyed fencing with much more success. Adjacent Vicmap titles were attempted to be fitted using the accurate keyed-in titles and fencing as reference. Again, this proved unsuccessful due to inaccuracy of the Vicmap product.

The next step involved purchasing and keying in almost all titles adjacent to the levee (some titles were not found online). Once all titles were keyed in and placed approximately into position, the final stage of desktop re-establishment was 'fine-tune' positioning, rotating, and even scaling as appropriate to expertly achieve a cadastre that more accurate fits occupation for the titles affected by the levee.

Finally, the levee was 'intersected' with the newly established cadastre to determine which parcels contained even the smallest length of levee inside it and which parcels contained no levee. In the Tenure set of plans, the titles were coloured to differentiate between containing levee and not containing levee. Parcel identifiers are annotated on the plans for each title.

2.4 Results

2.4.1 Land tenure

Spatial analysis of the levee crest alignment has been undertaken to determine the land tenure using the corrected private land title boundaries. For the Murray River levees the analysis indicates that 43 km (37%) of the levees are within private land. For the Goulburn River levees 72 km (49%) of the levees are within private land. This has been assessed using the levee crest.

2.4.2 Plans

The outputs from the survey components include plans prepared in AutoCAD and delivered as native DWG and Adobe PDF formats. All plans are to scale when plotted at A1 sheet size, but legible when printed as A3, which results in halving scales.

A drawing set was produced for each of the following three 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;
- Land Tenure, including parcels coloured according to whether they contain levee, running distances, and base data; and
- Sections, containing cross sections of the levee including weakness cross sections, and longitudinal sections.

Plans were produced for the above three themes for each levee section. There are 16 sections along the Goulburn River and 12 along the Murray River (the levee sections are described further in Section 3. This resulted in 84 plan sets produced, and a total of 409 A1-sized plan sheets.

2.4.3 GIS datasets

GIS datasets were provided for the engineering assessment. The GIS data includes the 3D survey data of all cross sections, longitudinal sections, points and lines of weakness, geo-tagged and hyperlinked photos, as well as the adjusted land parcels attributed by Vicmap fields with an additional field identifying if each parcel contains a levee.

A polygon layer representing the on-ground 'footprints' for all plans was also supplied with live hyperlinks to the DWG and PDF plans.

These datasets were supplied as ArcGIS MXD projects with accompanying Shapefiles.

2.5 Key findings / discussion

2.5.1 Survey

Surveyors working independently, but within close proximity of each other was an operational decision that had several benefits, particularly safety, morale, and technical support.

If one surveyor was ahead of the other, he or she surveyed nearby fencing to feed into the land tenure process or assisted the other surveyor in his/her tasks.

For approximately half of the project, quad bikes were used during survey. This enabled surveyors to carry a day's supplies (food, water, and survey consumables) and work longer without becoming exhausted and dehydrated. At times, however, the quad bikes were deemed inappropriate due to the number of fences that could only be crossed by climbing over.

At least 90 percent of the project was completed using Real-Time-Kinematic (RTK) GPS connected via mobile phone to Victoria's Continually Operating Reference Stations (CORS). The remaining 10 percent where mobile phone coverage was unavailable was completed using ThinkSpatial's base station that was set up when required to provide RTK GPS.

At no stage was it required to resort to Total Station in order to survey levee banks or points of weakness. In certain cases, GPS was not available due to tree canopy cover, but this problem was rectified by surveying nearby instead. For example, if the surveyor was attempting to survey a set of 50 m interval longitudinal section points, but was unable to due to lack of GPS signal, he or she would simply walk another few metres backwards or forwards until GPS signal was achieved.

The large number of points of weakness was not anticipated prior to commencement. In preparing the survey task it was believed there may be up to four points of weakness per kilometre. The reality was closer to 20 surveyed weakness points/lines per kilometre (and significantly more if the number of vertices in each line is considered).

As a result of the condition of the levees impacting survey progress, the survey specifications were relaxed so that the survey team could achieve nearer to the anticipated rate of progress of 6-7 km per day. ThinkSpatial consulted with Water Technology's engineers and GBCMA to increase the interval of longitudinal-section points from 100 m to 500 m. As a result, the survey team increased the progress to, on average, approximately 4.5-5 km per day.

2.5.2 Land Tenure

As expected, the existing digital cadastral base available via DSE's Vicmap GIS data layer was inaccurate. Anecdotally, it is understood that Victoria's cadastre is least accurate near rivers as geometric errors accumulate away from more frequently surveyed and populated locations. An initial attempt to fit DSE's Vicmap 'Parcel' layer to surveyed fencing was not successful as there were too many unresolved title boundaries with relative discrepancies as well as less-problematic absolute errors. For example, a Vicmap parcel can easily be moved (and rotated) to fit fencing if its

relative dimensions are accurate, but in many cases, the relative length of a side would disagree with title plan by up to 40 m. All titles were purchased online and keyed in manually without using DSE's Vicmap Parcel layer. The title boundaries were then positioned in an absolute sense using surveyed fencing and relative to each other.

3. LEVELS OF PROTECTION

3.1 Methodology

The levees were divided into sections for reporting and mapping as shown in Figures 3-1 and 3-2. The sections were assigned by creating 10 km long regular sections and then adjusting to start and stop sections where natural breaks in the system occur. There are 16 sections along the Goulburn River and 12 sections along the Murray River. Each section has a start and end river chainage and has been mapped separately in the survey plans.

The crest levels were captured by survey (Section 2) and prepared as 3D line shapefiles. From this data, 1 m points were created along the length and at each point, the crest level and a Water Surface Elevation (WSE) for each flood event were extracted. Comparison of the levee crest and the WSE at each point, with an allowance of 300 mm freeboard, was undertaken with each point assigned a level of protection as per the following tables (Tables 3-1 and 3-2).

For the Goulburn River levees, the WSE were derived from the Lower Goulburn Floodplain Rehabilitation Scheme hydraulic modelling study (Water Technology 2005).

For the Murray River levees the WSE were derived from a number of sources. Upstream of the Barmah Forest (levee sections 1 to 6), the Murray Regional Flood Study VFD contours (Water Technology 2012) were used. Downstream of the Barmah Forest (levee sections 6 to 12), the Barmah-Millewa forest hydrodynamic modelling calibration models for the October 1993 and peak 2010 events (Water Technology 2006 and 2012) were used. In addition, the 1975 flood contours in the VFD were also used. The 1975 event is estimated to have a 20 – 30 year Average Recurrence Interval (ARI) at Yarrawonga and Tocumwal and a 10-20 year ARI at Barmah. The 1993 event is estimated at approximately a 30 year ARI at Tocumwal and a 10-20 year ARI at Barmah. The 2010 event is estimated at less than a 5 year ARI.

For the Goulburn River, it should be noted that flood modelling of large floods greater than the 20 year ARI event inherently includes levee failure (based on past observations), which allows extensive flooding of adjoining floodplain areas. It is understood that given the nature of the lower Goulburn floodplain and the constriction imposed by the levees, that levee failure will occur in these large events, but it is unknown exactly where this will happen. Therefore, the level of protection for events equal to or larger than the 20 year ARI is uncertain and dependant on levee failure. Similarly this is the case with the upper Murray River levees.

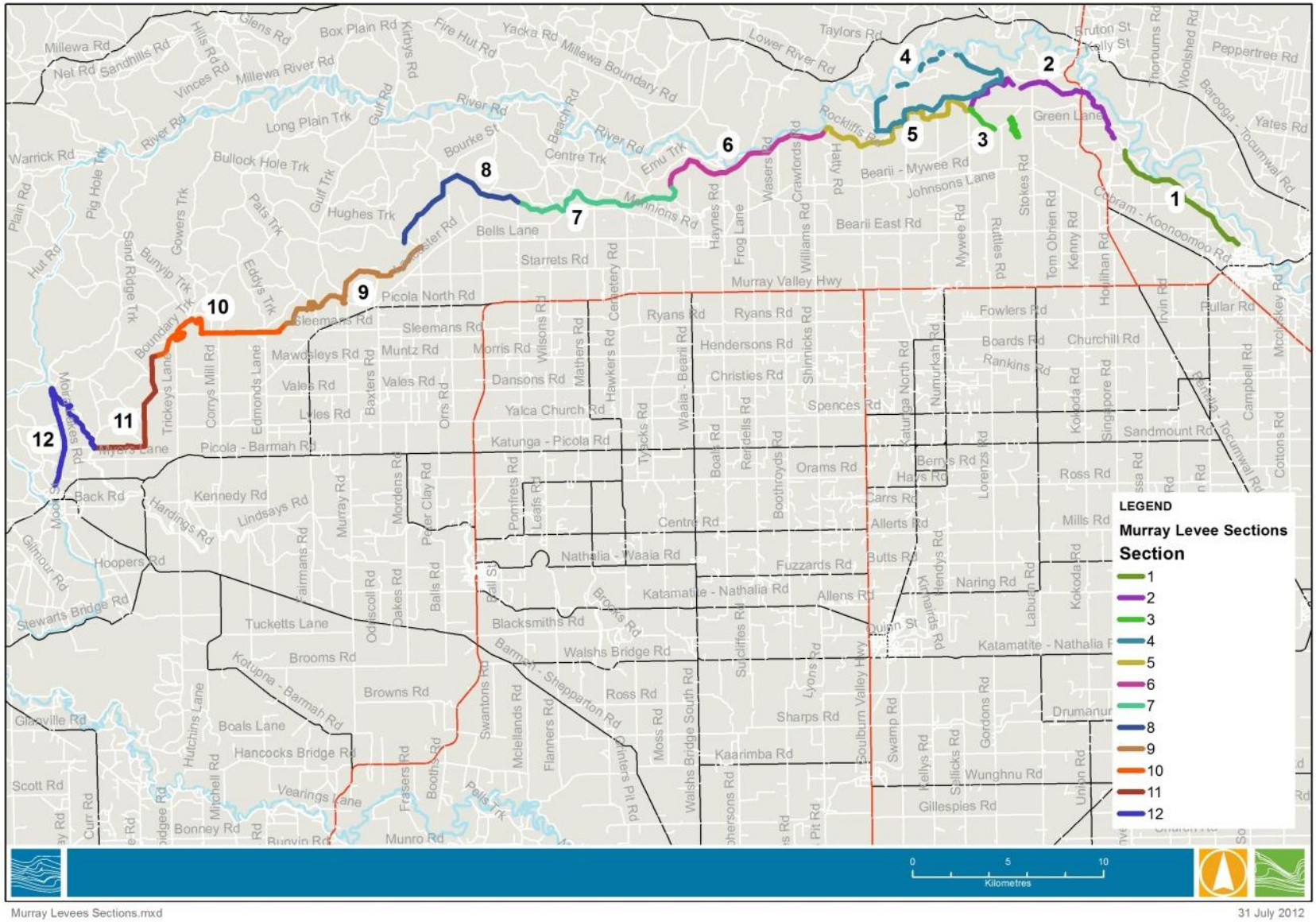

Figure 3-1 Murray River levee sections

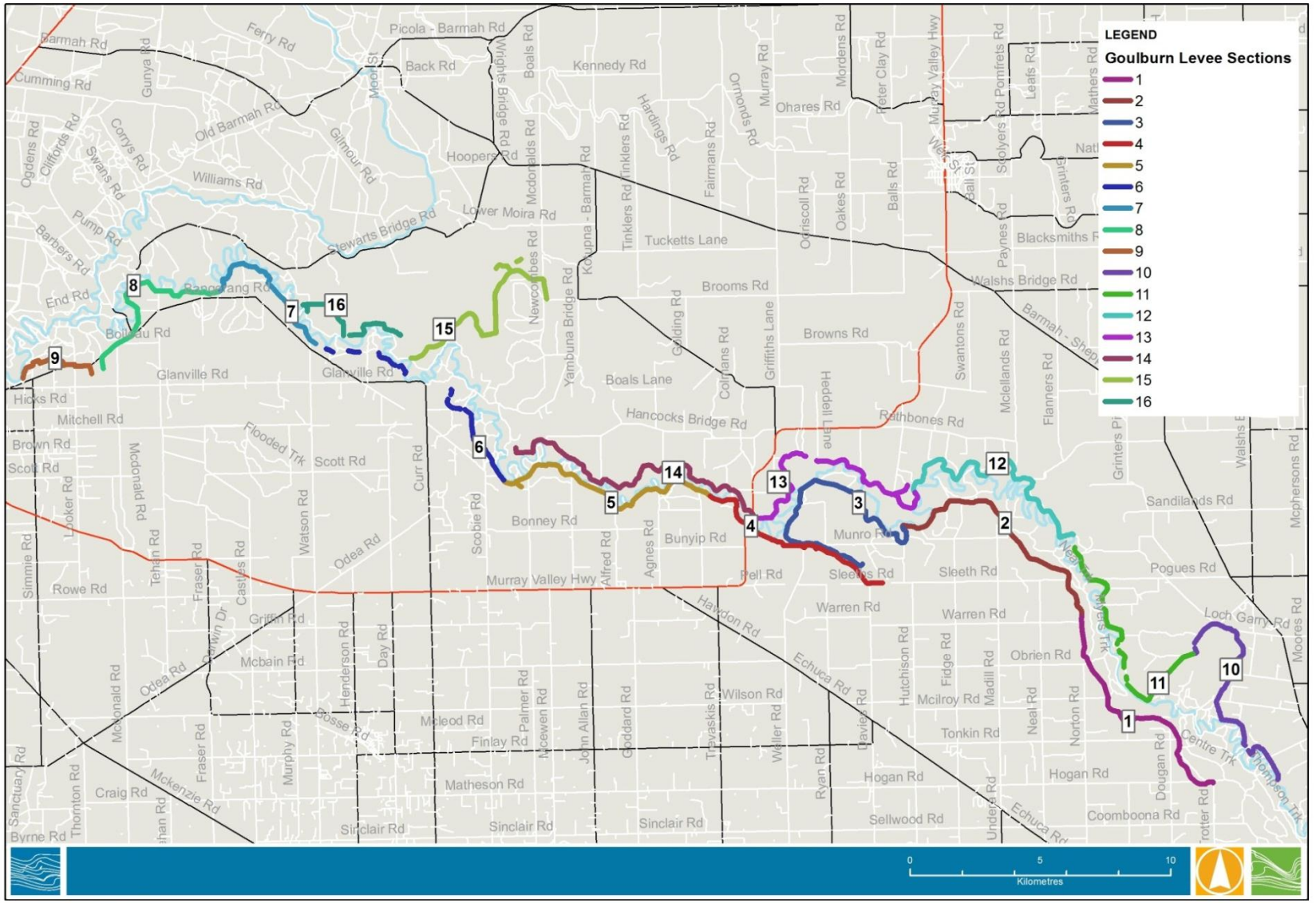

Figure 3-2 Goulburn River levee sections

Table 3-1 Level of protection classification for Murray levees[1]. The gauge height relates to the design event water level (WSE) and does not include the 300 mm freeboard

Location	Assigned Level of Protection	Gauge Height (m)	Description
Upstream of Barmah Forest (reference gauge Murray River @ Downstream of Yarrawonga Weir)	100 year ARI	9.3	Crest is > 300 mm higher than 100 year ARI WSE
	50 year ARI	9.0	Crest is > 300 mm higher than 50 year ARI WSE
	20 year ARI	8.5	Crest is > 300 mm higher than 20 year ARI WSE
	< 20 year ARI	< 8.5	Crest is lower than 20 year ARI WSE
	1975	8.3	Crest is greater than or equal to the 1975 WSE (with no freeboard)
Downstream of Barmah Forest (reference gauge Murray River @ Tocumwal)	1975	7.53	Crest is higher than the recorded 1975 WSE
	1993	7.37	Crest is > 300 mm higher than the modelled 1993 WSE (and not at 1975 LOP)
	2010	6.66	Crest is > 300 mm higher than the modelled 2010 WSE (and not at 1975 or 1993 LOP)
	< 2010	< 6.66	Crest is <= 300 mm higher or lower than the modelled 2010 WSE

Table 3-2 Level of protection classification for Goulburn levees. The reference gauge is Shepparton.[2] The gauge height relates to the design event water level (WSE) and does not include the 300 mm freeboard

Assigned Level of Protection	Gauge height (m)	Description
100 year ARI	12.13	Crest is > 300 mm higher than 100 year ARI WSE
50 year ARI	11.89	Crest is > 300 mm higher than 50 year ARI WSE
20 year ARI	11.56	Crest is > 300 mm higher than 20 year ARI WSE
10 year ARI	11.22	Crest is > 300 mm higher than 10 year ARI WSE
5 year ARI	10.75	Crest is > 300 mm higher than 5 year ARI WSE
< 5 year ARI	< 10.75	All mapped WSEs overtop the levee

[1],[2] refer to Section 3.1, paragraph 4 discussion on levee failure and level of protection

3.2 Results

The Level of Protection (LOP) for each section of the Murray and Goulburn river levees are summarised below in the charts presented in Figures 3-3 to 3-6 and Tables A-1 and A-2 in Appendix A. The LOP for each levee crest point is shown in Figures 3-7 to 3-9.

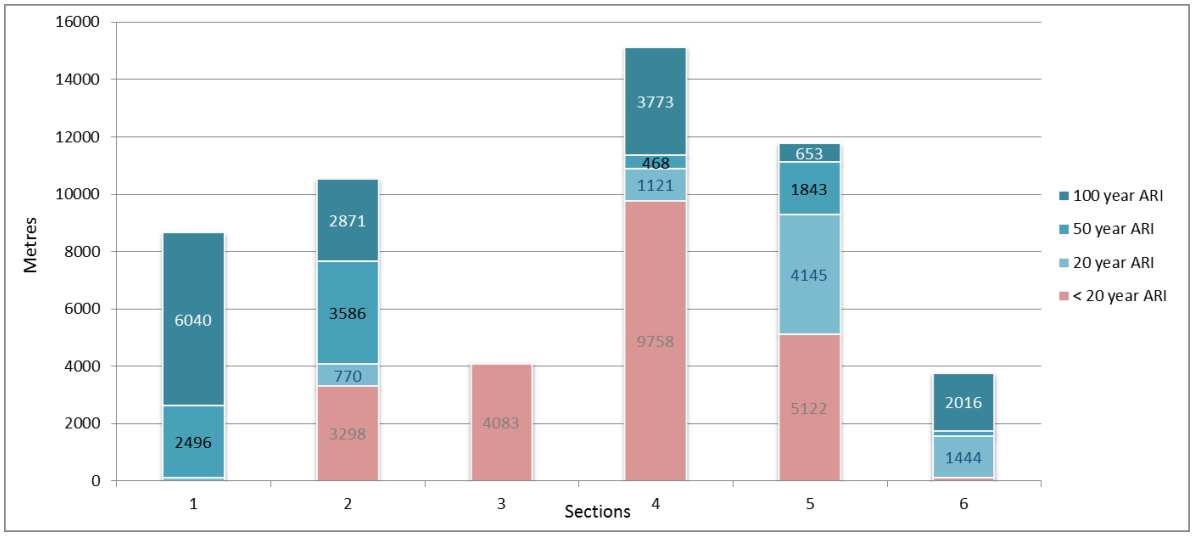

Figure 3-3 Level of protection of Murray River levees upstream of Barmah Forest

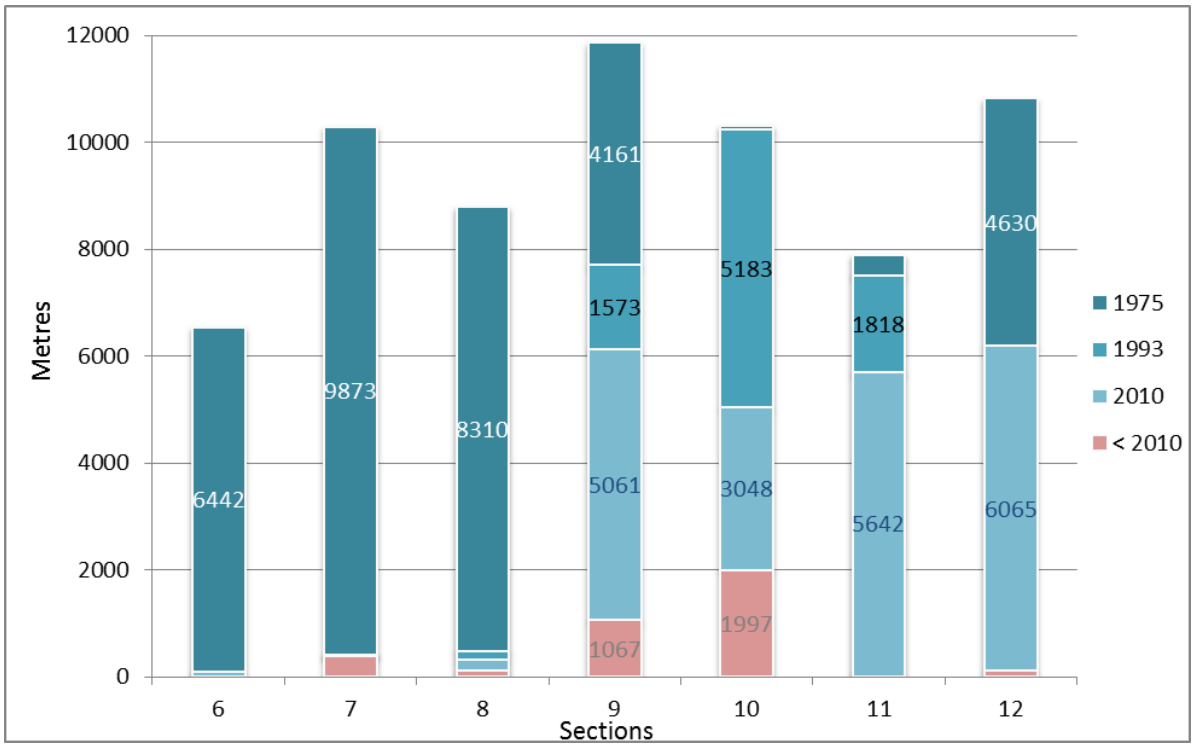

Figure 3-4 Level of protection of Murray River levees downstream of Barmah Forest

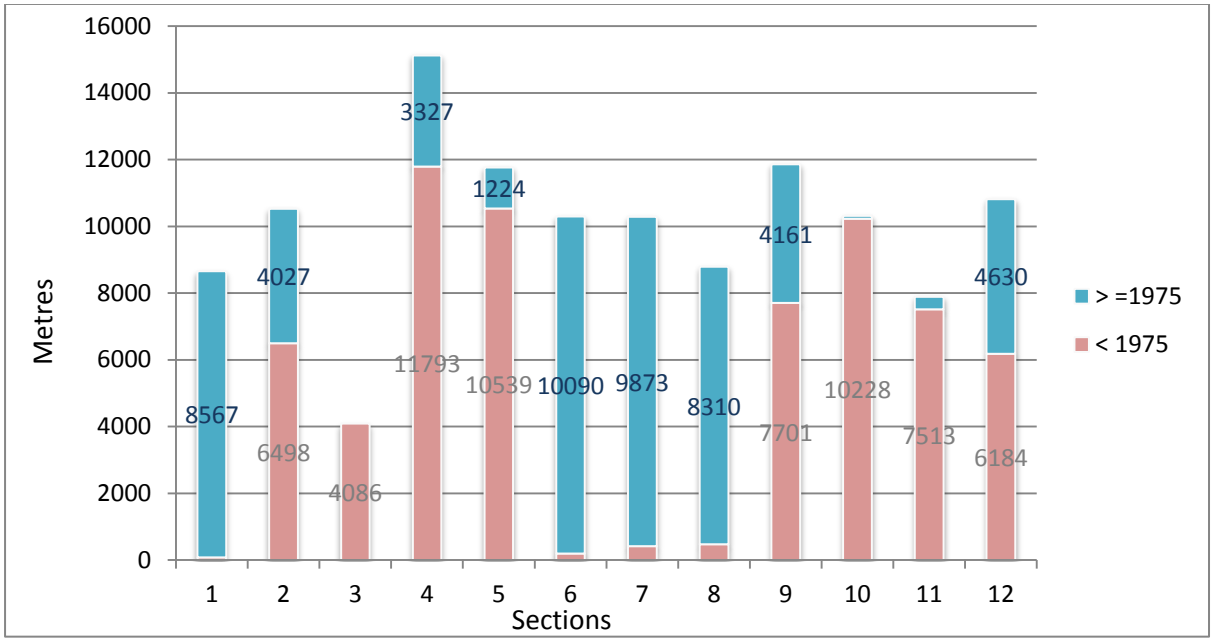

Figure 3-5 Murray River levees compared to 1975 flood levels

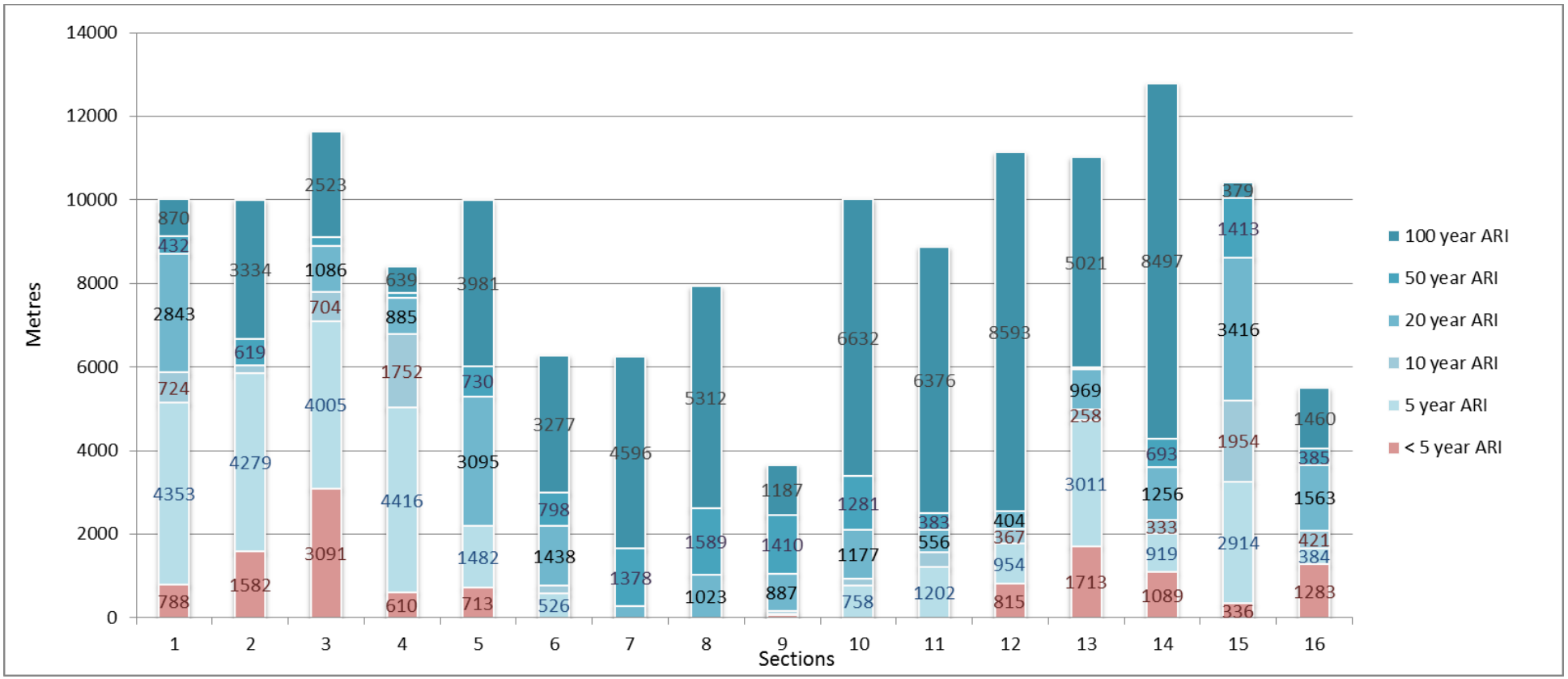

Figure 3-6 Level of protection of Goulburn River levees

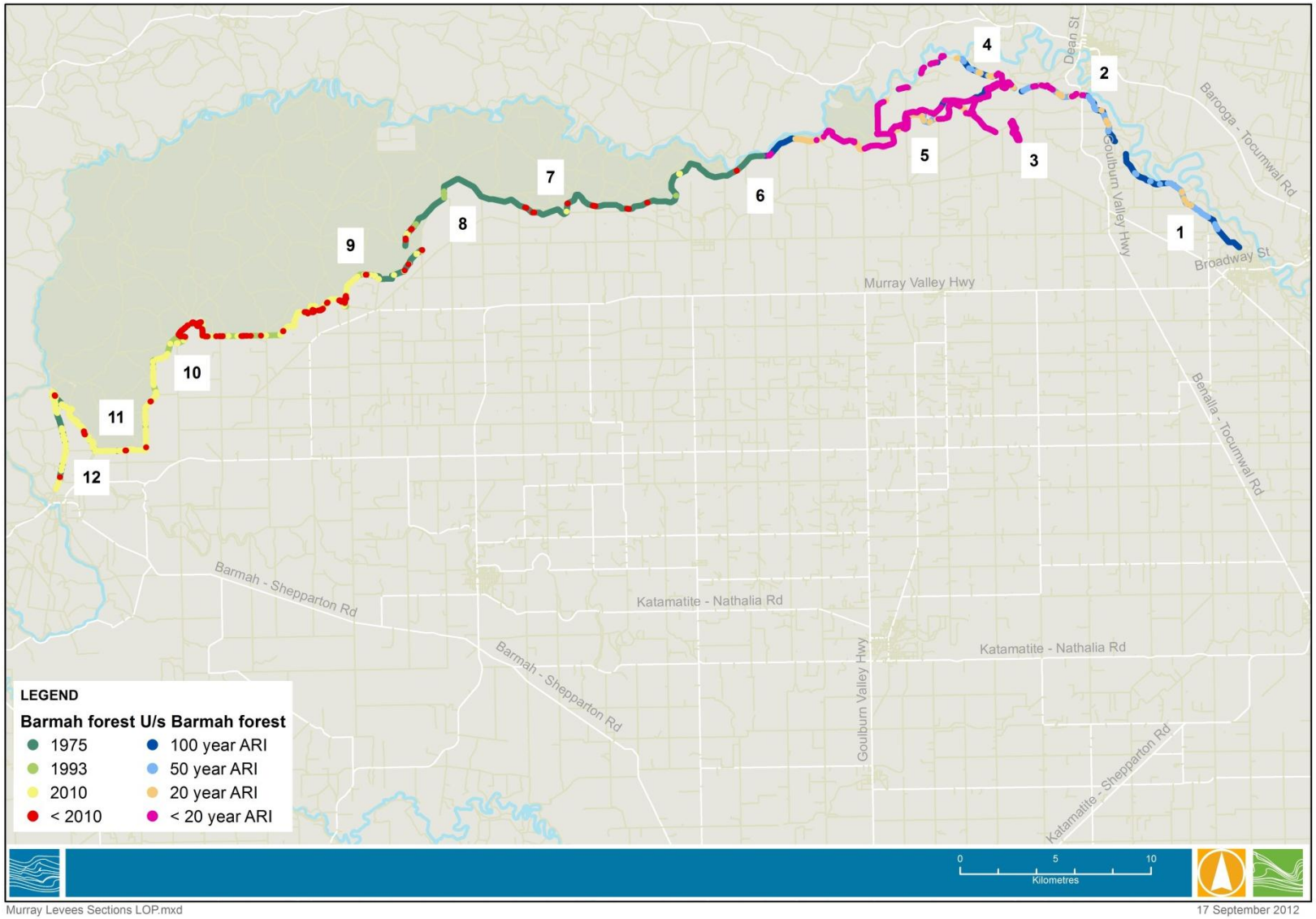

Figure 3-7 Map of level of protection of Murray River levees (Due to the scale of mapping, points overlap with the lowest LOP taking precedence)

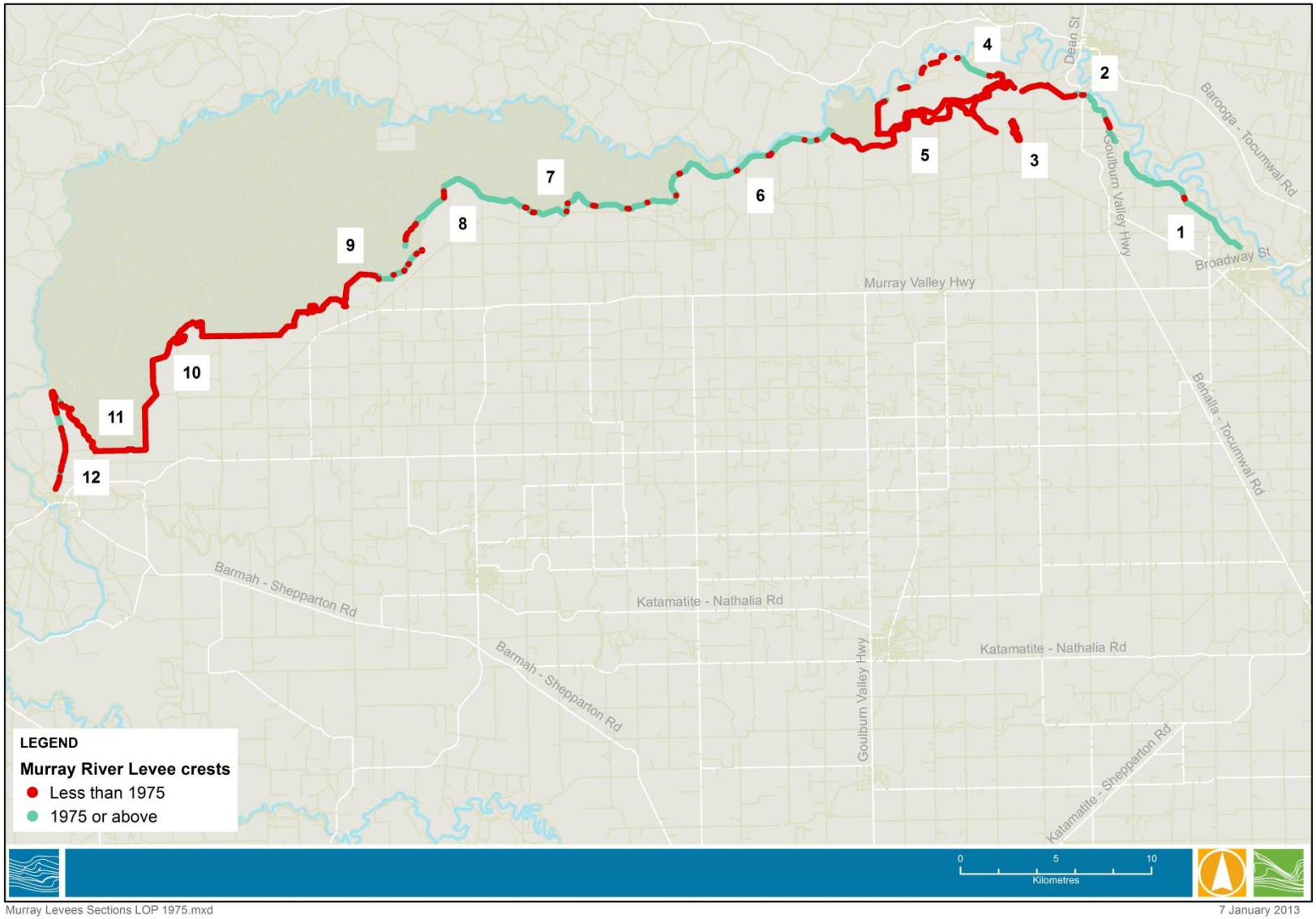

Figure 3-8 Map of Murray River levees crest levels compared to 1975 levels (Due to the scale of mapping, points overlap with < 1975 level taking precedence)

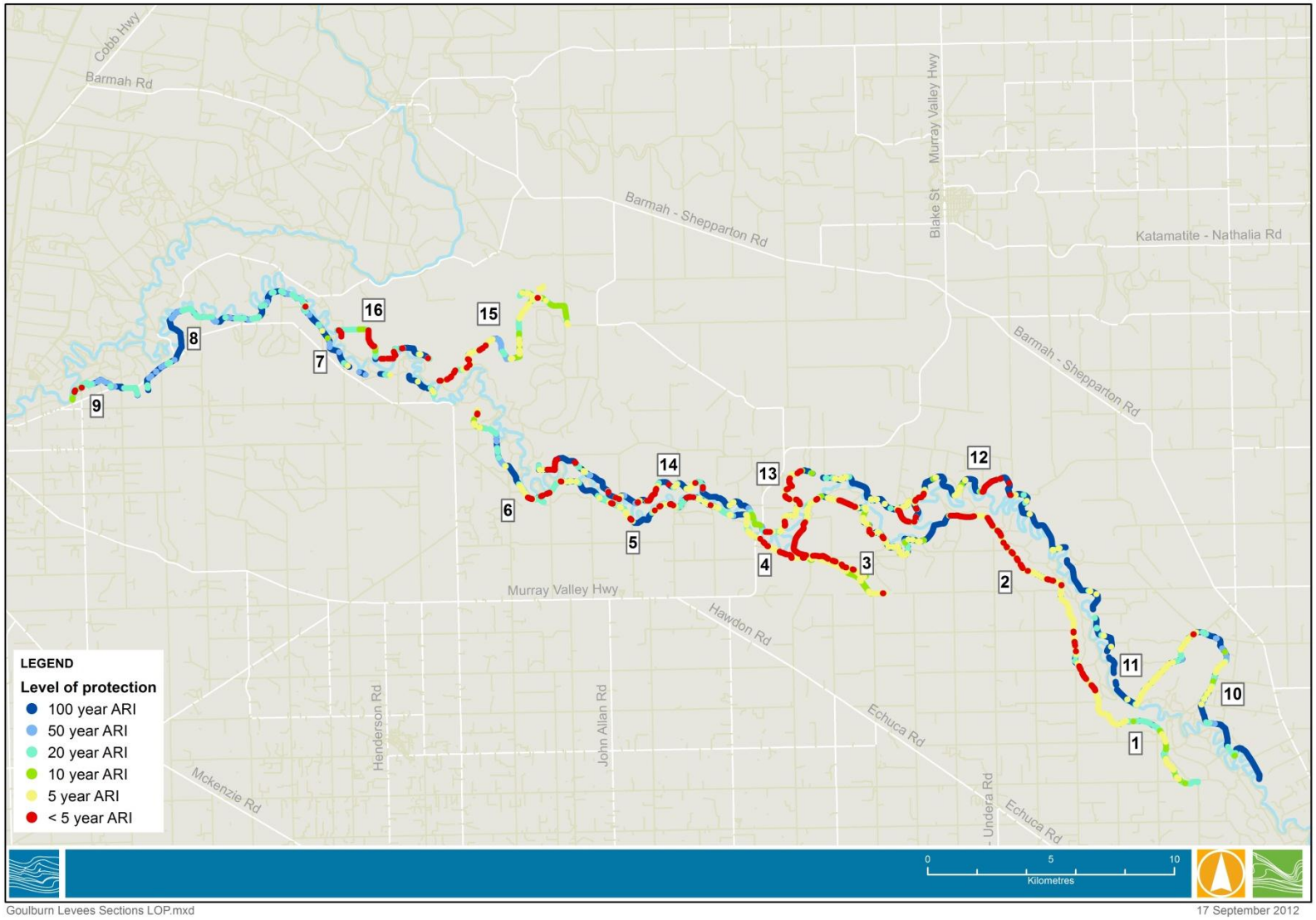

Figure 3-9 Map of level of protection of Goulburn River levees (Due to the scale of mapping, points overlap with the lowest LOP taking precedence)

The total length of Murray River levees with a level of protection below the 1975 level is 67.5 km. This represents 58% of the length of the Murray River levees surveyed. The distribution of these sections is shown in Figure 3-5 where it can be observed that significant lengths along 8 of the 12 sections are below the 1975 level. A minimum level has been nominally assigned to each section to estimate the capital works cost to provide a minimum LOP. This approach has identified over 26.5 km of works with over 80% of this located in Sections 2,3,4 and 5 (Table 3-3). This analysis does not include consideration of the points of weakness data which has identified discrete points of lower levee crests and other potential points of weakness. During flood events overtopping, leaking and failure is likely to occur in an unpredictable fashion regardless of the nominal minimum Level of Protection.

Table 3-3 Capital cost estimates for a minimum LOP for the Murray River Levees[3]

Section	Minimum LOP	Length of levee < minimum LOP (m)	Estimated capital cost to provide minimum LOP
1	1975	83	$70,409
2	20 year ARI	3298	$1,640,316
3	20 year ARI	4083	$1,385,006
4	20 year ARI	9758	$3,189,582
5	20 year ARI	5122	$1,618,745
6	1975	200	$74,078
7	1975	413	$151,934
8	1975	477	$177,147
9	2010	1067	$213,776
10	2010	1997	$492,841
11	2010	53	$16,406
12	2010	119	$28,012
Total		**26,670**	**$9,058,251**

[3] The capital costs are initial estimates only and do not include project management, labour and associated study and contingency costs. The capital works assume cutting the existing levee and replacing with new fill. The Volume of the cut is assumed to be the same as the volume of the new fill.

Works would be required along 12.2 km of the Goulburn River levees to bring all levees up to a minimum standard level of protection of a 5 year ARI flood event (8% of the levees) with an estimated capital cost of works to be in the order of $6 million. This analysis does not include consideration of the points of weakness data which has identified discrete points of lower levee crests and other potential points of weakness. In addition, the Goulburn River levees would need to be significantly modified in order to provide a uniform level of protection (Water Technology 2005). This is because the levees need to be modified to enable a hydraulically balanced system between the levee system and its floodplain areas.

Table 3-4 Capital cost estimates for a minimum LOP for the Goulburn River Levees[4]

Section	Minimum LOP	Length of levee < minimum LOP (m)	Estimated capital cost to provide minimum LOP
1	5 year ARI	788	$492,501
2	5 year ARI	1,582	$767,260
3	5 year ARI	3,091	$1,593,919
4	5 year ARI	610	$343,735
5	5 year ARI	713	$372,542
6	5 year ARI	50	$18,024
7	5 year ARI	9	$2,724
8	5 year ARI	0	$-
9	5 year ARI	73	$34,245
10	5 year ARI	20	$10,724
11	5 year ARI	0	$-
12	5 year ARI	815	$379,983
13	5 year ARI	1,713	$920,212
14	5 year ARI	1,089	$585,101
15	5 year ARI	336	$104,940
16	5 year ARI	1,283	$358,357
Total		**12,172**	**$5,984,266**

[4] The capital costs are initial estimates only and do not include project management, labour and associated study and contingency costs. The capital works assume cutting the existing levee and replacing with new fill. The Volume of the cut is assumed to be the same as the volume of the new fill.

4. POINTS OF WEAKNESS

Points of weakness (POW) are defined locations along a 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 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 Tables 4-1 and 4-2. Photo examples of many types identified in the field are provided in Appendix C.

Table 4-1 Point of weakness types

Type	Feature
Crest	Narrow Crest
Culvert	Culvert
Erosion	Ants Nest Cracks Poor Material Pugging Rilling
Hole	Erosion Fallen tree Rabbit Burrow Sink Hole Wheel Ruts
Low Crest	Road Crossing
Other	Recent Works No Vegetation Overtopping
Pipe	Pipe
River Bank	Outside Straight
Structure	Stay Electricity Supply Pole Dam
Trees	Mature in Bank Mature in Crest Sapling in Bank Sapling in Crest Stump in Bank Other (eg.Root)

Table 4-2 Point of weakness threat table

POW Threat
Minor to moderate potential
High to very high potential
Moderate (current)
High current (current)
Very high (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, determined by aerial photograph and LiDAR DEM interpretation were assigned in accordance with the ratings and descriptions provided in Table 4-3. The minor, moderate and major classes have been adopted from the Bureau of Meteorology's flood warning definitions.

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.
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.

A GIS data set was developed for consequence and all points of weakness were assigned a consequence rating.

4.1.4 Likelihood of failure

The likelihood of levee failure due to a point of weakness was assessed for each point of weakness feature listed in Table 4-1. It was not possible to assess individual POW due to the large number of locations collected during the survey. The likelihood of failure assessment estimated the likelihood of failure of a POW classification rather than individual POW features. This allowed a standardised rapid assessment.

The relative likelihood of failure for each weakness combination was determined in accordance with the ratings and descriptions provided in Table 4-4. The likelihood of levee failure due to a point of weakness assumed a planning horizon of 20 years and an imminent failure water level of 300 mm below the existing crest level (as defined in the standardised levee assessment method). This assessment is quite subjective as it requires an estimate of both the likelihood of a flood event occurring and also 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.

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	Moderate	Moderate likelihood that impact 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.

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.

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 Moderate	**Low**	**Low**	**Medium**	**Medium**	**High**
D Unlikely	**Low**	**Low**	**Low**	**Medium**	**Medium**
E Rare	**Low**	**Low**	**Low**	**Low**	**Medium**

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.

4.2 Results

4.2.1 Risk analysis

The risk assessment for each feature is summarised by sections for the Murray River levees (Figure 4-1) and for the Goulburn River levees (Figure 4-2). Summary tables of the data are provided in Appendix A, Tables A-3 and A-4. It should be noted that some POW occur in clusters that could change the risk profile for that section of levee, i.e. the combined risk of multiple POW in close proximity to each other may be different to the sum of individual POW risks. However this study has considered each POW separately and has not considered the cumulative risk as each site would require a separate investigation which is beyond the scope of this study.

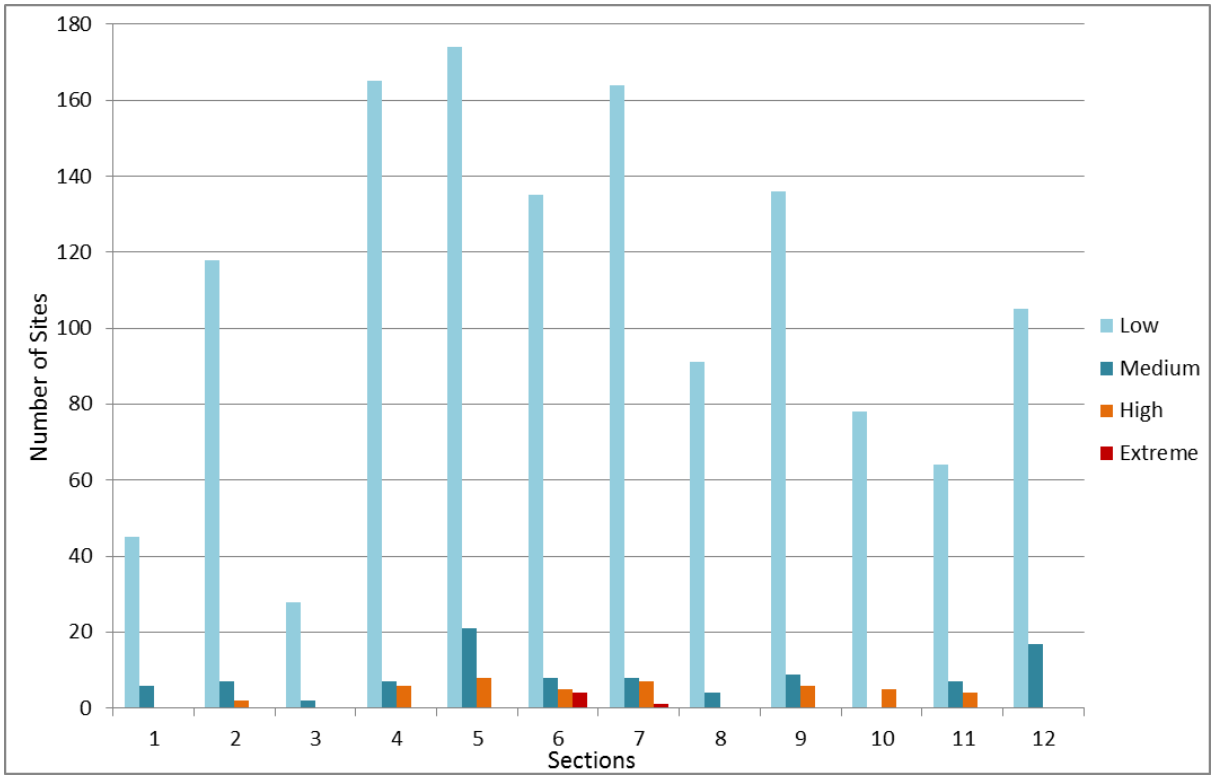

Figure 4-1 Points of weakness risk analysis for Murray River levees

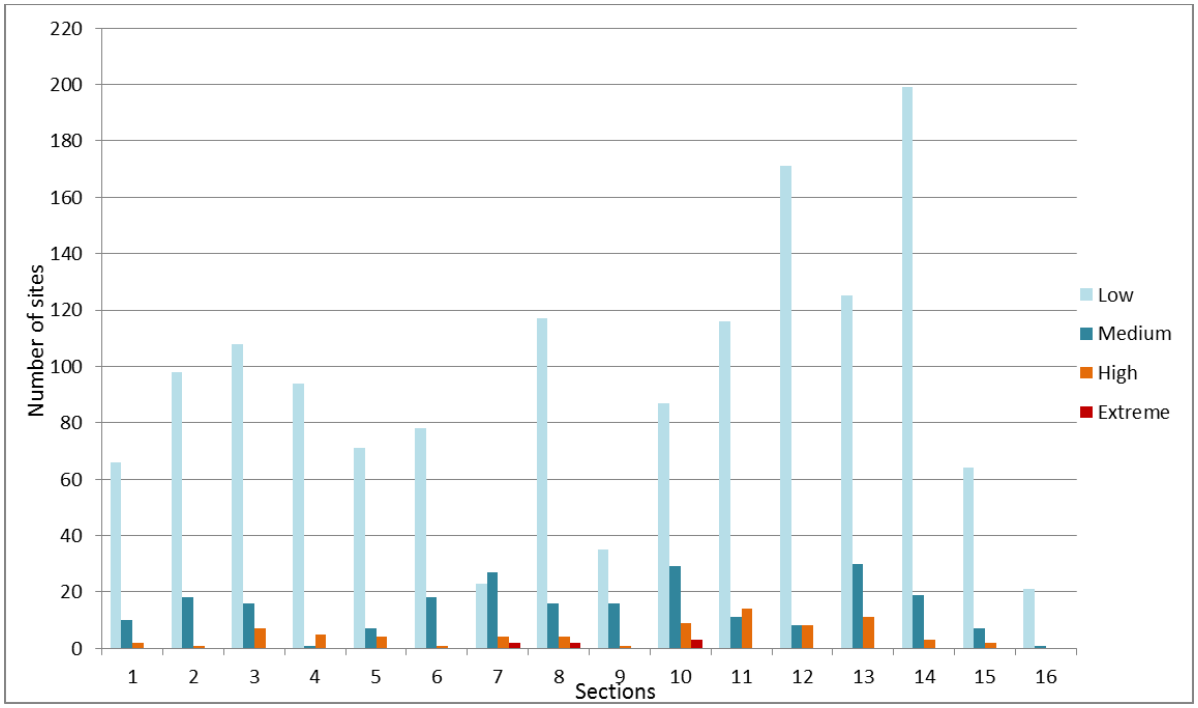

Figure 4-2 Points of weakness risk analysis for Goulburn River levees

4.2.2 Priority Points of Weakness

The priority POW sites were selected as the sites with either an extreme or high risk rating. Sites identified with extreme or high risk generally correspond with areas where a breach has occurred in the past and it has been repaired or where there is a discrete site with a low crest. Of the more than 3,000 POW sites identified in the field, 131 sites and approximately 1 km of linear features have been ranked as extreme or high risk:

- 48 sites for the Murray River levees; and
- 83 sites and 943 m for the Goulburn River levees

The distribution of the POW sites and linear features are shown in Figures 4-3 and 4-4.

The priority points occur on levees within private and public land. The breakdown of sites on private land is as follows:

- 14 extreme or high risk sites are situated on private land for the Murray River levees (29% of high priority sites); and
- 29 extreme or high risk sites are situated on private land for the Goulburn River levees (35% of high priority sites).

Table 4-7 Summary of location of extreme and high risk sites

Levee system	Number within Private land	Number within Public Land
Murray River	14	34
Goulburn River	29	54

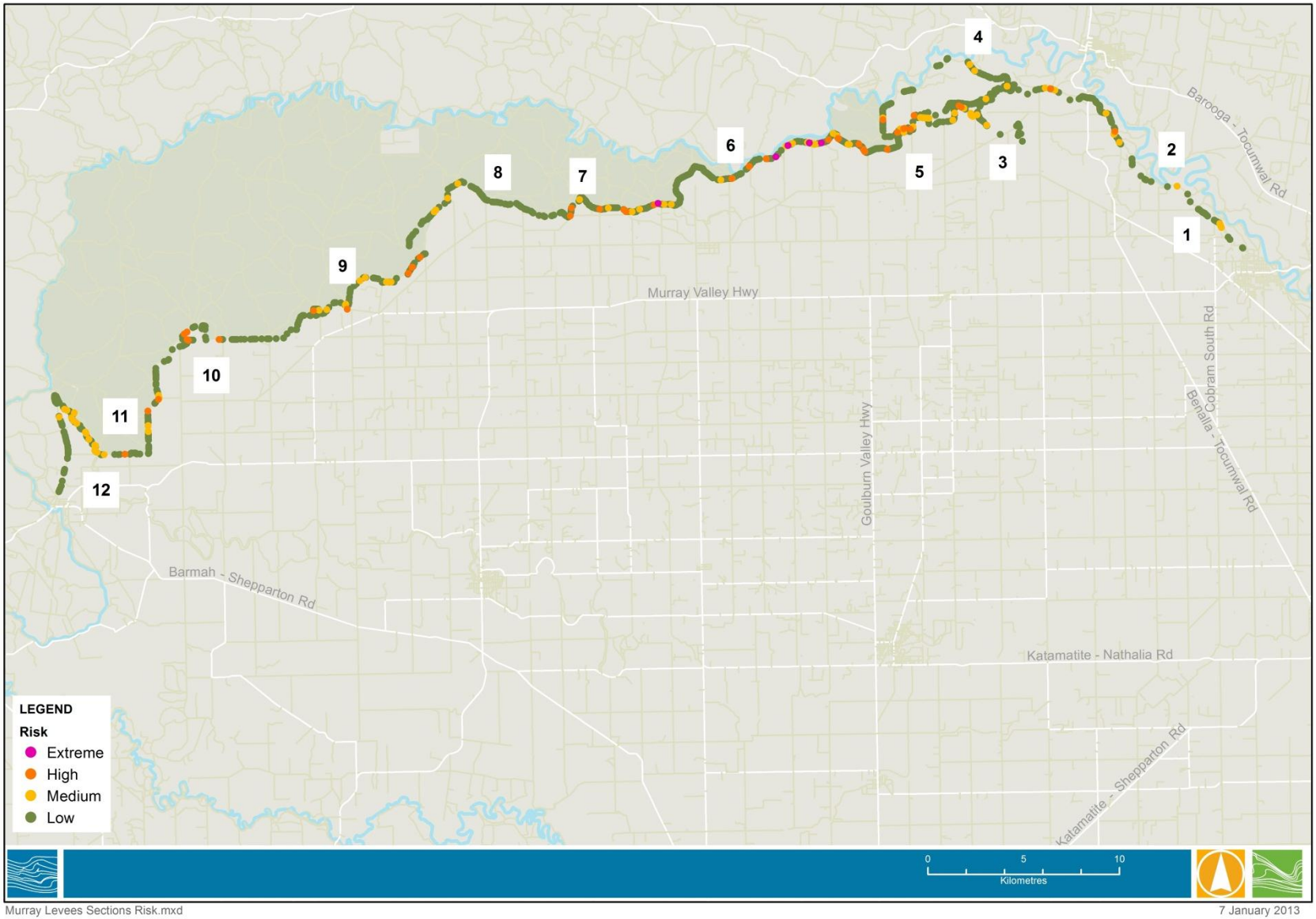

Figure 4-3 Points of weakness risk mapping for the Murray River levees. (Due to the scale of mapping, points overlap with the highest risk taking precedence)

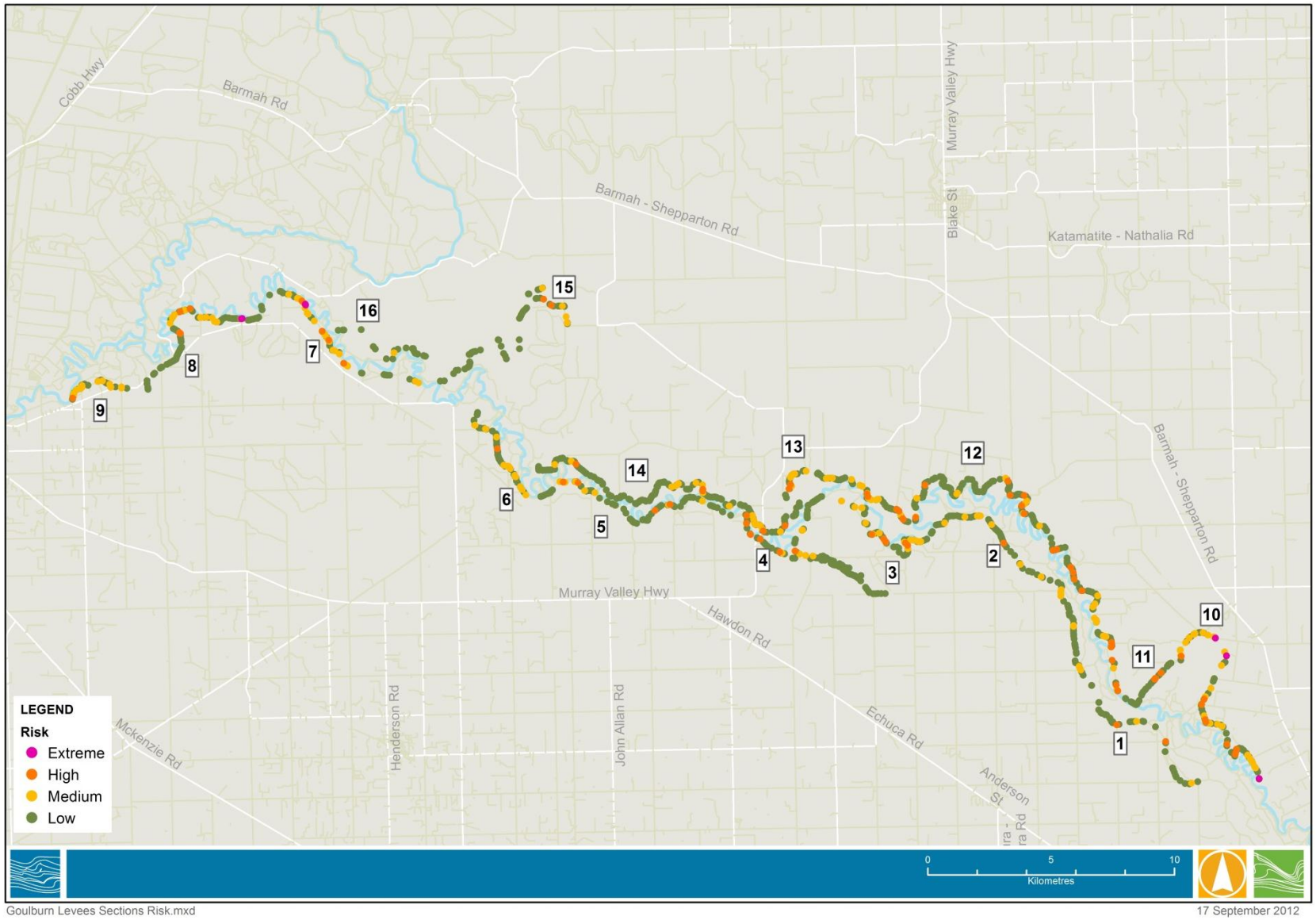

Figure 4-4 Points of weakness risk mapping for the Goulburn River levees. (Due to the scale of mapping, points overlap with the highest risk taking precedence)

5. COSTING

5.1 Methodology

Indicative cost estimates were prepared for each of the prioritised sites and sections of levee where works were deemed necessary to bring the levee up to a consistent standard of protection. The cost estimates have been prepared within the context of this project's broad objectives and aims and have been derived from the survey information and photographs collected at the time of survey. Whilst the levee survey information and associated photographs are quite detailed, the magnitude of each individual priority POW can be difficult to discern from the available information. As such the cost estimates are considered preliminary only and should be confirmed or refined with detailed site visits and survey.

The nominated works activities associated with the prioritised sites and sections of levee and indicative cost estimates have been broadly identified as either crest maintenance works or levee replacement works. Tree removal works have also been identified where it was considered necessary to undertake the crest maintenance or levee replacement works. The nominated works have been based on identified weaknesses in the levee system, not wholesale improvements to an entire length of levee. The indicative cost estimates assumed that the nominated works activities would involve the maintenance and/or replacement of a conventional earth bank levee. The cost estimates did not take into account cost efficiencies associated with addressing non-priority issues within close proximity to priority sites/sections.

The cost estimate process involved approximating a volume and plan-form area for each of the prioritised sites and sections of levee, as provided in Appendix A (Tables A-5 and A-6). This process involved approximating a length and height of maintenance/repair works derived from the survey information and photographs collected at the time of survey. The volume and plan-form area estimates assumed batter slopes of 2.5(H):1(V) and a crest width of 2 m. Cost estimates for each priority site and sections of levee have been based on unit costs provided in Table 5-1. The works activities identified in Table 5-1 have been selected based on the design and construction considerations detailed in Department of Natural Resources and Environment (2002). The unit rates identified in were determined with consideration of:

- Melbourne Water's standard rates for earthworks and pipe/headwall construction costs.
- Rawlinsons Australian Construction Handbook Rates
- Comparison to cost estimates for similar mitigation works prepared by Water Technology in comparable geographic regions.

Table 5-1 Works unit costs

Item	Unit	Rate
Excavation	$/m3	10
Fill	$/m3	25
Top Soil	$/m2	17
Grassing	$/m3	1
Labour	$/hour	80

5.2 Results

A summary of the costs for the priority sites is provided below, with more detail provided in Appendix A (Tables A-5 and A-6). The works required assigned to the priority sites include:

- Replace levee section
- Crest Maintenance
- Construct new levee section (where the levee appears to be missing)
- Tree removal

Initial and annual maintenance costs are presented in Table 5-2 allowing for contingency and planning costs and annual maintenance for the works. . A 40% contingency cost has been added along with an annual maintenance cost of 1.5%.

Table 5-2 Summary of estimated costs of priority works

Item	Description	Murray River	Goulburn River
A	Capital cost	$243,326	$1,230,945
B	Engineering Fee @ 15% of A	$36,499	$184,641
C	Cultural Heritage @ 5% of A	$12,166	$61,547
D	Administration Fee @ 9% of (A+B+C)	$26,279	$132,941
E	Contingency @ 40% of A	$97,330	$492,378
	TOTAL	**$415,601**	**$2,102,452**
	Annual Maintenance @ 1.5% of A	$3,650	$18,464

The priority works and **capital costs** are not evenly distributed across the levees as shown in Figures 5-1 and 5-2. The priority levee sections in terms of **capital costs** are Sections 3 and 12 of the Goulburn River levees and Sections 11 of the Murray River levees.

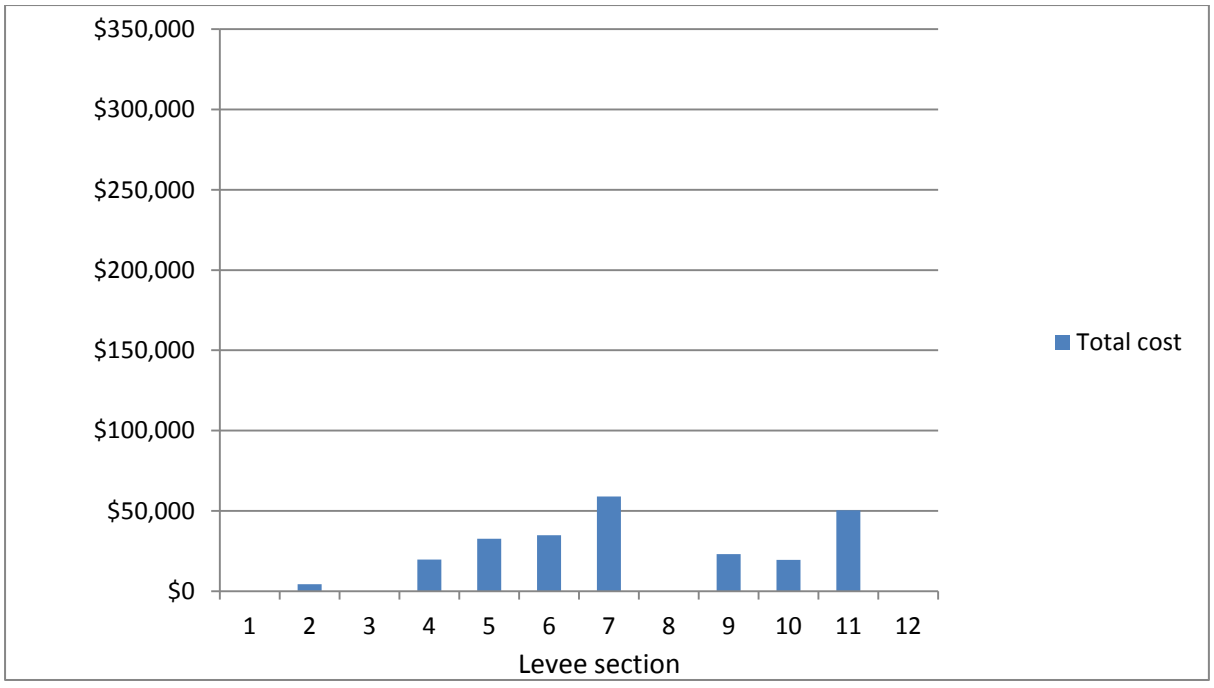

Figure 5-1 Summary of capital costs for priority works per section for the Murray River levees

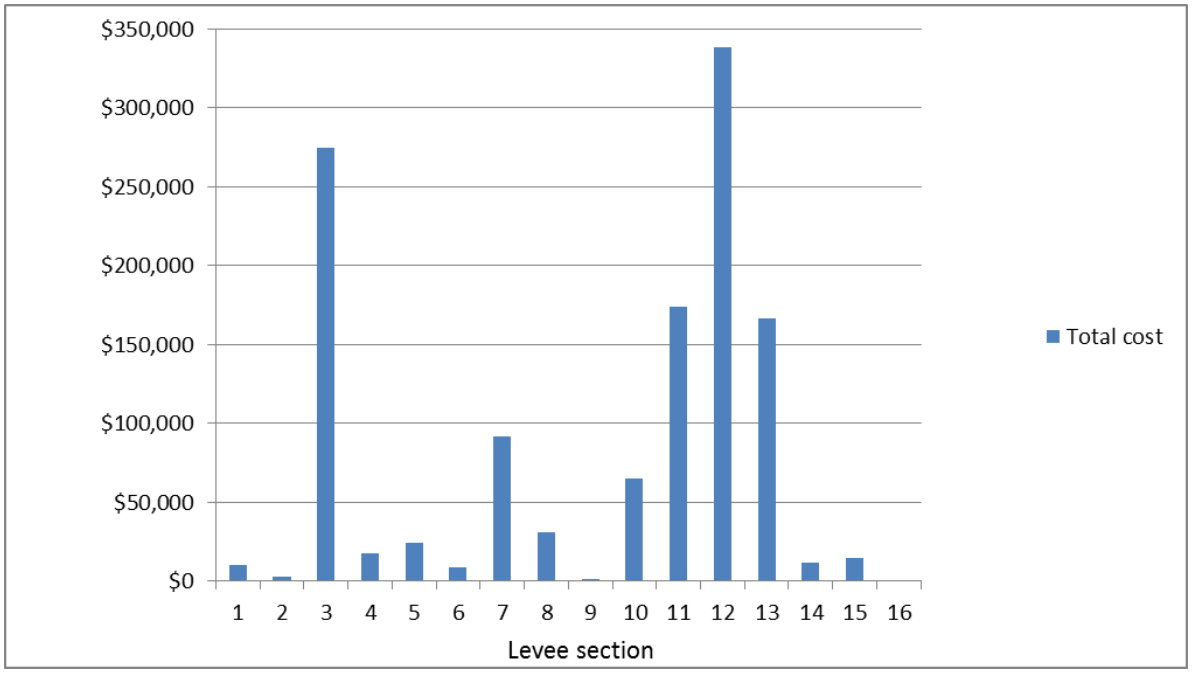

Figure 5-2 Summary of capital costs for priority works per section for the Goulburn River levees

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Limitations

There are a number of assumptions and limitations that should be understood when considering the outputs of this study as follows:

- No geotechnical analysis of the POW has been undertaken. Further analysis should be considered prior to any significant repair or maintenance works on the system.
- The grading of levees in this project was by visual assessment with no penetrative tests carried out. Potential levee performance issues such as leaking or piping failure as a result of poor construction techniques or materials are not able to be clearly identified by this process.
- Due to significant extent of levees surveyed in this project, the analysis of each individual site should only be considered preliminary, with associated indicative costings and identification of priority areas.
- The mapping in this project does not provide a definitive list of where and when the levees will fail but rather a sound basis for identifying relative risks and priorities for future actions.
- The costings provided in this report should be considered as indicative.

6.2 Conclusions

The information on land tenure along the levees provides a clear understanding of where these assets are located and highlights the challenges of developing future maintenance agreements.

The results show in general that the level of protection and condition of the levees both on the Goulburn and Murray Rivers is inconsistent along their length. This may be due to inconsistencies in their design and construction and/or due to differential deterioration over time. Whatever the reason it is clear that a large flood on the Goulburn River and/or River Murray would be likely to produce very uncertain results in terms of the performance of the levee system. Overtopping and failure is likely to occur in an unpredictable fashion, leading to difficulties in flood response and management.

Overall the results suggest that on the Goulburn River, the left (south) bank levee is generally lower than the opposite (north) side. This would indicate that during a large flood, levee failure to the south may be more likely than to the north. If this is not the intention of the levee scheme, then perhaps a fairer outcome would be to raise the height of the south levee to be similar to that of the north levee.

Whilst not part of this study, it is anecdotally understood that the NSW levees along the River Murray are generally of a higher performance standard than the Victorian ones. Hence the location of overtopping of the River Murray levee can be deduced by comparing the performance level longitudinally. The results for the River Murray levees suggest that the section downstream of Barham Forest generally has a lower level of protection than upstream of Barmah.

6.3 Recommendations

Whilst inconsistencies have been identified in the level of performance exhibited by the levees throughout the study area, it would be a significant undertaking to upgrade the system to achieve a uniform level of performance. For the Murray River levees, costs have been presented to bring the levees up to a consistent level of protection for each section, however unintended results are likely if the system is not upgraded in its entirety. In the case of the Goulburn River, costs have been presented to bring each section up to a minimum 5 year ARI level however the levees would need to be significantly modified in order to provide a uniform level of protection (Water Technology 2005).

This is because the levees need to be modified to enable a hydraulically balanced system between the levee system and its floodplain areas. This has been explored in the floodplain rehabilitation program study (Water Technology 2005).

A prioritised program of works to address the identified areas of significant weakness and greatest risk may be a more efficient use of any resources that may become available in the future.

Further it may be desirable to develop a minimum standard of performance to avoid failure of some levees at a relatively low threshold compared to the rest of the system.

The results of this study could be used to develop a pilot maintenance program to address some of the highlighted areas of greatest risk on private and public land. Outcomes of such a program could prove valuable in assessing the broader requirements of a system-wide approach to maintaining the levee system.

In order to gain a better understanding of the long-term trajectory of the levee system and the impact of erosion, weathering and wear processes, a limited monitoring program could also be considered, with repeat surveys at fixed locations along with photos to record any changes over time. These results could be extrapolated over the system to provide a better understanding of the long-term maintenance requirements of the levee system.

7. REFERENCES

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Standards Australia (2004) AS/NZS 4360:2004 Risk Management. Sydney, Standards Australia.

Water Technology (2005). Lower Goulburn Floodplain Rehabilitation Scheme hydraulic modelling study. Goulburn Broken CMA.

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Water Technology (2012). Murray River Regional Flood Study. Goulburn Broken CMA, Berrigan Shire and Moira Shire.

APPENDIX A ANALYSIS RESULTS

Table A-1 Murray River levees: assigned standard level of protection.

Location	Section	Level of protection	Length (m)	Percentage of section
Upstream of Barmah Forest	1	100 year ARI	6040	70
		50 year ARI	2496	29
		20 year ARI	114	1
	2	100 year ARI	2871	27
		50 year ARI	3586	34
		20 year ARI	770	7
		< 20 year ARI	3298	31
	3	20 year ARI	3	0
		< 20 year ARI	4083	100
	4	100 year ARI	3773	25
		50 year ARI	468	3
		20 year ARI	1121	7
		< 20 year ARI	9758	65
	5	100 year ARI	653	6
		50 year ARI	1843	16
		20 year ARI	4145	35
		< 20 year ARI	5122	44
	6	100 year ARI	2016	20
		50 year ARI	195	2
		20 year ARI	1444	14
		< 20 year ARI	98	1
Downstream of Barmah Forest	6	1975	6442	62
		1993	0	0
		2010	66	1
		< 2010	29	<1
	7	1975	9873	96
		1993	9	<1
		2010	23	<1
		< 2010	381	4
	8	1975	8310	95
		1993	154	2
		2010	199	2
		< 2010	124	1
	9	1975	4161	35
		1993	1573	13
		2010	5061	43
		< 2010	1067	9
	10	1975	82	<1
		1993	5183	50
		2010	3048	30
		< 2010	1997	19
	11	1975	377	5
		1993	1818	23
		2010	5642	72
		< 2010	53	1
	12	1975	4630	43
		1993	0	0
		2010	6065	56
		< 2010	119	1

Table A-2 Goulburn River levees: assigned standard level of protection.

Section	Level of protection	Length (m)	Percentage of section
1	100 year ARI	870	9
	50 year ARI	432	4
	20 year ARI	2843	28
	10 year ARI	724	7
	5 year ARI	4353	43
	< 5 year ARI	788	8
2	100 year ARI	3334	33
	20 year ARI	619	6
	10 year ARI	187	2
	5 year ARI	4279	43
	< 5 year ARI	1582	16
3	100 year ARI	2523	22
	50 year ARI	226	2
	20 year ARI	1086	9
	10 year ARI	704	6
	5 year ARI	4005	34
	< 5 year ARI	3091	27
4	100 year ARI	639	8
	50 year ARI	112	1
	20 year ARI	885	11
	10 year ARI	1752	21
	5 year ARI	4416	52
	< 5 year ARI	610	7
5	100 year ARI	3981	40
	50 year ARI	730	7
	20 year ARI	3095	31
	5 year ARI	1482	15
	< 5 year ARI	713	7
6	100 year ARI	3277	52
	50 year ARI	798	13
	20 year ARI	1438	23
	10 year ARI	186	3
	5 year ARI	526	8
	< 5 year ARI	50	1
7	100 year ARI	4596	74
	50 year ARI	1378	22
	20 year ARI	244	4
	10 year ARI	13	<1
	5 year ARI	13	<1
	< 5 year ARI	9	<1
8	100 year ARI	5312	67
	50 year ARI	1589	20
	20 year ARI	1023	13
9	100 year ARI	1187	33
	50 year ARI	1410	39

Section	Level of protection	Length (m)	Percentage of section
9 (cont.)	20 year ARI	887	24
	10 year ARI	80	2
	5 year ARI	15	< 1
	< 5 year ARI	73	2
10	100 year ARI	6632	66
	50 year ARI	1281	13
	20 year ARI	1177	12
	10 year ARI	153	2
	5 year ARI	758	8
	< 5 year ARI	20	<1
11	100 year ARI	6376	72
	50 year ARI	383	4
	20 year ARI	556	6
	10 year ARI	355	4
	5 year ARI	1202	14
12	100 year ARI	8593	77
	20 year ARI	404	4
	10 year ARI	367	3
	5 year ARI	954	9
	< 5 year ARI	815	7
13	100 year ARI	5021	46
	50 year ARI	50	<1
	20 year ARI	969	9
	10 year ARI	258	2
	5 year ARI	3011	27
	< 5 year ARI	1713	16
14	100 year ARI	8497	66
	50 year ARI	693	5
	20 year ARI	1256	10
	10 year ARI	333	3
	5 year ARI	919	7
	< 5 year ARI	1089	9
15	100 year ARI	379	4
	50 year ARI	1413	14
	20 year ARI	3416	33
	10 year ARI	1954	19
	5 year ARI	2914	28
	< 5 year ARI	336	3
16	100 year ARI	1460	27
	50 year ARI	385	7
	20 year ARI	1563	28
	10 year ARI	421	8
	5 year ARI	384	7
	< 5 year ARI	1283	23

Table A-3 Summary of points of weakness risk analysis for the Murray River levees

Note: due to overlapping linear features, lengths reported may exceed length of actual levee. For example for a length of levee, two weaknesses have been reported: Erosion due to rilling and mature trees in bank.

Section	Risk	Number of sites	Length of linear features (m)
1	Low	45	2,266
	Medium	6	-
2	Low	118	6,166
	Medium	7	-
	High	2	-
3	Low	28	553
	Medium	2	9
4	Low	165	1,982
	Medium	7	276
	High	6	-
5	Low	174	1,135
	Medium	21	231
	High	8	-
6	Low	135	1,123
	Medium	8	44
	High	5	-
	Extreme	4	-
7	Low	164	3,270
	Medium	8	73
	High	7	-
	Extreme	1	-
8	Low	91	2,085
	Medium	4	-
9	Low	136	10,590
	Medium	9	-
	High	6	-
10	Low	78	11,706
	High	5	-
11	Low	64	4,413
	Medium	7	146
	High	4	-
12	Low	105	2,426
	Medium	17	675
	High	0	-
	Extreme	0	-

Table A-4 Summary of points of weakness risk analysis for the Goulburn River levees

Section	Risk	Number of sites	Length of linear features (m)
1	Low	66	5,485
	Medium	10	478
	High	2	-
2	Low	98	1,930
	Medium	18	154
	High	1	-
3	Low	108	10,834
	Medium	16	150
	High	7	327
4	Low	94	5,307
	Medium	1	-
	High	5	-
5	Low	71	3,555
	Medium	7	389
	High	4	-
6	Low	78	1,545
	Medium	18	84
	High	1	-
7	Low	23	3842
	Medium	27	1,588
	High	4	25
	Extreme	2	59
8	Low	117	4,125
	Medium	16	686
	High	4	-
	Extreme	2	-
9	Low	35	1,337
	Medium	16	395
	High	1	-
10	Low	87	3,300
	Medium	29	2,137
	High	9	-
	Extreme	3	37
11	Low	116	6,530
	Medium	11	22
	High	14	130
12	Low	171	8,670
	Medium	8	-
	High	8	308

Section	Risk	Number of sites	Length of linear features (m)
13	Low	125	5,313
	Medium	30	2
	High	11	57
14	Low	199	4282
	Medium	19	-
	High	3	-
15	Low	64	5,456
	Medium	7	1,275
	High	2	-
16	Low	21	3,664
	Medium	1	419

Note: due to overlapping linear features, lengths reported may exceed length of actual levee. For example for a length of levee, two weaknesses may have been reported: Erosion due to rilling and Mature trees in bank.

Table A-5 Costing of works for priority sites for the Murray levees

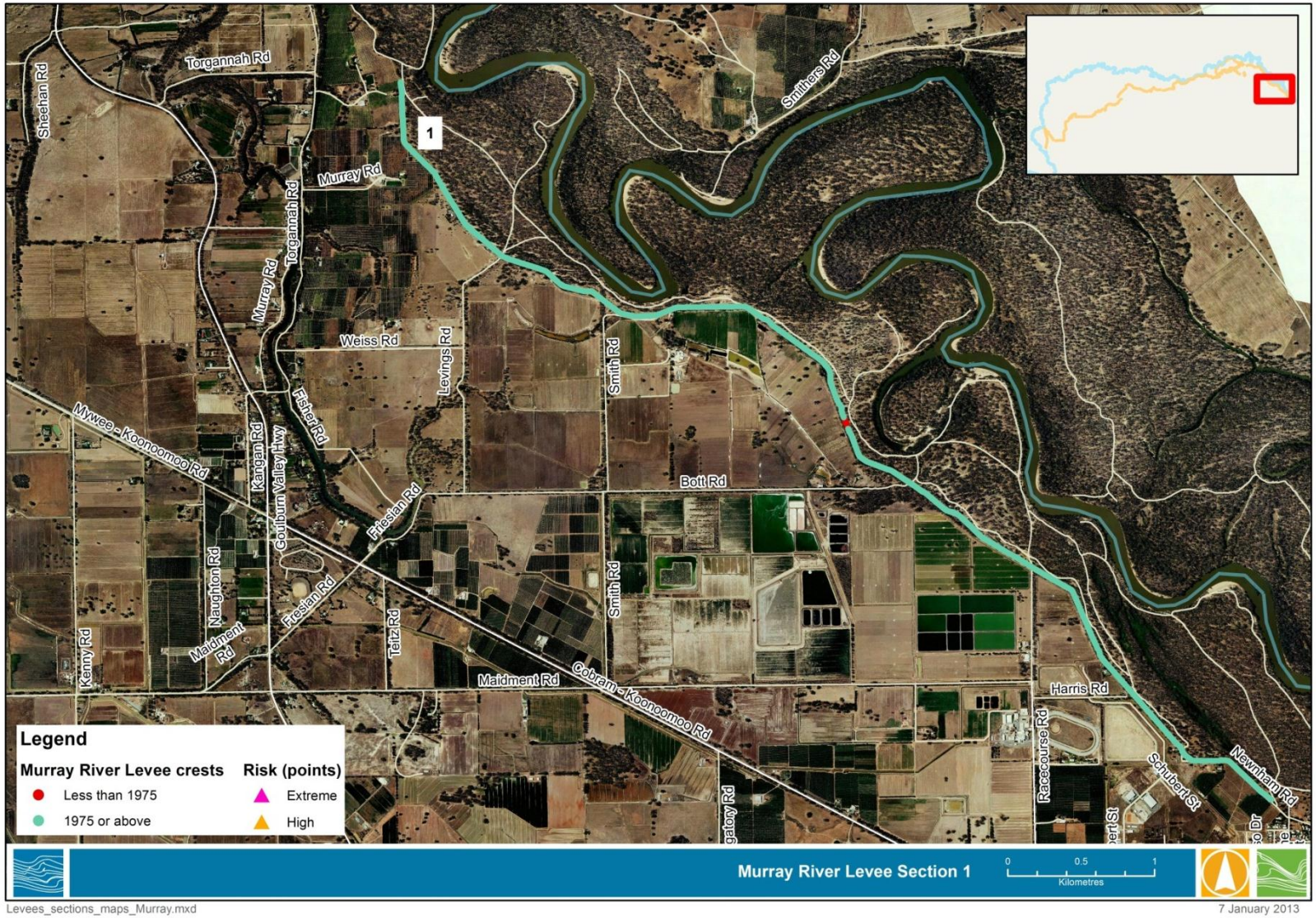
Section	Points of weakness		Linear features of weakness		Total cost
	Number of points	Cost of works	Length	Cost of works	
1					-
2	2	$4,378			$4,378
3					-
4	6	$19,608			$19,608
5	8	$32,626			$32,626
6	9	$34,838			$34,838
7	8	$59,009			$59,009
8					-
9	6	$23,008			$23,008
10	5	$19,406			$19,406
11	4	$50,453			$50,453
12					-

Table A-6 Costing of works for priority sites for the Goulburn levees

Section	Points of weakness		Linear features of weakness		Total cost
	Number of points	Cost of works	Length (m)	Cost of works	
1	2	$10,111			$10,111
2	1	$2,907			$2,907
3	7	$19,950	327	$254,520	$274,470
4	5	$17,442			$17,442
5	4	$23,769			$23,769
6	1	$8,721			$8,721
7	6	$62,037	59	$29,692	$91,729
8	6	$30,990			$30,990
9	1	$1,471			$1,471
10	12	$46,443	37	$18,097	$64,540
11	14	$49,254	130	$124,298	$173,552
12	8	$87,992	308	$250,498	$338,490
13	11	$115,682	57	$51,032	$166,714
14	3	$11,628			$11,628
15	2	$14,408			$14,408
16					-

APPENDIX B SECTION SUMMARIES

Levee system: Murray River ***Section: 1*** ***Length: 8.650 km***



Levee system: Murray River ***Section: 1*** ***Length: 8.650 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	6,040	70
50 year ARI	2,496	29
20 year ARI	114	1

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	-	-
Medium	6	-
Low	45	2,266

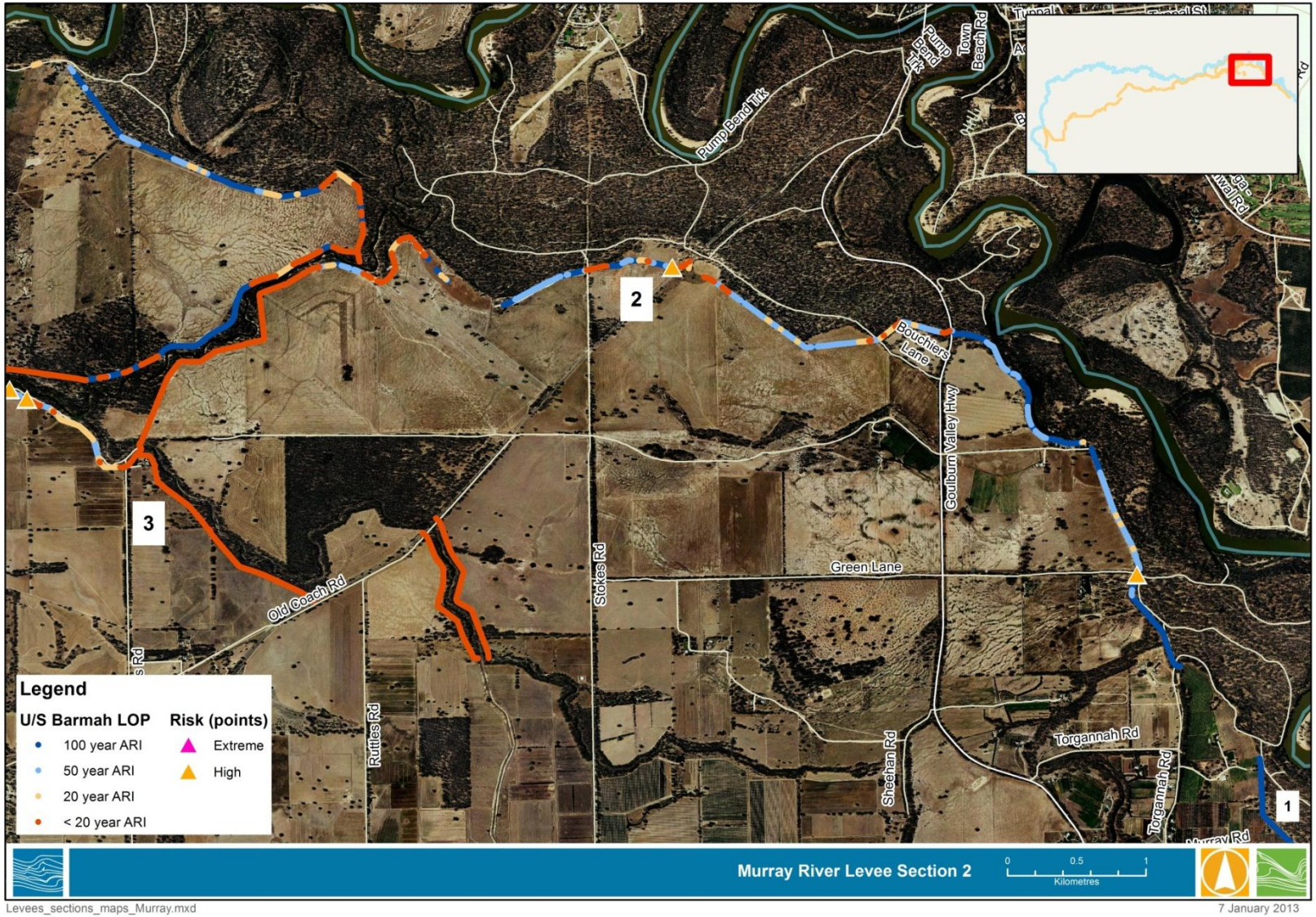
Crest comparison to 1975 level

Level of protection	Length (m)	%
1975 or above	8,567	99
Below 1975	83	1

Comment:

There are no high priority points of weakness identified for this section, however, works of < 100 m may be undertaken to bring the level of protection up to at least the 1975 level.

Levee system: Murray River ***Section: 2*** ***Length: 10.525 km***



Levee system: Murray River ***Section: 2*** ***Length: 10.525 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	2,871	27
50 year ARI	3,586	34
20 year ARI	770	7
< 20 year ARI	3,298	31

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	2	-
Medium	7	-
Low	118	6,166

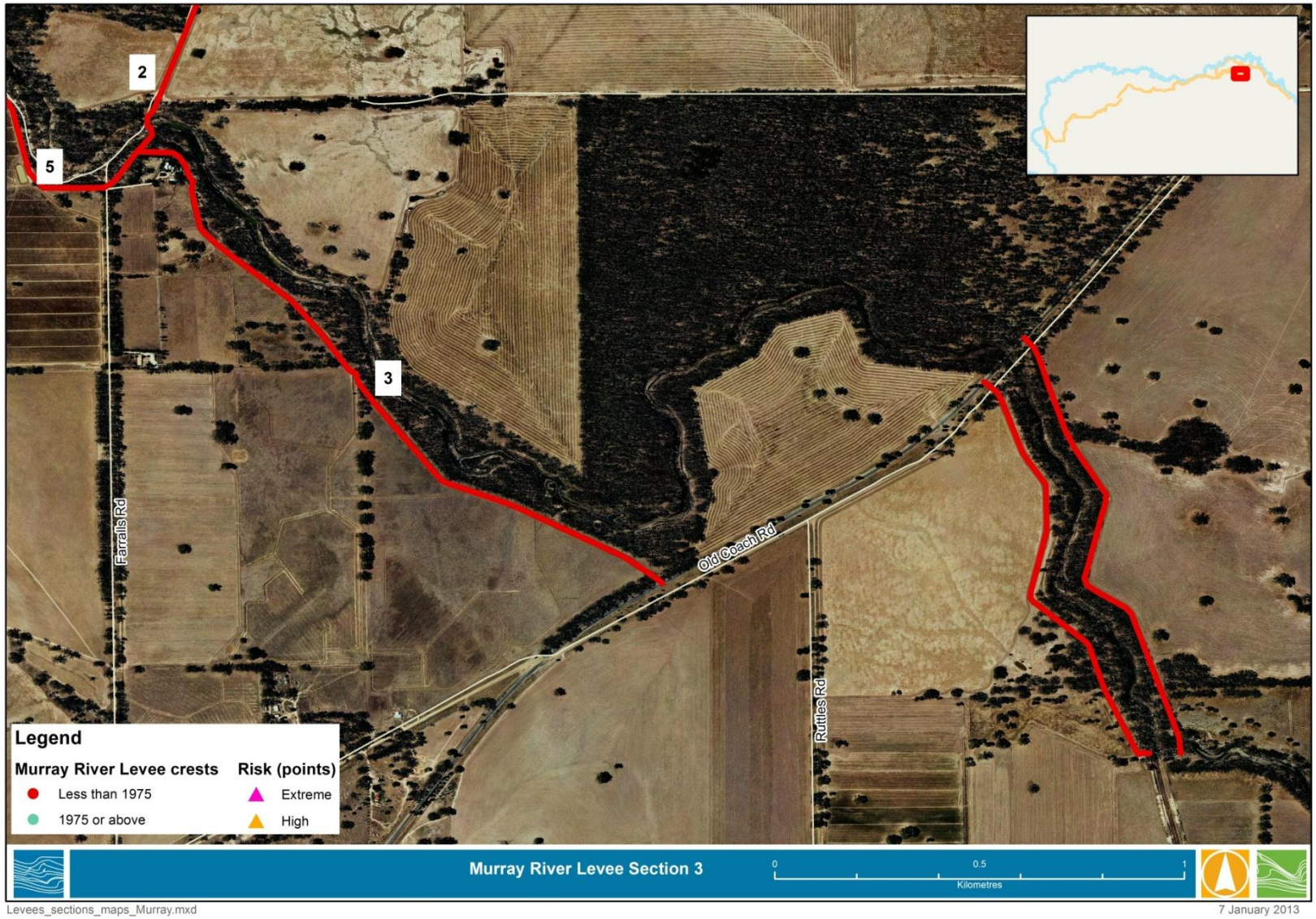
Crest comparison to 1975 level

Level of protection	Length (m)	%
1975 or above	4,027	38
Below 1975	6,498	62

Comment:

Significant works are required to bring the standard Level of Protection of this section up to a 20 year ARI level of protection or greater with works required along > 3 km of levee. In addition, this study has identified 2 discrete points of weakness that are a priority for works and the indicative cost for these works is ~$5,000.

Levee system: Murray River ***Section: 3*** ***Length: 4.086 km***



Levee system: Murray River ***Section: 3*** ***Length: 4.086 km***

Level of protection summary

Level of protection	Length (m)	%
20 year ARI	3	< 1
< 20 year ARI	40,83	100

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	-	-
Medium	2	9
Low	28	553

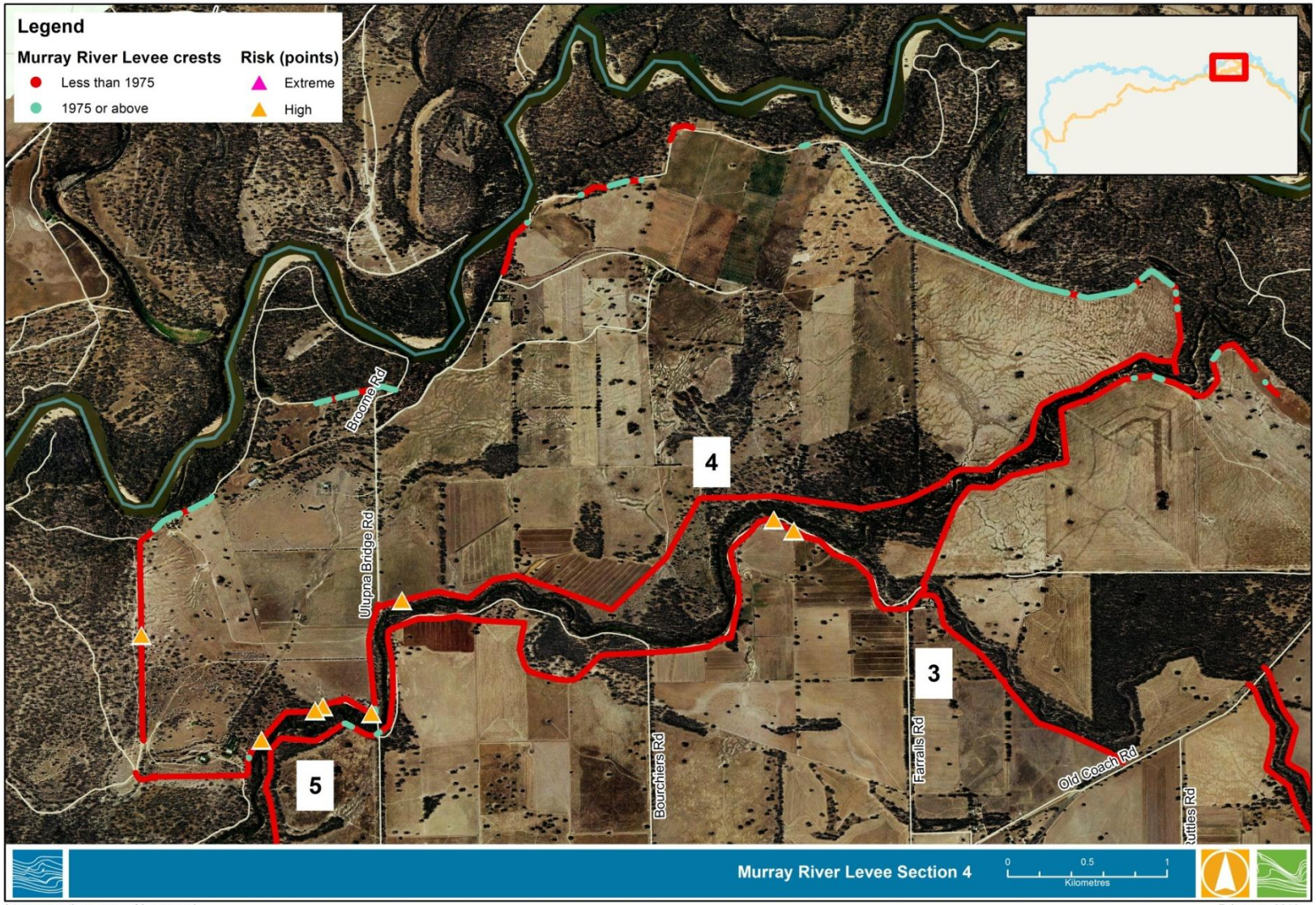
Crest comparison to 1975 level

Level of protection	Length (m)	%
1975 or above	-	-
Below 1975	4,086	100

Comment:

There are no high priority points of weakness identified for this section, and it is difficult to ascertain the standard level of protection for this section of levees as it is largely below the 20 year ARI and the 1975 level.

Levee system: Murray River ***Section: 4*** ***Length: 15.120 km***



Levee system: Murray River ***Section: 4*** ***Length: 15.120 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	3,773	25
50 year ARI	468	3
20 year ARI	1,121	7
< 20 year ARI	9,758	65

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	6	-
Medium	7	276
Low	165	1,982

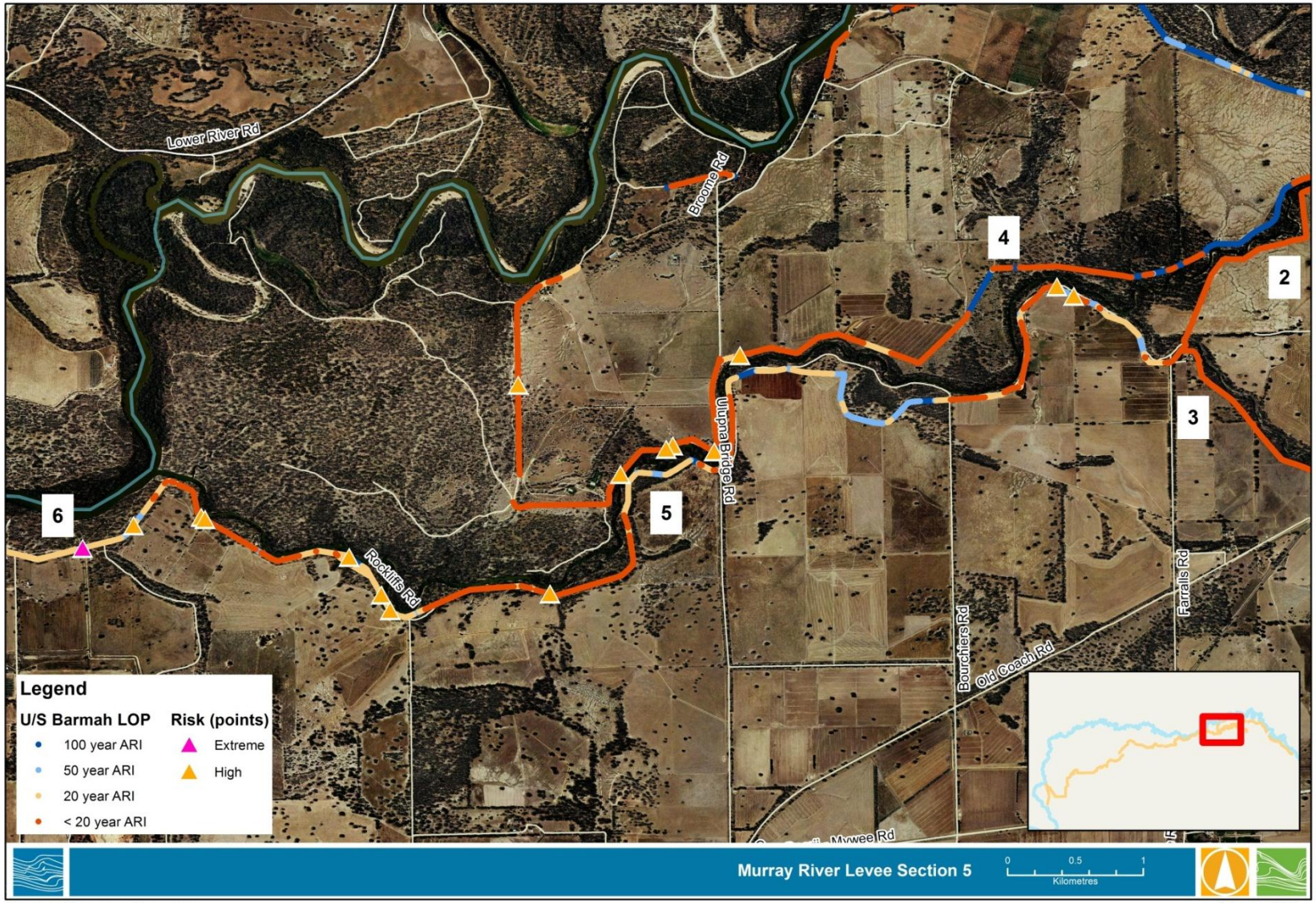
Crest comparison to 1975 level

Level of protection	Length (m)	%
1975 or above	3,327	22
Below 1975	11,793	78

Comment:

Extensive works are required to bring the standard Level of Protection of this section up to a 20 year ARI or 1975 level of protection or greater works required along ~ 10 km of levee. In addition, this study has identified 6 discrete points of weakness that are a priority for works and the indicative cost for these works is in the order of $20,000.

Levee system: Murray River ***Section: 5*** ***Length: 11.763 km***



Levee system: Murray River ***Section: 5*** ***Length: 11.763 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	653	6
50 year ARI	1,843	16
20 year ARI	4,145	35
< 20 year ARI	5,122	44

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	8	-
Medium	21	231
Low	174	1,135

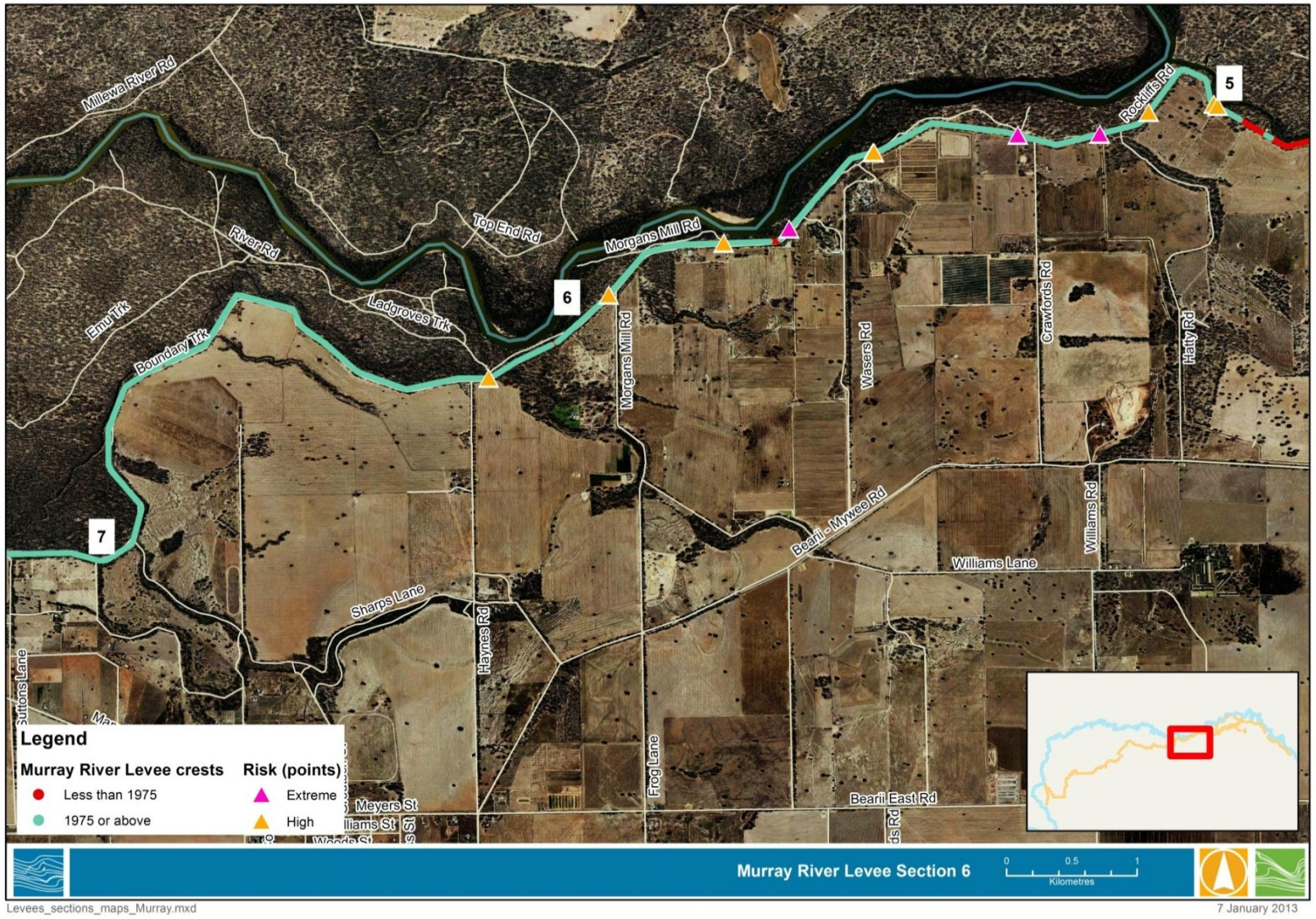
Crest comparison to 1975 level

Level of protection	Length (m)	%
1975 or above	1,224	10
Below 1975	10,539	90

Comment:

This section of level is largely below the 1975 level. Extensive works are required to bring the standard Level of Protection of this section up to a 20 year ARI level of protection or greater with works required along >5 km of levee. In addition, this study has identified 8 discrete points of weakness that are a priority for works and the indicative cost for these works is ~ $30,000.

Levee system: Murray River ***Section: 6*** ***Length: 3.753 km***



Levee system: Murray River ***Section: 6*** ***Length: 3.753 km***

Level of protection summary

Murray River Upstream of Barmah*

Level of protection	Length (m)	%
100 year ARI	2,016	20
50 year ARI	195	2
20 year ARI	1,444	14
< 20 year ARI	98	1

*Comparison with 1975 level: 105 m below 1975 level

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	4	-
High	5	-
Medium	8	44
Low	135	1,123

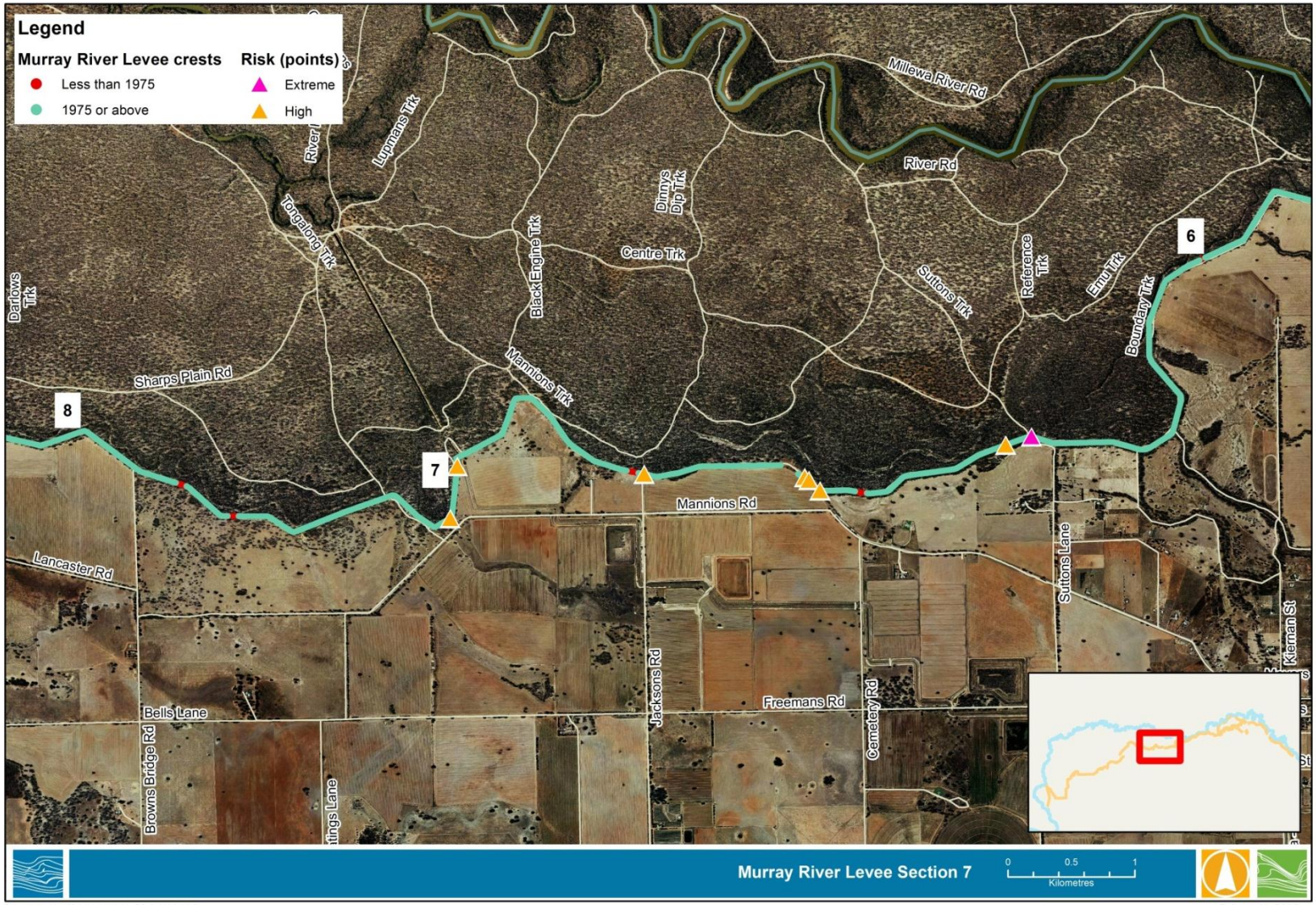
Murray River Downstream of Barmah

Level of protection	Length (m)	%
1975	6,442	39
2010	66	9
< 2010	29	0

Comment:

It is feasible to bring the standard Level of Protection of this section up to the 1975 level with works required along 200 m of levee. In addition, there are 9 discrete points identified for priority works and the indicative cost for these works is $35,000.

Levee system: Murray River ***Section: 7*** ***Length: 10.286 km***



Levee system: Murray River ***Section: 7*** ***Length: 10.286 km***

Level of protection summary

Level of protection	Length (m)	%
1975	9,873	96
1993	9	< 1
2010	23	< 1
< 2010	381	4

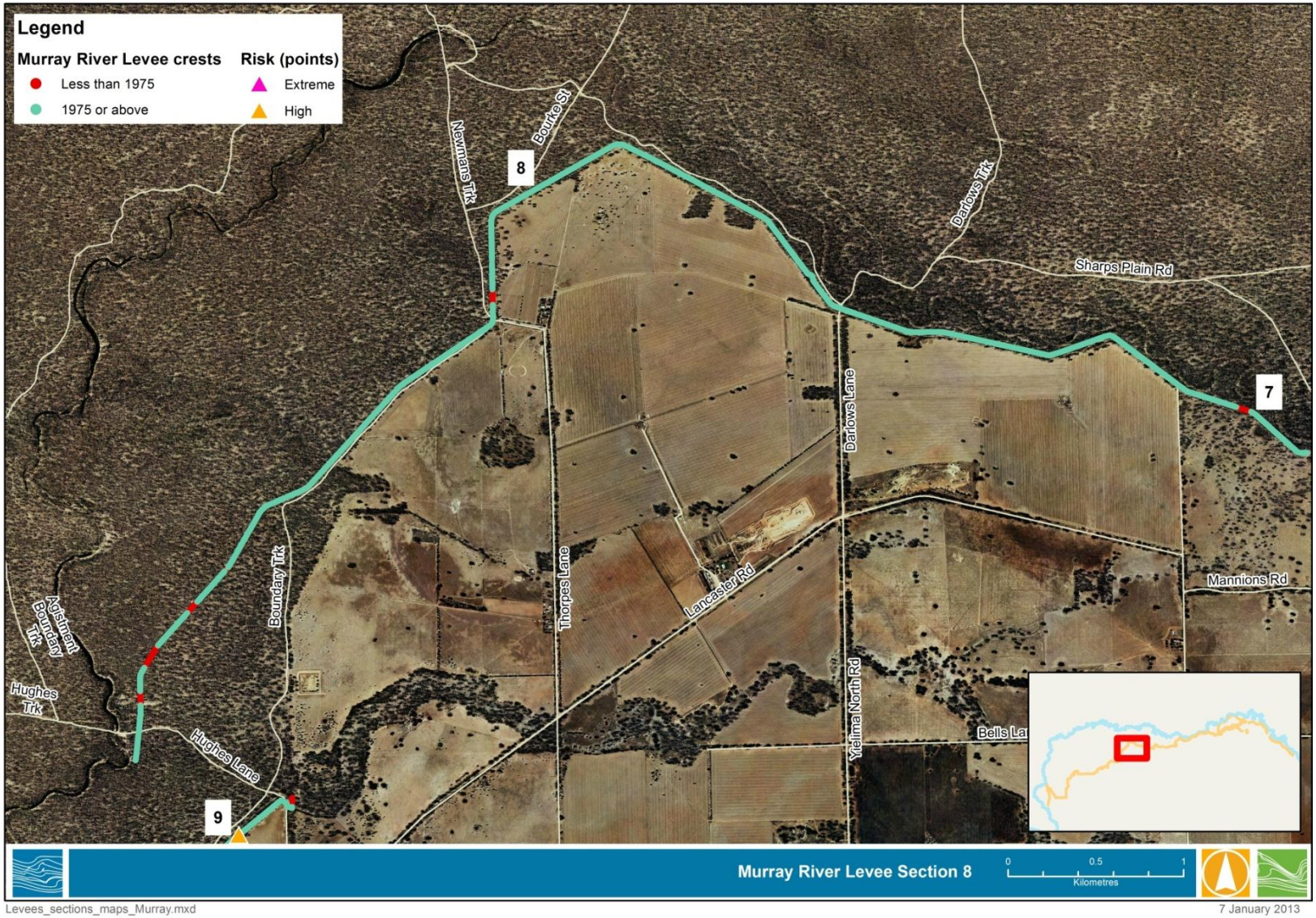
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	1	-
High	7	-
Medium	8	73
Low	164	3,270

Comment:

It is feasible to bring the standard Level of Protection of this section up to the 1975 level with works required along ~ 400 m of levee. In addition, there are 8 discrete points identified for priority works and the indicative cost for these works is ~$60,000.

Levee system: Murray River ***Section: 8*** ***Length: 8.787 km***



Levee system: Murray River ***Section: 8*** ***Length: 8.787 km***

Level of protection summary

Level of protection	Length (m)	%
1975	8,310	95
1993	154	2
2010	199	2
< 2010	124	1

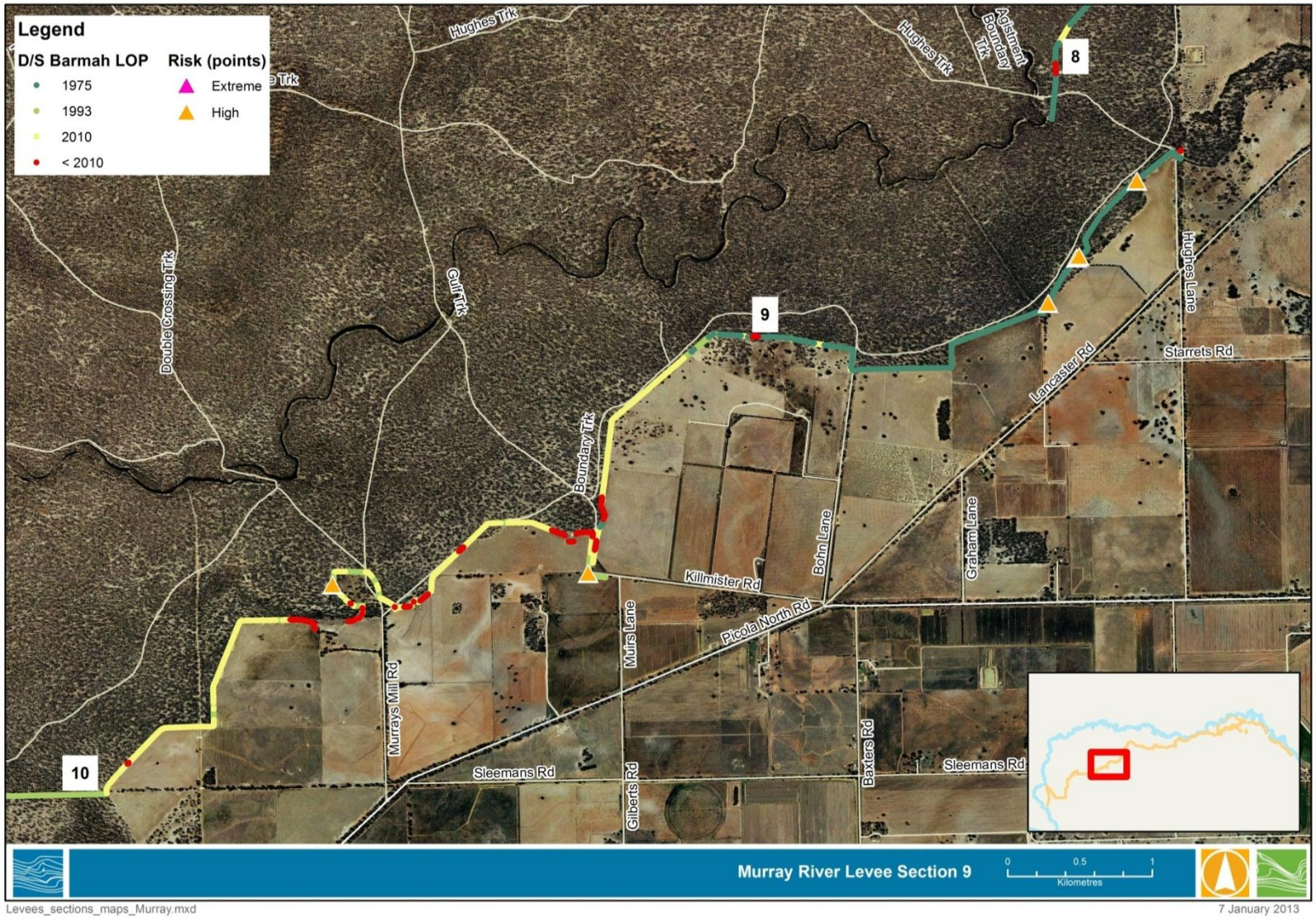
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	-	-
Medium	4	-
Low	91	2,085

Comment:

There are no high priority points of weakness identified for this section, and the standard level of protection for this section of levees may be brought up to the 1975 level with works along ~ 500 m of levee.

Levee system: Murray River ***Section: 9*** ***Length: 11.862 km***



Levee system: Murray River ***Section: 9*** ***Length: 11.862 km***

Level of protection summary

Level of protection	Length (m)	%
1975	4,161	35
1993	1,573	13
2010	5,601	43
< 2010	1,067	9

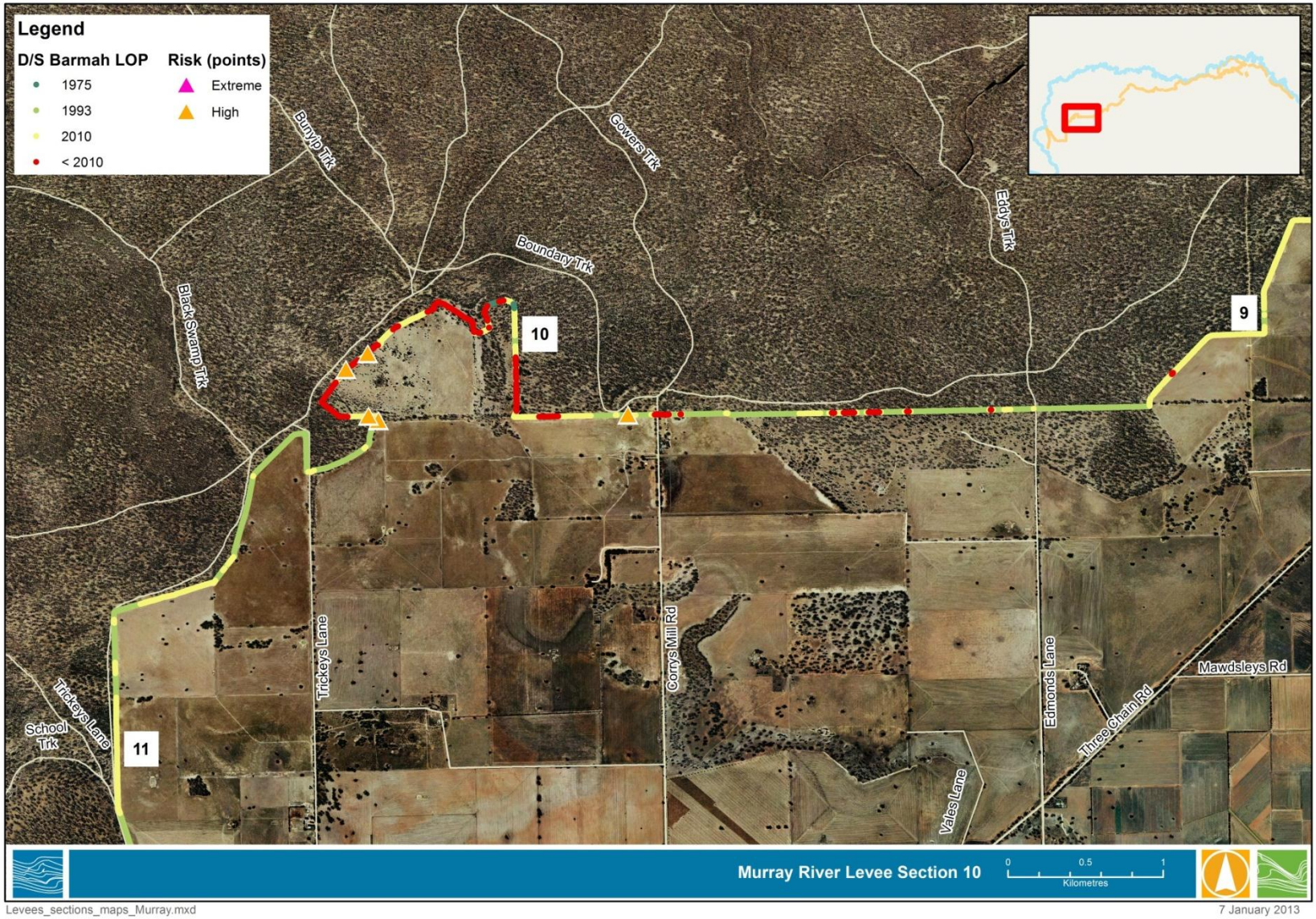
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	6	-
Medium	9	-
Low	136	10,590

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 2010 level or greater with works required along ~1 km of levee. In addition, there are 6 discrete points identified for priority works and the indicative cost for these works is ~$25,000.

Levee system: Murray River ***Section: 10*** ***Length: 10.310 km***



Levee system: Murray River ***Section: 10*** ***Length: 10.310 km***

Level of protection summary

Level of protection	Length (m)	%
1975	82	1
1993	5,183	50
2010	3,048	30
< 2010	1,997	19

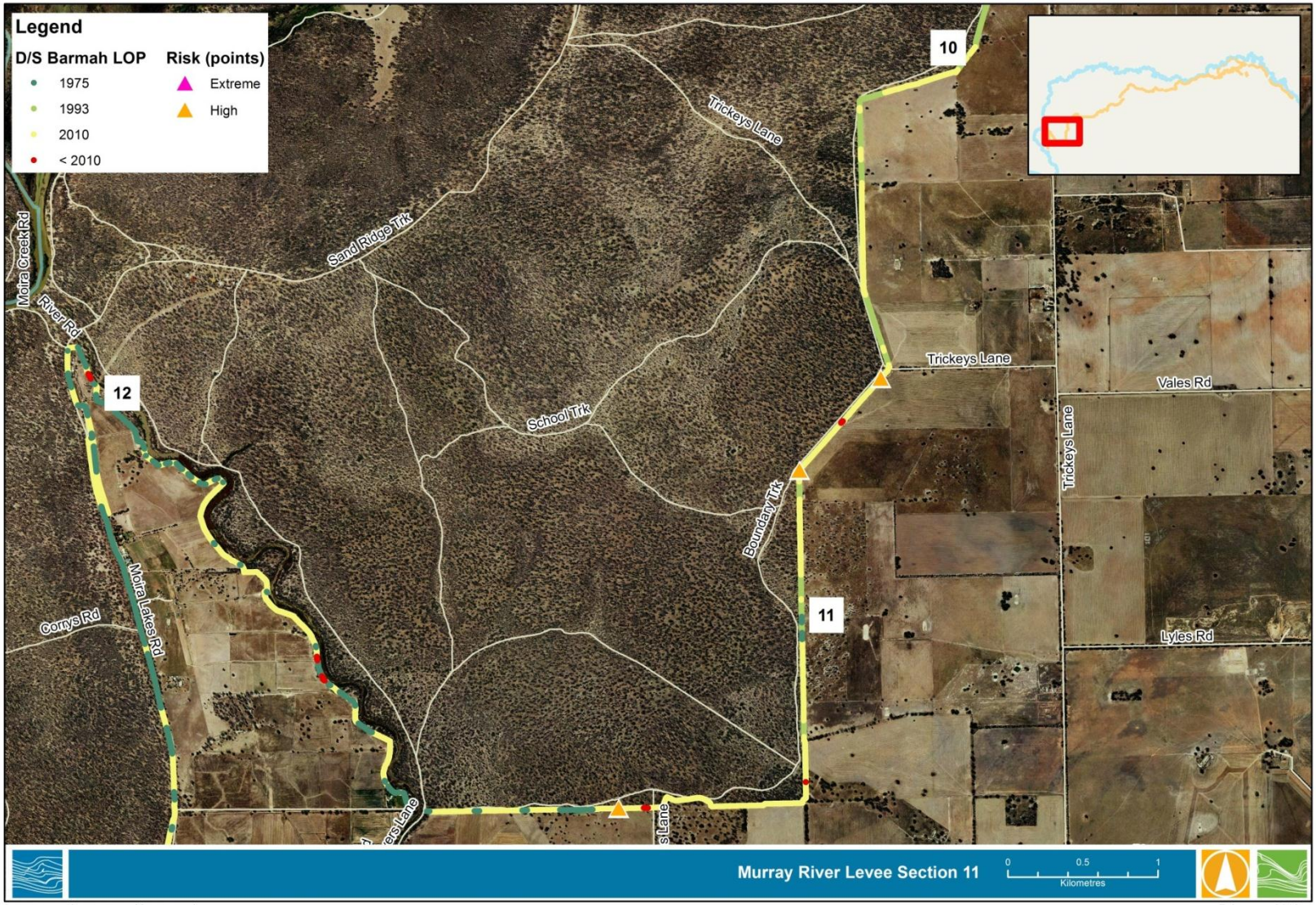
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	5	-
Medium	-	-
Low	78	11,706

Comment:

Significant works are required to bring the standard Level of Protection of this reach of levees up to at least the 2010 level with works required along ~ 2 km of levee. In addition, this study has identified 5 discrete points of weakness that are a priority for works and the indicative cost for these works is ~ $20,000.

Levee system: Murray River ***Section: 11*** ***Length: 7.890 km***



Levee system: Murray River ***Section: 11*** ***Length: 7.890 km***

Level of protection summary

Level of protection	Length (m)	%
1975	377	5
1993	1,818	23
2010	5,642	72
< 2010	53	<1

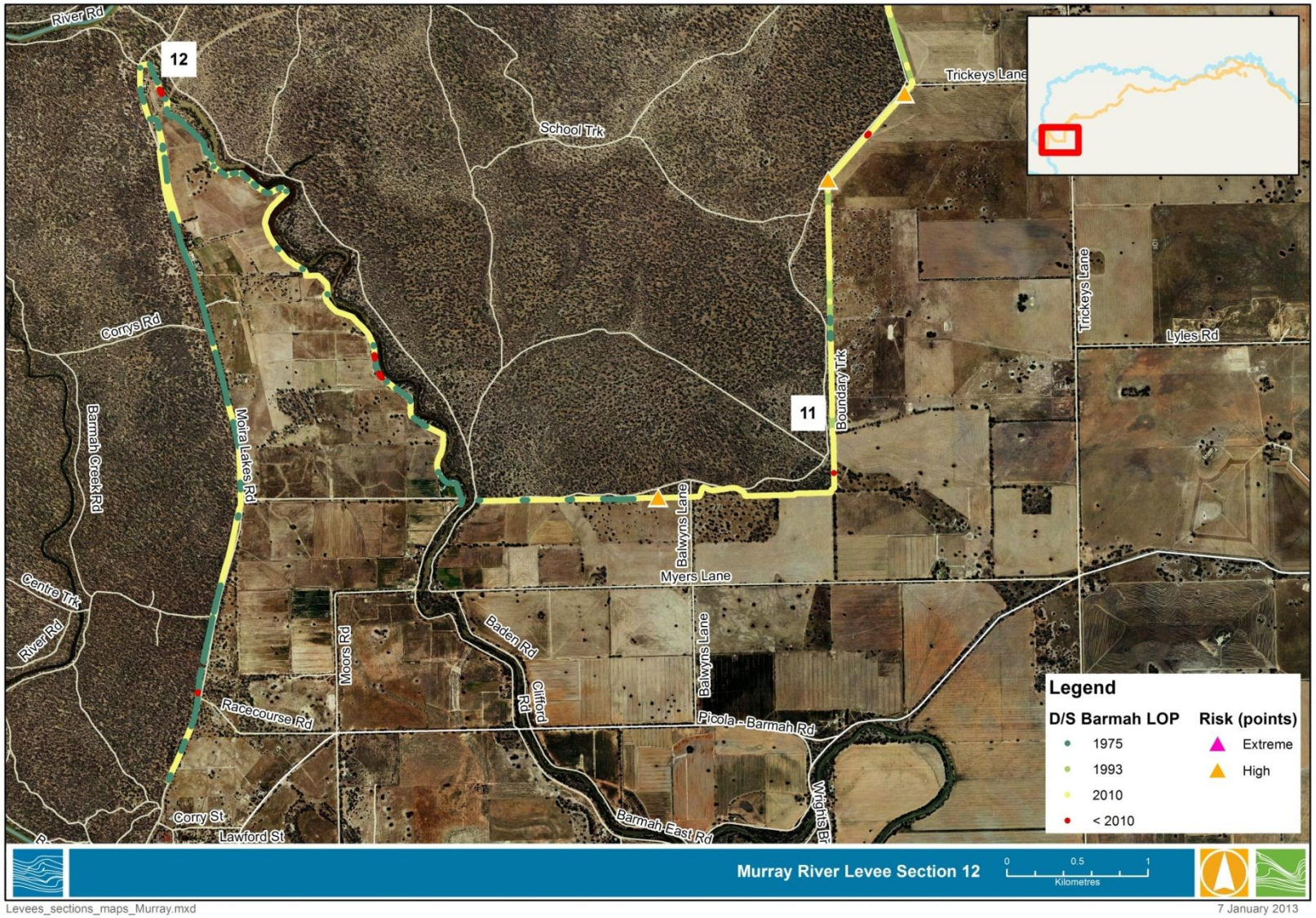
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	4	-
Medium	7	146
Low	64	4,413

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 2010 level or greater with works required along < 100 m of levee. In addition, there are 4 discrete points identified for priority works and the indicative cost for these works is ~$50,000.

Levee system: Murray River ***Section: 12*** ***Length: 10.814 km***



Levee system: Murray River ***Section: 12*** ***Length: 10.814 km***

Level of protection summary

Level of protection	Length (m)	%
1975	4,630	43
1993		-
2010	6,065	56
< 2010	119	1

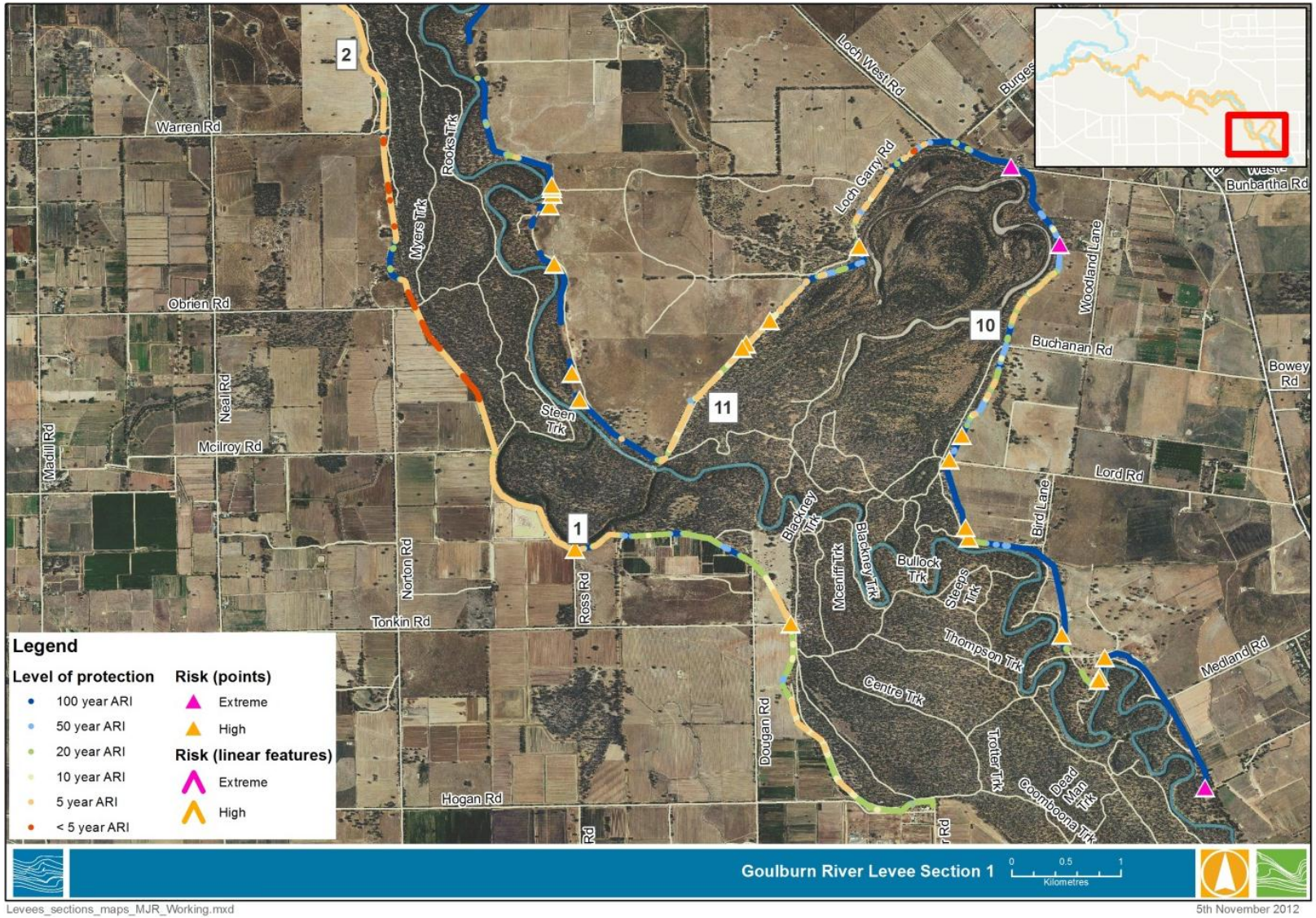
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	-	-
Medium	17	675
Low	105	2,426

Comment:

It is feasible to bring the standard Level of Protection of this reach of levees up to a 2010 level or greater with works required along ~ 100 m of levee. In addition, there were no points of weakness identified for priority works.

Levee system: Goulburn River ***Section: 1*** ***LENGTH: 10.010km***



Levee system: Goulburn River ***Section: 1*** ***LENGTH: 10.010km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	870	9
50 year ARI	432	4
20 year ARI	2,843	28
10 year ARI	724	7
5 year ARI	4,353	43
< 5 year ARI	788	8

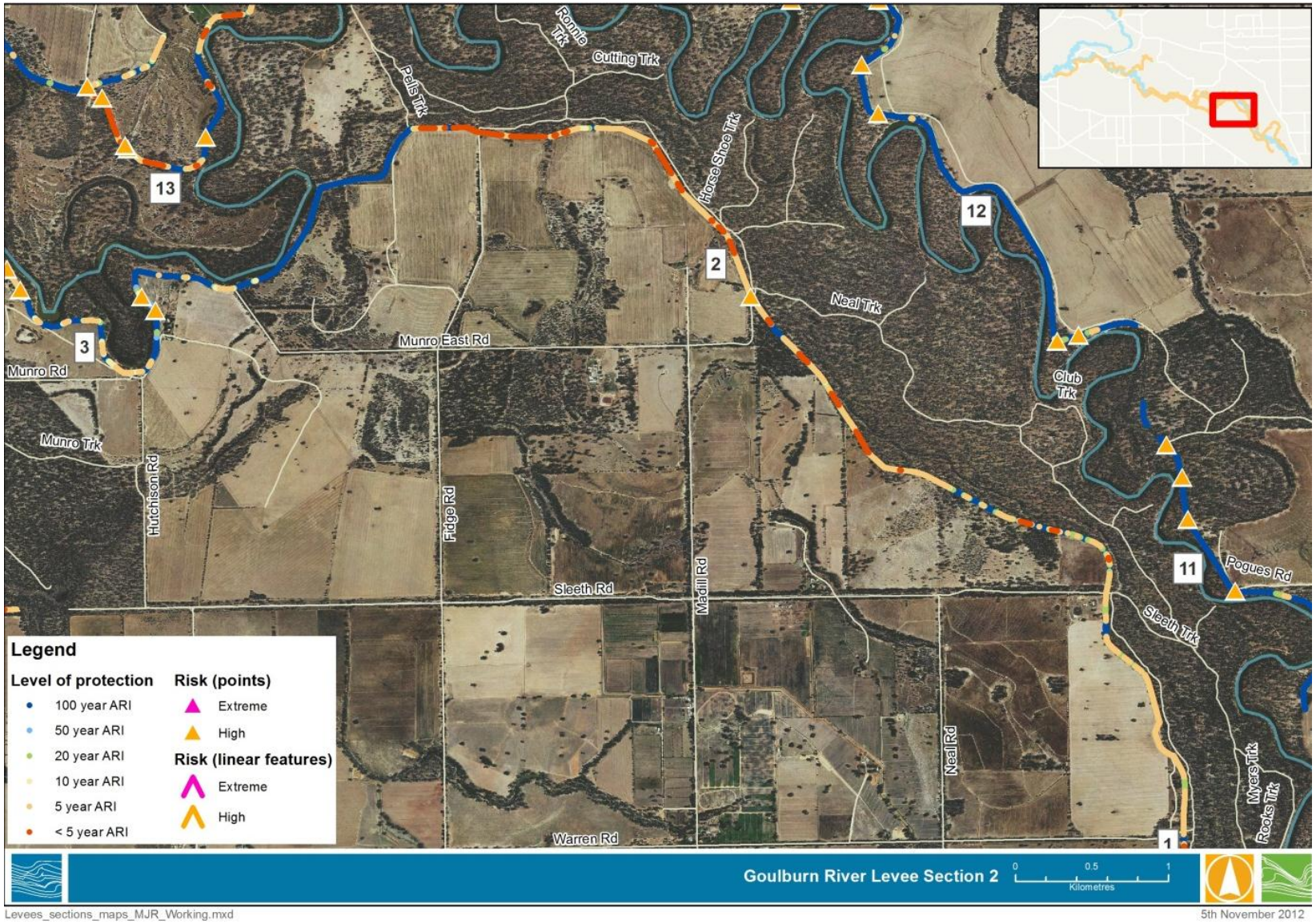
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	2	-
Medium	10	478
Low	66	5,485

Comment:

It is feasible to bring the standard Level of Protection of this reach up to a 5 year ARI level of protection or greater with works required along < 1 km of levee. There are 2 discrete points of weakness identified that are a priority for works and the indicative cost for these works is in the order of $10,000.

Levee system: Goulburn River ***Section: 2*** ***LENGTH: 10.001km***



Levee system: Goulburn River ***Section: 2*** ***LENGTH: 10.001km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	3,334	33
20 year ARI	619	6
10 year ARI	187	2
5 year ARI	4,279	43
< 5 year ARI	1,582	16

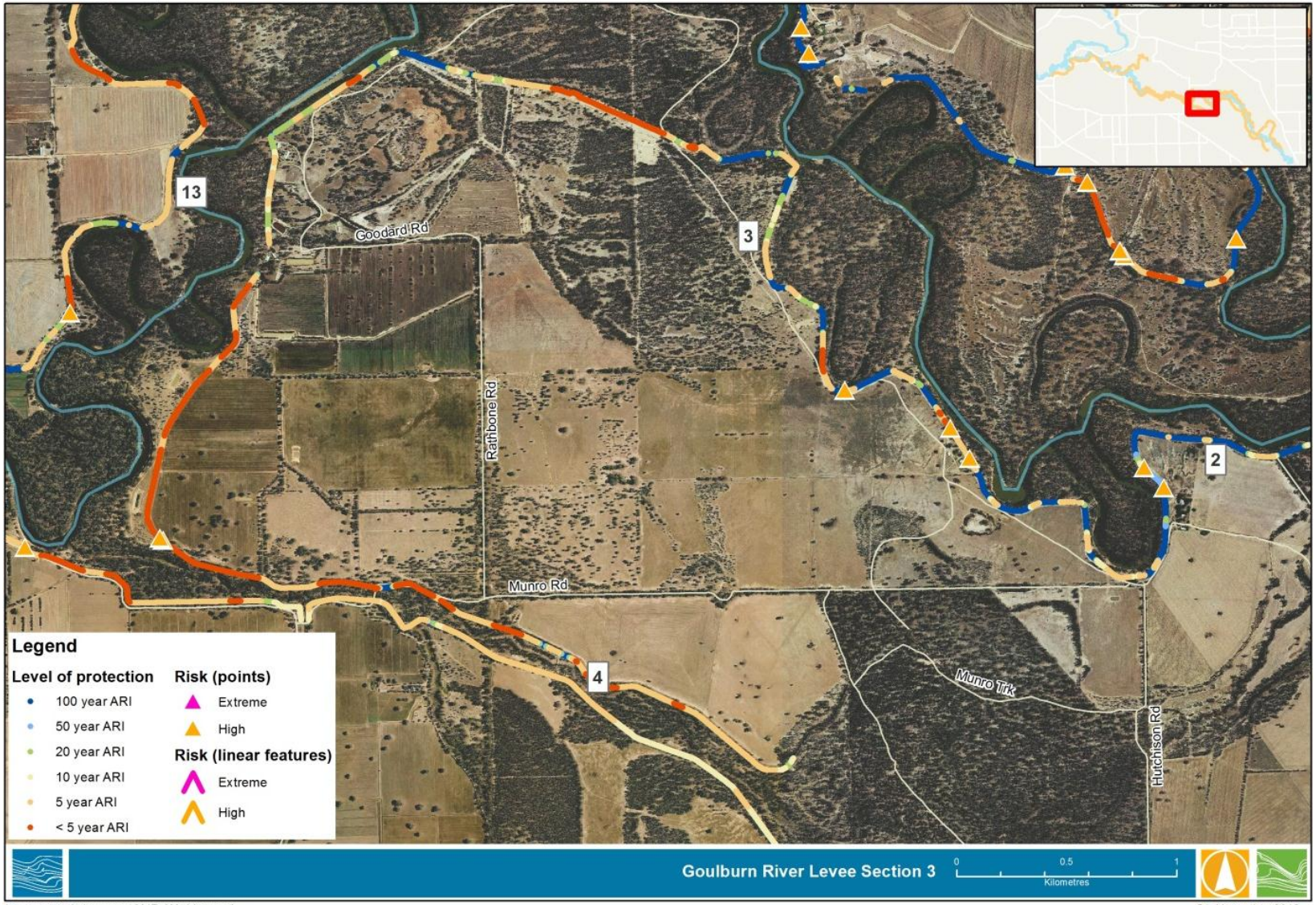
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	1	-
Medium	18	154
Low	98	1,930

Comment:

Significant works are required to bring the standard Level of Protection of this reach up to a 5 year ARI level of protection with works required along > 1.5 km of levee. There is 1 discrete point of weakness identified as a priority for works and the indicative cost for these works is < $5,000.

Levee system: Goulburn River ***Section: 3*** ***LENGTH: 11.635km***



Levee system: Goulburn River ***Section: 3*** ***LENGTH: 11.635km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	2,523	22
50 year ARI	226	2
20 year ARI	1,086	9
10 year ARI	704	6
5 year ARI	4,005	34
< 5 year ARI	3,091	27

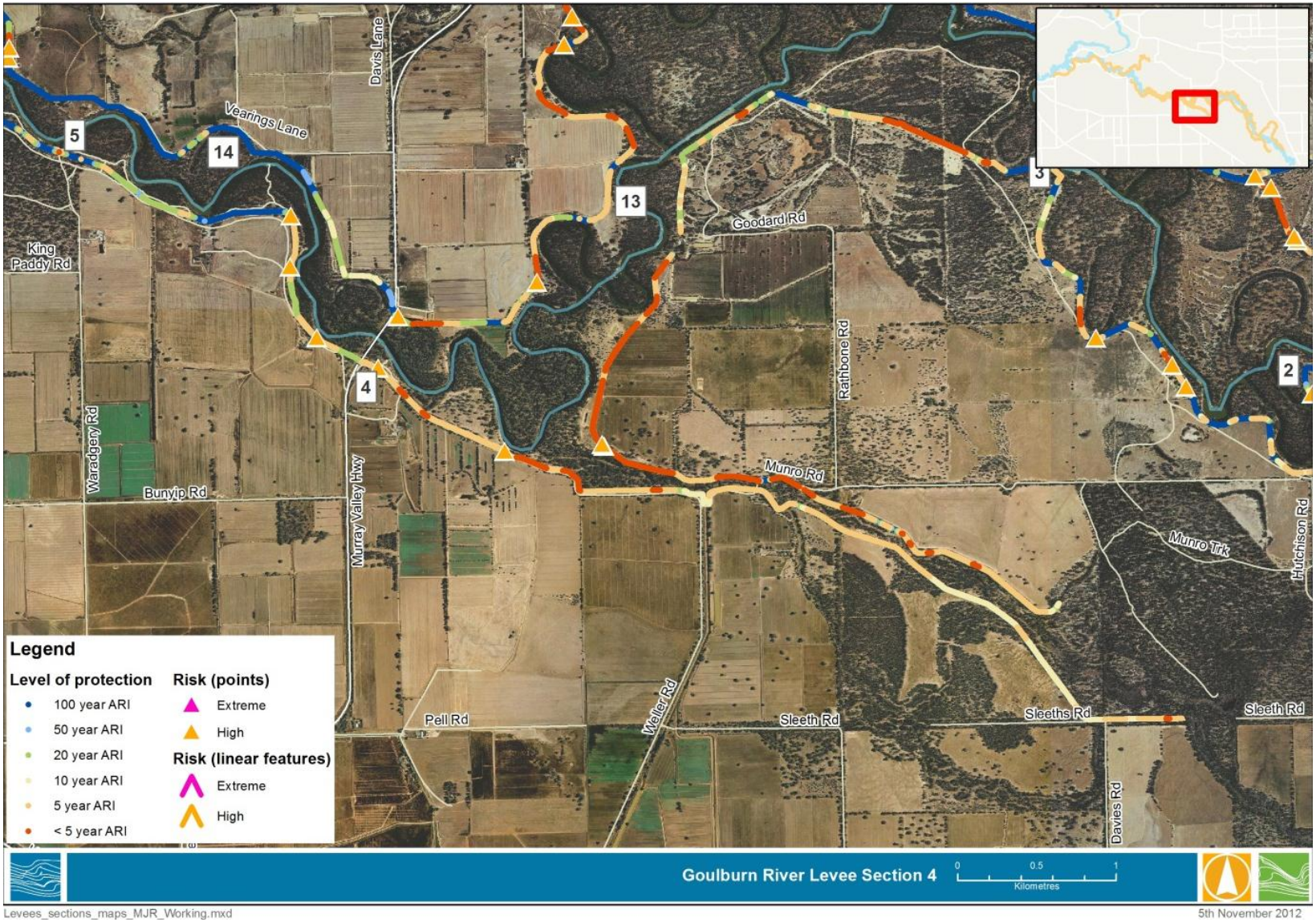
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	7	327
Medium	16	150
Low	108	10,834

Comment:

Significant works are required to bring the standard Level of Protection of this section up to a 5 year ARI level of protection or greater with works required along over 3 km of levee. In addition, this study has identified 7 discrete points of weakness and 327 m of levee that are a priority for works and the indicative cost for these works is in the order of $275,000. This is the second highest cost of priority works for a levee section in this study.

Levee system: Goulburn River ***Section: 4*** ***LENGTH: 8.414 km***



Levee system: Goulburn River ***Section: 4*** ***LENGTH: 8.414 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	639	8
50 year ARI	112	1
20 year ARI	885	11
10 year ARI	1,752	21
5 year ARI	4,416	52
< 5 year ARI	610	7

Points of weakness summary

Risk	No. sites	Length (m)
Extreme		-
High	5	-
Medium	1	-
Low	94	5,307

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 5 year ARI level of protection or greater with works required along < 1 km of Levee. There are 5 discrete points of weakness identified that are a priority for works and the indicative cost for these works is ~ $20,000.

Levee system: Goulburn River ***Section: 5*** ***LENGTH: 10.001km***

Levee system: Goulburn River ***Section: 5*** ***LENGTH: 10.001km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	3,981	40
50 year ARI	730	7
20 year ARI	3,095	31
5 year ARI	1,482	15
< 5 year ARI	713	7

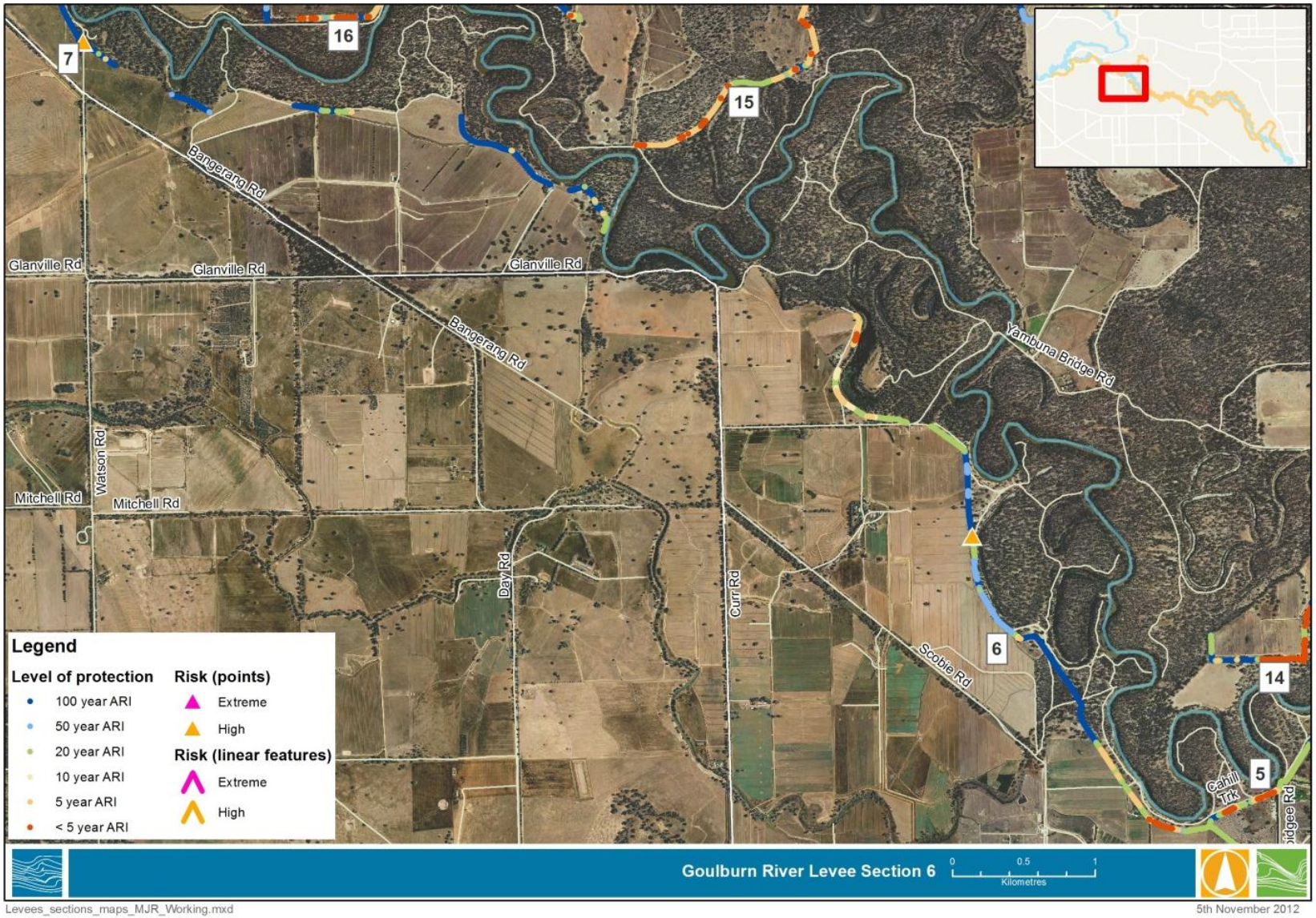
Points of weakness summary

Risk	No. sites	Length (m)
Extreme		-
High	4	-
Medium	7	389
Low	71	3,555

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 5 year ARI level of protection or greater with works required along < 1 km of levee. There are 4 discrete points of weakness identified that are a priority for works and the indicative cost for these works are in the order of $20,000.

Levee system: Goulburn River ***Section: 6*** ***LENGTH: 6.275 km***



Levee system: Goulburn River ***Section: 6*** ***LENGTH: 6.275 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	3,277	52
50 year ARI	798	13
20 year ARI	1,438	23
10 year ARI	186	3
5 year ARI	526	8
< 5 year ARI	50	1

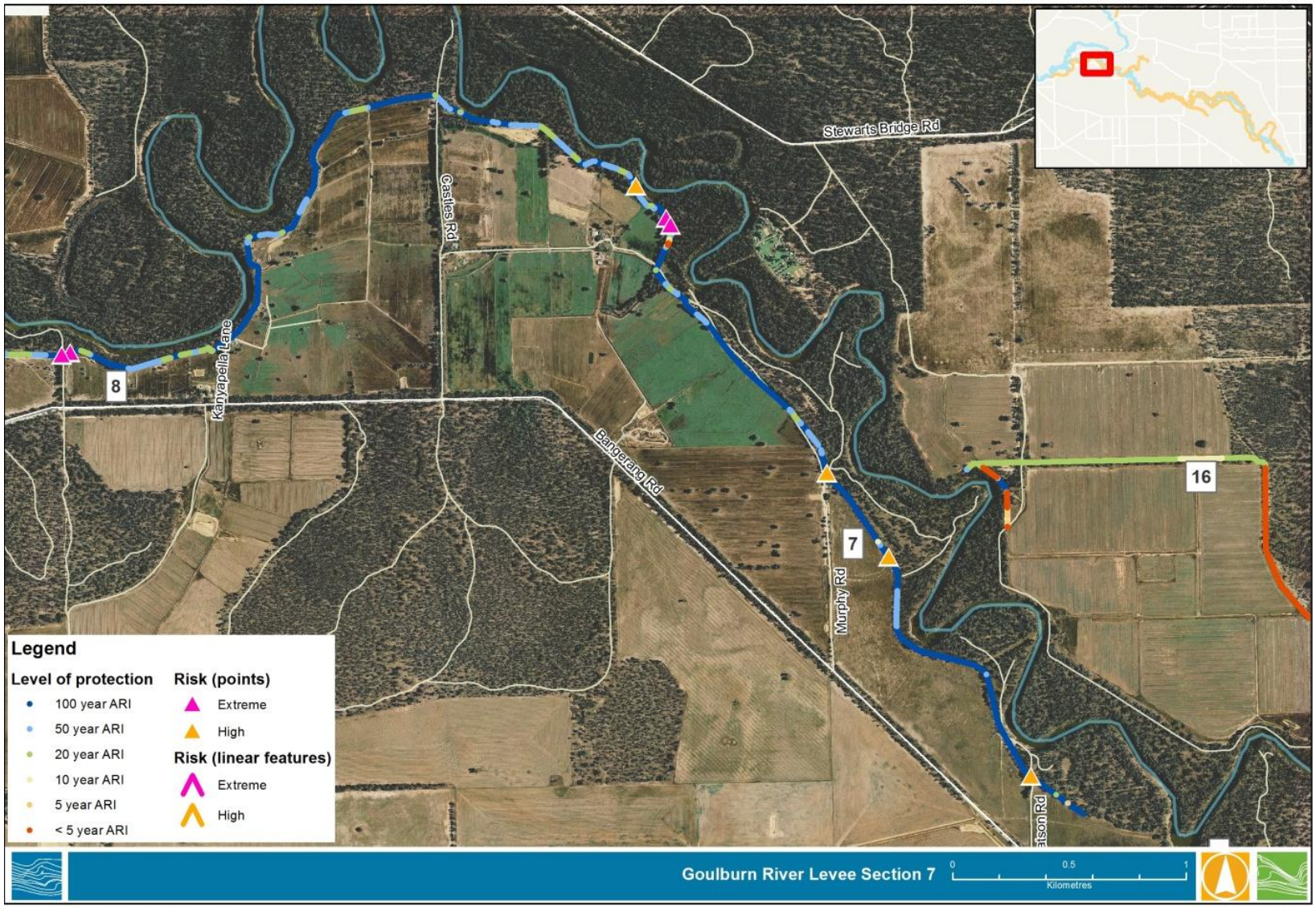
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	1	-
Medium	18	84
Low	78	1,545

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 20 year ARI level of protection or greater with works required along < 100 m of Levee. There is 1 discrete point of weakness identified as a priority for works and the indicative cost for these works is ~ $10,000.

Levee system: Goulburn River ***Section: 7*** ***LENGTH: 6.253 km***



Levee system: Goulburn River ***Section: 7*** ***LENGTH: 6.253 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	4,596	74
50 year ARI	1,378	22
20 year ARI	244	4
10 year ARI	13	< 1
5 year ARI	13	< 1
< 5 year ARI	9	< 1

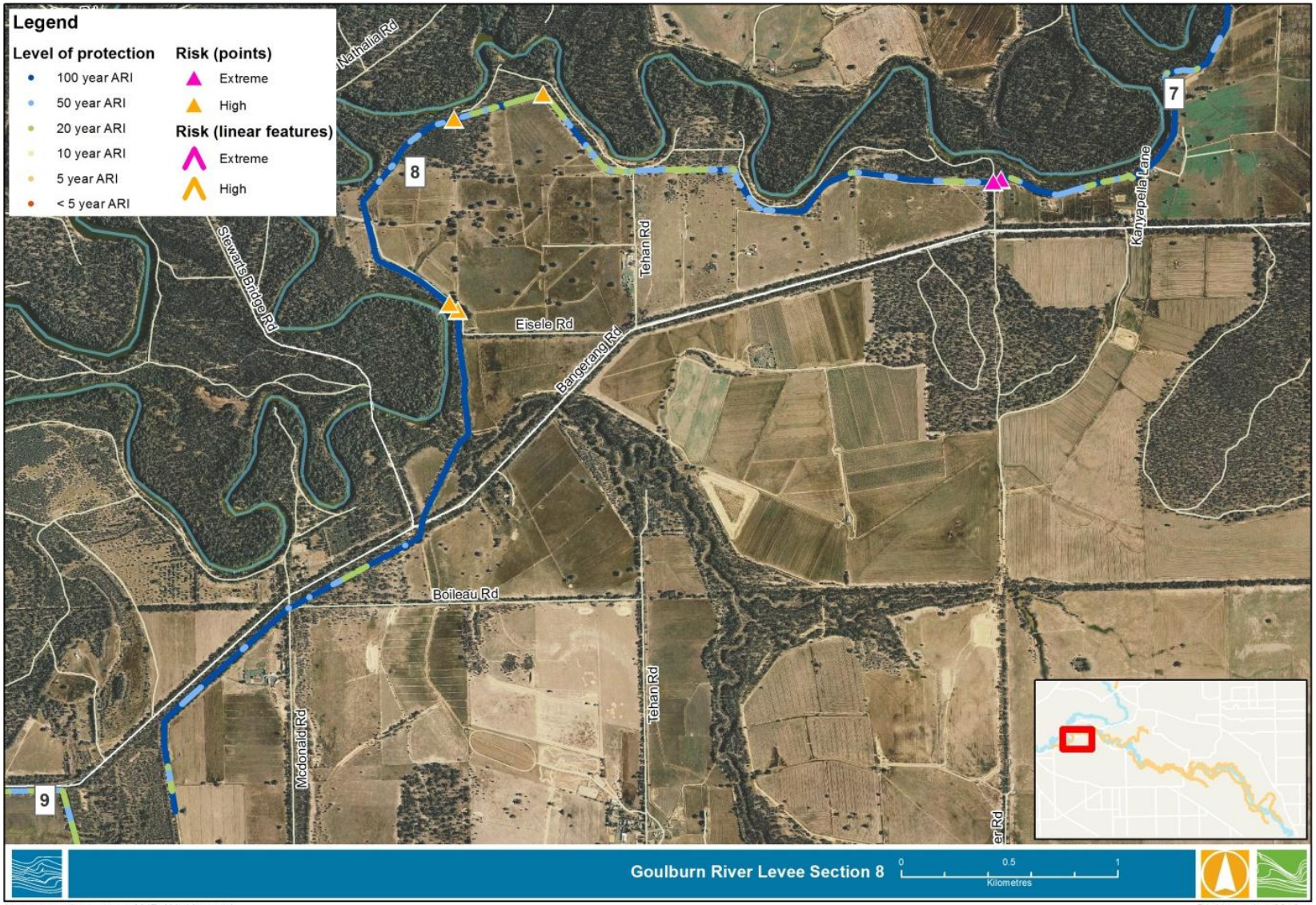
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	2	59
High	4	25
Medium	27	1,588
Low	23	3,842

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 50 year LOP or greater with works required along < 500 m of levee. In addition, there are 6 discrete points and ~100 m of levee identified for priority works and the indicative cost for these works is ~$90,000.

Levee system: Goulburn River ***Section: 8*** ***LENGTH: 7.924 km***



Levee system: Goulburn River ***Section: 8*** ***LENGTH: 7.924 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	5,312	67
50 year ARI	1,589	20
20 year ARI	1,023	13

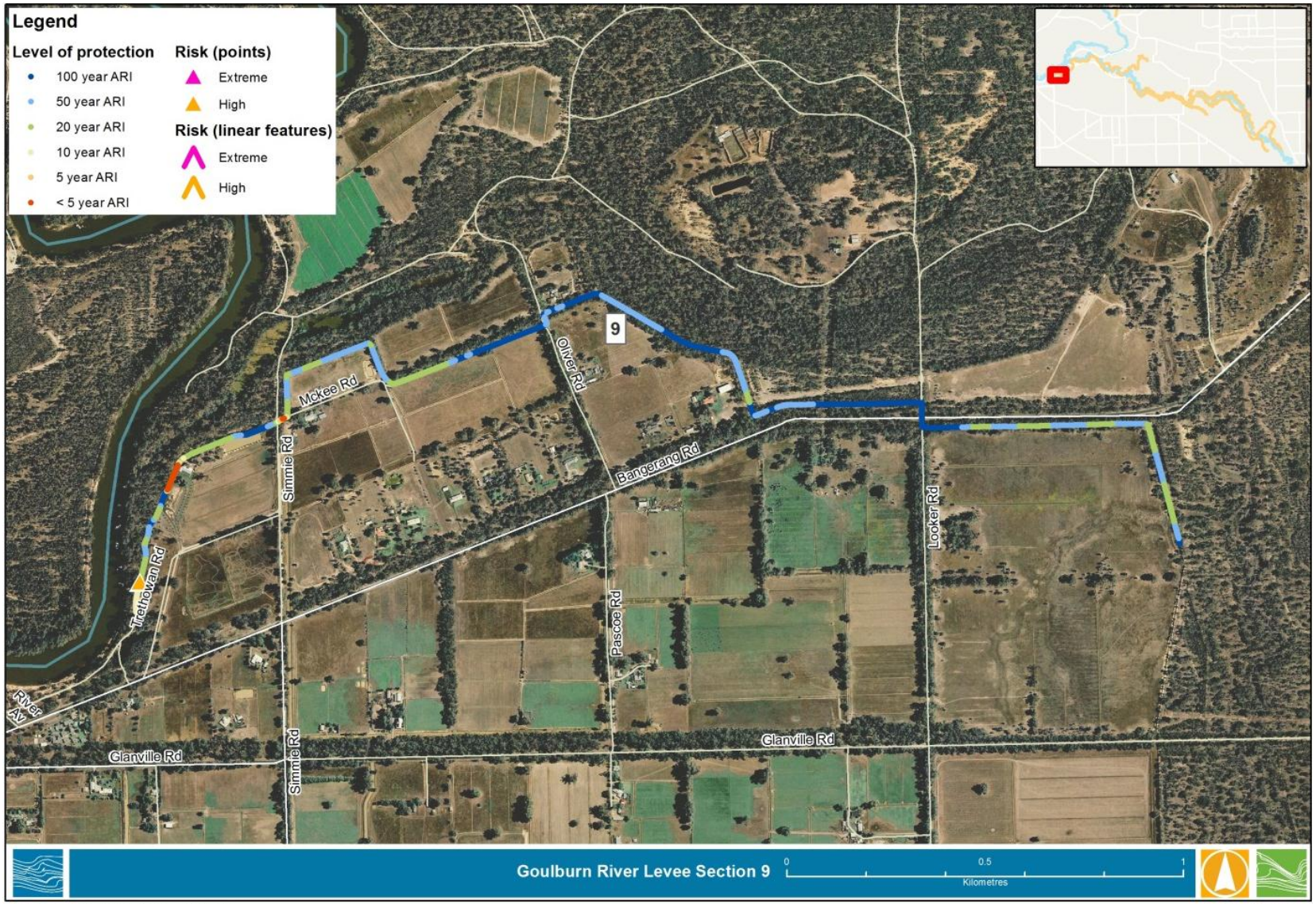
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	2	-
High	4	-
Medium	16	686
Low	117	4,125

Comment:

The analysis of crest levels indicates has found that this section has a 20 year ARI level of protection or greater. There are 6 discrete points of weakness identified that are a priority for works and the indicative costs for these works are in the order of $30,000.

Levee system: Goulburn River ***Section: 9*** ***LENGTH: 3.652 km***



Levee system: Goulburn River ***Section: 9*** ***LENGTH: 3.652 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	1,187	33
50 year ARI	1,410	39
20 year ARI	887	24
10 year ARI	80	2
5 year ARI	15	<1
< 5 year ARI	73	2

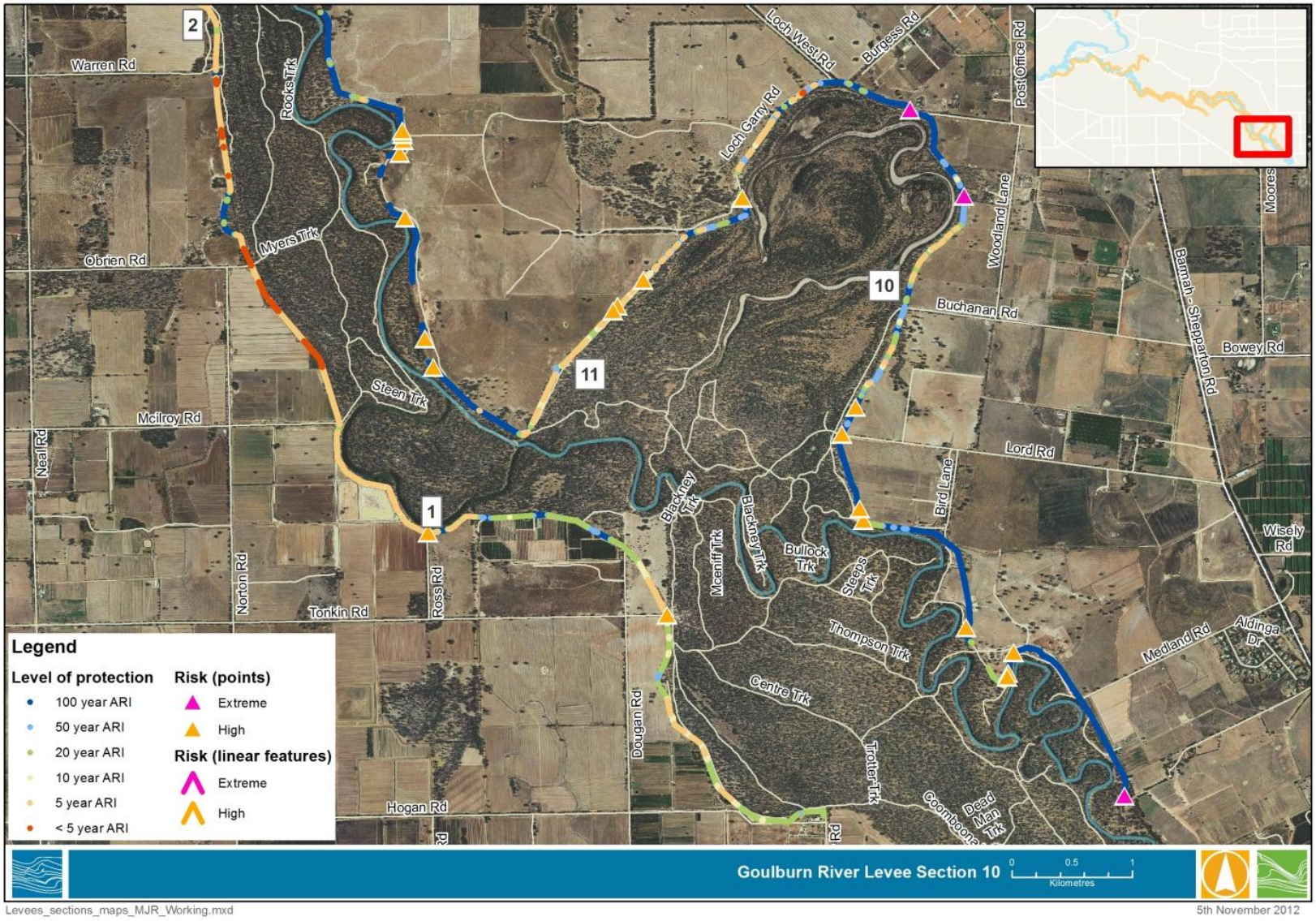
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	1	-
Medium	16	395
Low	35	1,337

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 5year LOP or greater with works required along < 100 m of levee. There is 1 discrete point of weakness identified as a priority for works and the indicative costs for these works is less than $2,000.

Levee system: Goulburn River ***Section: 10*** ***LENGTH: 10.021 km***



Levee system: Goulburn River ***Section: 10*** ***LENGTH: 10.021 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	6,632	66
50 year ARI	1,281	13
20 year ARI	1,177	12
10 year ARI	153	2
5 year ARI	758	8
< 5 year ARI	20	< 1

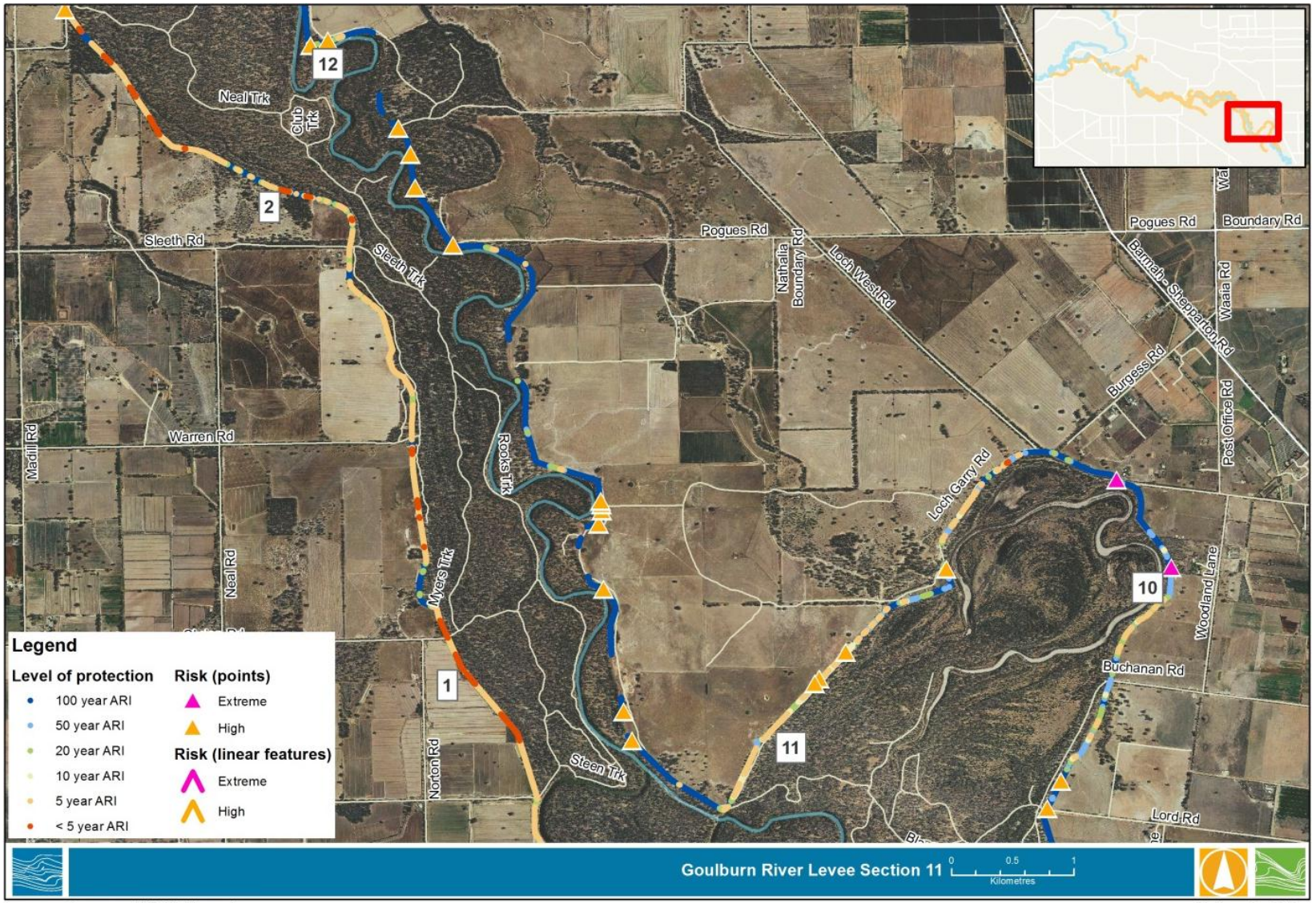
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	3	-
High	9	-
Medium	29	2,137
Low	87	3,300

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 5 year LOP or greater with works required along < 100 m of levee. In addition, there are 12 discrete points identified for priority works and the indicative cost for these works is ~$65,000.

Levee system: Goulburn River ***Section: 11*** ***LENGTH: 8.872 km***



Levees_sections_maps_MJR_Working.mxd 5th November 2012

Levee system: Goulburn River ***Section: 11*** ***LENGTH: 8.872 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	6,376	72
50 year ARI	383	4
20 year ARI	556	6
10 year ARI	355	4
5 year ARI	1,202	14

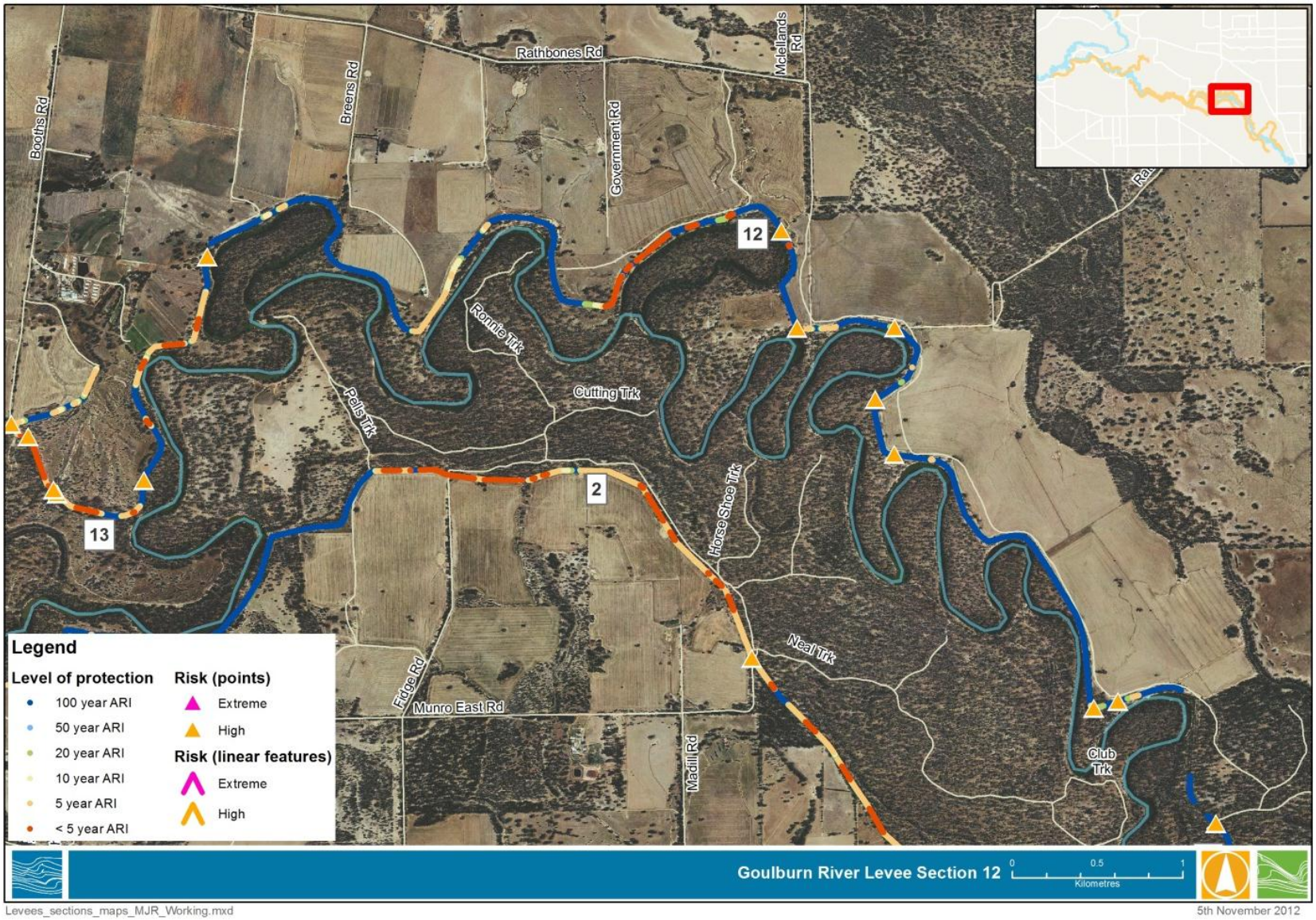
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	14	130
Medium	11	22
Low	116	6,530

Comment:

The analysis of crest levels has found that this section has at least a 5 year ARI level of protection. There are 14 discrete points and 130 m of levee identified for priority works. This is the highest number of points identified for a section along the Goulburn River levees in this study, and the indicative cost for works is in the order of $175,000.

Levee system: Goulburn River ***Section: 12*** ***LENGTH: 11.133 km***



Levee system: Goulburn River ***Section: 12*** ***LENGTH: 11.133 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	8,593	77
20 year ARI	404	4
10 year ARI	367	3
5 year ARI	954	9
< 5 year ARI	815	7

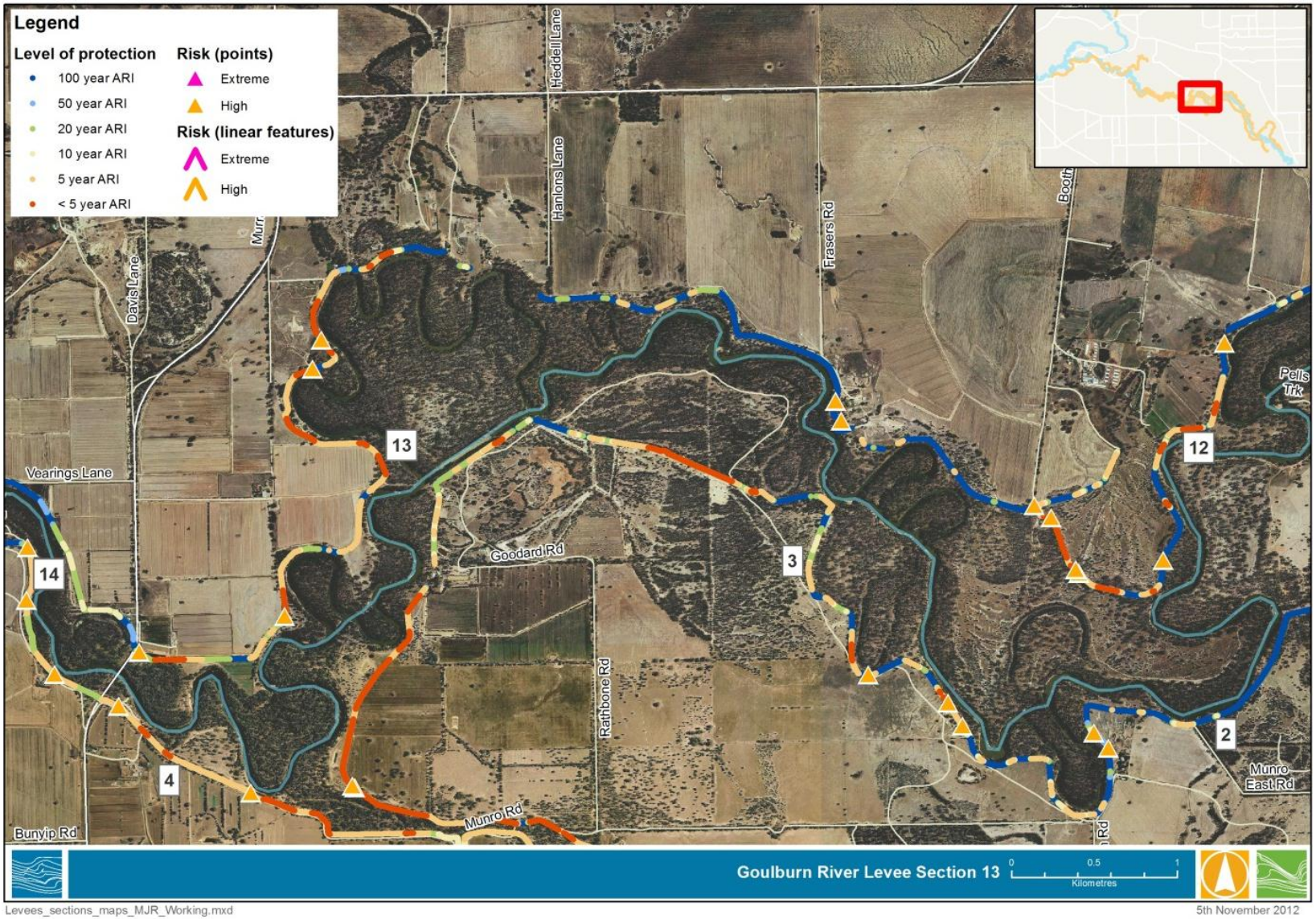
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	8	308
Medium	8	-
Low	171	8,670

Comment:

Works are required along ~ 1 km of levee to bring the standard Level of Protection of this section up to a minimum of a 5 year ARI level of protection. In addition, this study has identified 8 discrete points of weakness and 308 m of levee that are a priority for works and the indicative cost for these works is ~ $340,000. This is the highest cost of works for a levee section in this study.

Levee system: Goulburn River ***Section: 13*** ***LENGTH: 11.022 km***



Levee system: Goulburn River ***Section: 13*** ***LENGTH: 11.022 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	5,021	46
50 year ARI	50	< 1
20 year ARI	969	9
10 year ARI	258	2
5 year ARI	3,011	27
< 5 year ARI	1,713	16

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	11	57
Medium	30	2
Low	125	5,313

Comment:

Significant works are required to bring the standard Level of Protection of this section up to a 5 year ARI level of protection or greater with works required along >1.5 km of levee. In addition, this study has identified 11 discrete points of weakness and 57 m of levee that are a priority for works and the indicative costs for these works are in the order of $170,000.

Levee system: Goulburn River ***Section: 14*** ***LENGTH: 12.787 km***

Levee system: Goulburn River ***Section: 14*** ***LENGTH: 12.787 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	8,497	66
50 year ARI	693	5
20 year ARI	1,256	10
10 year ARI	333	3
5 year ARI	919	7
< 5 year ARI	1,089	9

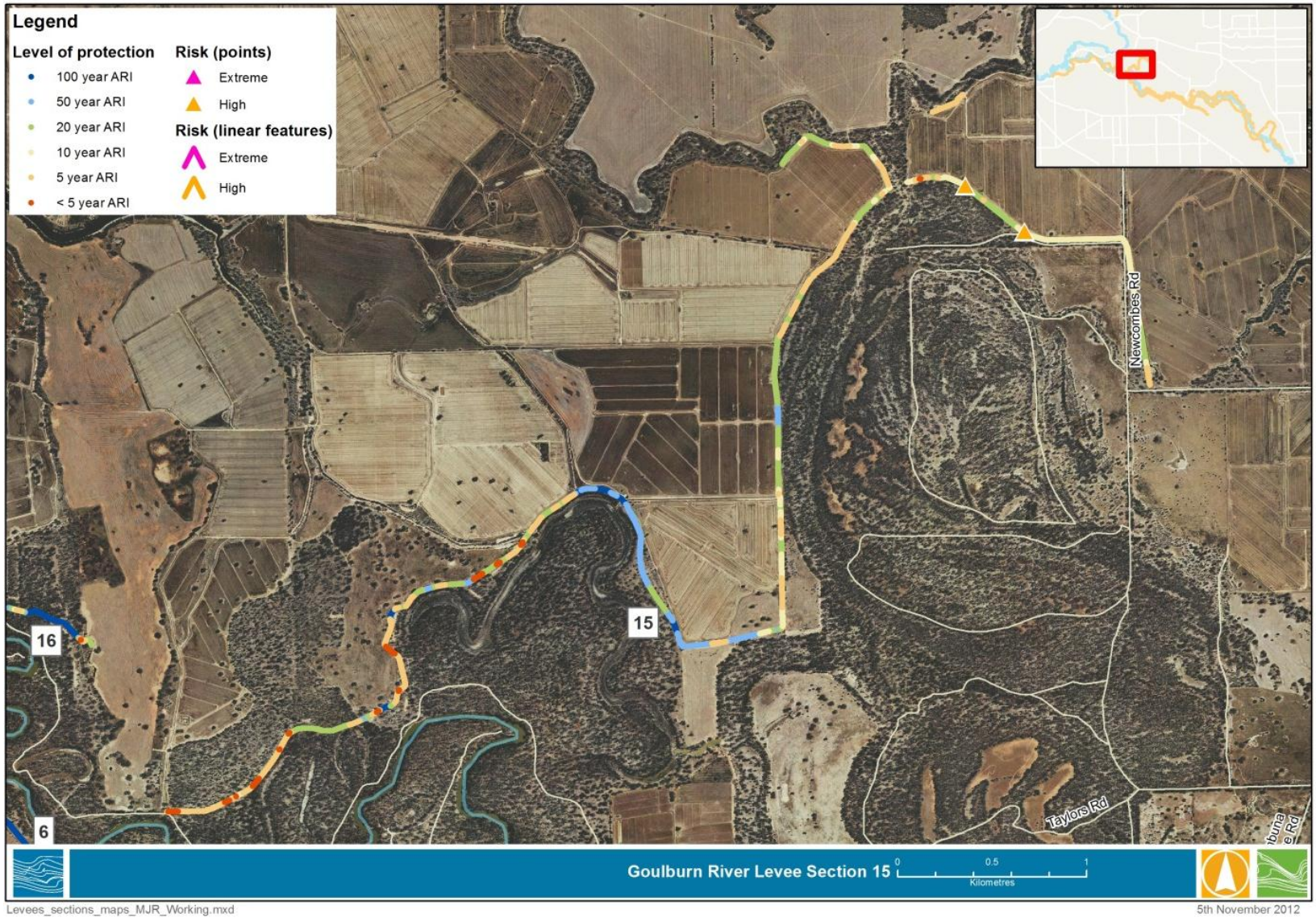
Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	3	-
Medium	19	-
Low	199	4,282

Comment:

Works are required along ~ 1 km of levee to bring the standard Level of Protection of this section up to a minimum 5 year ARI level of protection or greater. In addition, this study has identified 3 discrete points of weakness that are a priority for works and the indicative cost for these works is ~$12,000.

Levee system: Goulburn River ***Section: 15*** ***LENGTH: 10.412 km***



Levee system: Goulburn River ***Section: 15*** ***LENGTH: 10.412 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	379	4
50 year ARI	1,413	14
20 year ARI	3,416	33
10 year ARI	1,954	19
5 year ARI	2,914	28
< 5 year ARI	336	3

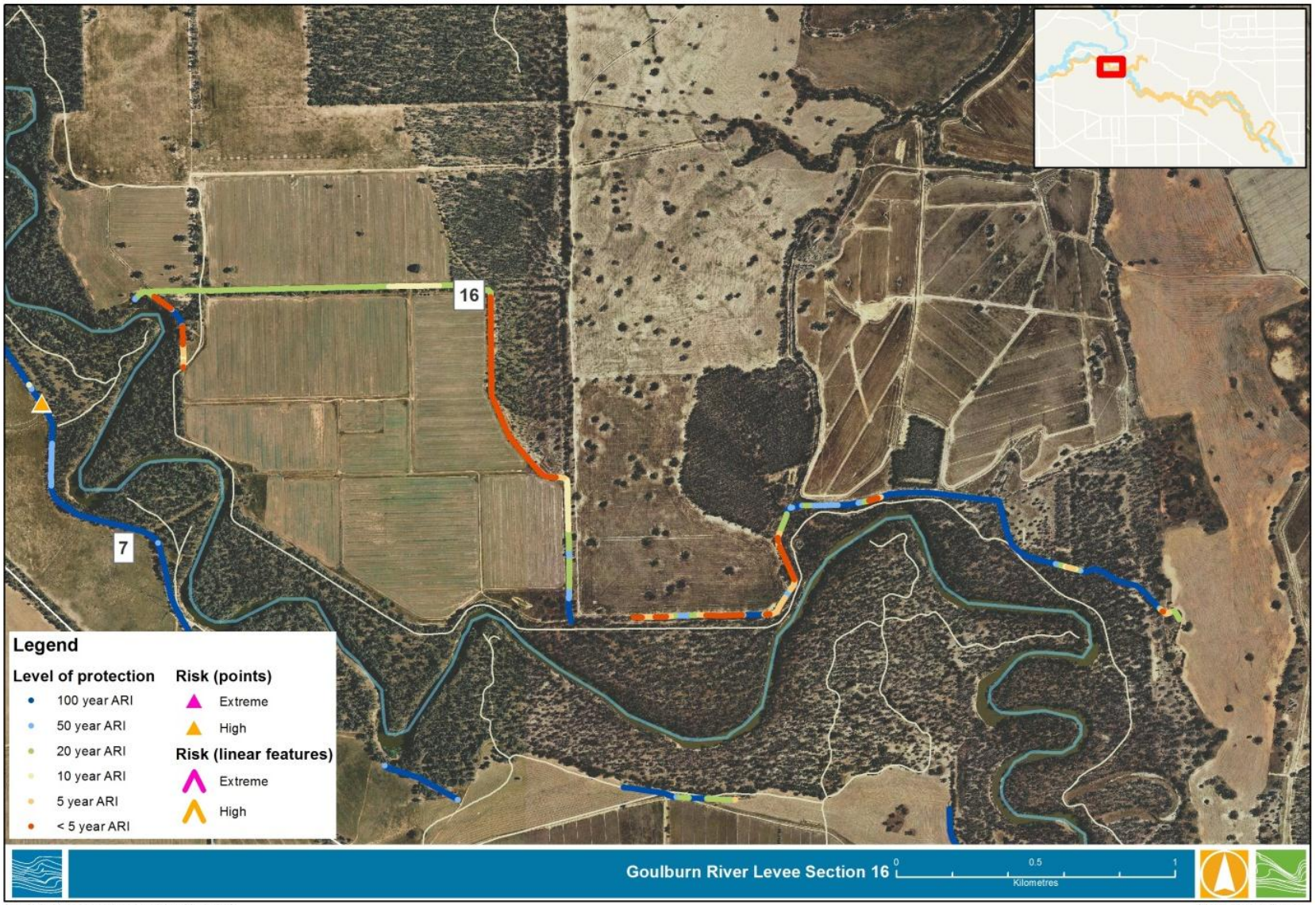
Points of weakness summary

Risk	No. sites	Length (m)
Extreme		
High	2	
Medium	7	1,275
Low	64	5,456

Comment:

It is feasible to bring the standard Level of Protection of this section up to a 5 year Level of Protection or greater with works required along < 500 m of Levee. There are 2 discrete points of weakness identified as a priority for works and the indicative cost for these works is in the order of $15,000.

Levee system: Goulburn River ***Section: 16*** ***LENGTH: 5.496 km***



Levee system: Goulburn River ***Section: 16*** ***LENGTH: 5.496 km***

Level of protection summary

Level of protection	Length (m)	%
100 year ARI	1,460	27
50 year ARI	385	7
20 year ARI	1,563	28
10 year ARI	421	8
5 year ARI	384	7
< 5 year ARI	1,283	23

Points of weakness summary

Risk	No. sites	Length (m)
Extreme	-	-
High	-	-
Medium	1	419
Low	21	3,664

Comment:

There are no high priority points of weakness identified for this section, however, works addressing the Level of Protection may be undertaken to bring the standard level of protection up to at least a 5 year ARI.

APPENDIX C EXAMPLES OF POINTS OF WEAKNESS

Narrow crest

Erosion : cracks

Erosion : ants nest

Erosion : poor material

Erosion : pugging (left)

Erosion : rilling (below)

Hole : erosion

Hole : fallen tree

Hole : rabbit burrow

Hole : sink hole (above); Hole : wheel ruts (below)

Low crest (above); Low crest : road crossing (below)

No vegetation (above); Overtopping (below)

Recent works (left)

Pipe (below)

Riverbank (above); Structure : dam (below)

Trees : mature in bank (above); Trees : saplings in crest (below)