Lower Goulburn Floodplain Rehabilitation Scheme

ASSESSMENT OF FLOOD RISK TO THE TOWNSHIP OF BARMAH AND PRELIMINARY FLOOD MITIGATION REVIEW

- Final
- 12th August 2008

Lower Goulburn Floodplain Rehabilitation Scheme

ASSESSMENT OF FLOOD RISK TO THE TOWNSHIP OF BARMAH AND PRELIMINARY FLOOD MITIGATION REVIEW

- Final
- 12th August 2008

Sinclair Knight Merz
ABN 37 001 024 095
590 Orrong Road, Armadale 3143
PO Box 2500
Malvern VIC 3144 Australia
Tel: +61 3 9248 3100
Fax: +61 3 9248 3400
Web: www.skmconsulting.com

Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft A	23-9-05	B. Tate	T. Dando		
Draft A	25-11-05	B. Tate	T. Dando		
Draft B	23-01-06	B. Tate	T. Dando	23-01-06	
Final (for review)	01-08-08	R. Morden	D. Sheehan	01-08-08	Incorporation of new data and comments from Goulburn Broken CMA
Final	12-08-08	R. Morden	D. Sheehan	12-08-08	Incorporation of comments from Goulburn Broken CMA

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft A	25-11-05	1 (electronic)	Guy Tierney
Draft B	23-01-06	1 (electronic)	Guy Tierney
Final (for review)	01-08-08	1 (electronic)	Guy Tierney
Final	12-08-08	1 (electronic)	Guy Tierney

Printed:	12 August 2008
Last saved:	12 August 2008 01:30 PM
File name:	I:\WCMS\Projects\WC03332\Deliverables\Economics Reports\R02_BT_Economics_draft.doc
Author:	Ben Tate / Mark Gelinski
Project manager:	David Sheehan
Name of organisation:	Goulburn Broken Catchment Management Authority
Name of project:	Lower Goulburn Floodplain Rehabilitation Scheme
Name of document:	Assessment of Flood Risk to the Township of Barmah and Preliminary Flood Mitigation Review
Document version:	Final
Project number:	WC03332

1. Outline of Current Study

1.1 Introduction

The Goulburn Broken Catchment Management Authority (GBCMA) has been in the process of developing a proposed Lower Goulburn Floodplain Rehabilitation Scheme (LGFRS). The LGFRS involves restoring the northern floodplain of the lower Goulburn River to a more natural flooding regime by allowing flood flows at Loch Garry to enter the northern floodplain instead of being channelled down through the confined lower Goulburn River levee system. The LGFRS has potential positive environmental impacts for the lower Goulburn River floodplain, whilst reducing damage costs to the lower Goulburn River levee system. As a result of the LGFRS, a larger percentage of flood flows may enter the Murray River via Deep Creek, upstream of the confluence with the Murray River and Goulburn River confluence. This may result in an increase in the flood risk to the township of Barmah.

A review of the LGFRS was conducted by Monash International (August 2003), generating a number of additional project tasks to be addressed.

1.2 Aims of Study

The study outlined in this report addresses one of the additional project tasks arising from Monash International's review, assessing the flood risk to the township of Barmah.

The primary aims of this study are to investigate in more detail the impact of the LGFRS on the township of Barmah, and in particular:

- to assess the incremental increase in flood risk and flood damage costs associated with implementation of the LGFRS; and
- to determine the costs and benefits associated with any measures that might be implemented to offset any adverse impacts of the LGFRS on flooding of the township.

1.3 Methodology of Study

Past studies relating to flooding of the lower Goulburn River floodplain were reviewed, including an investigation into the hydrology and mechanisms of flooding. The study undertaken by Gutteridge Haskins & Davey (GHD) in 1994 was of particular interest, as it included an assessment of the existing flood risk to the township of Barmah, and an assessment of a range of potential flood mitigation measures.

A site investigation was carried out. All residential and commercial buildings were photographed and their floor levels estimated. The estimated floor levels were then used to fill the gaps in the surveyed floor levels from the GHD (1994) study, for use in the flood damage cost/benefit assessment. Existing flood mitigation measures and potential sites for future mitigation options were also assessed.

The hydraulic model developed for the LGFRS study and its estimation of flood levels at Barmah for a number of scenarios was reviewed to assess its suitability for use in this study. It was found that the township of Barmah is located at the extreme end of hydraulic model, and the modelling results are largely influenced by the model boundary conditions. Therefore, the modelling results were considered inappropriate.

This study was placed on hold until the Barmah-Millewa model was developed (as part of the Living Murray initiative). Recently both hydraulic models were combined with the focus at Barmah. Design flood levels at Barmah for existing conditions and post LGFRS conditions were adopted for a range of flood events up to and including the 100 year Average Recurrence Interval (ARI). The flood damage costs were calculated for the township of Barmah for existing and post LGFRS conditions assuming no additional flood mitigation measures, using the Rapid Appraisal Method (RAM) and current practice.

Potential flood mitigation options were investigated for the township of Barmah based on the GHD (1994) study findings. Two levee alignments were subject to a cost/benefit analysis.

The results of this study are presented in the following chapters.

2. Background to Study

2.1 Summary of Study Area

The Goulburn River flows from the Great Dividing Range in a north-westerly direction until its confluence with the Murray River upstream of Echuca. Approximately half way along its course is the Goulburn Weir (north of Nagambie), a major water diversion structure providing water for regional dairy, cropping, grazing and horticultural needs. A map of the Goulburn River is presented as Figure 2-2.

North of Shepparton, the lower Goulburn River floodplain has a reduced gradient with the river bounded by an almost continuous system of man made levees. Approximately 20 km downstream of Shepparton, the Loch Garry regulator manages the release of a proportion of flood waters from the Goulburn River into the northern floodplain, known as the Deep Creek system, flowing into the Murray River approximately 25 km upstream of the Murray River and Goulburn River confluence. The township of Barmah is situated on the Victorian bank of the Murray River approximately 7 km upstream of the confluence with Deep Creek. A locality map is presented as Figure 2-3.

2.2 Flooding Issues

The hydrology and hydraulics associated with flood flows and flood levels on the Murray River at Barmah are extremely complicated. The Barmah Flood Mitigation Study (GHD 1994) identified three mechanisms by which flooding of the River Murray at Barmah can occur:

1. Murray River flooding at Barmah caused by widespread floods in the Murray catchment.
2. "Backdoor Flooding" at Barmah caused by floodwaters arising principally from the Ovens River and other streams flowing from the Great Dividing Range to the Murray downstream of the Hume. In these cases floodwaters spill from the Murray proper at around Cobram and flow over the floodplain towards Barmah. This mechanism was evident in the 1870 and October 1993 floods.
3. Goulburn River flooding from the Deep Creek system, where floodwaters back up through Barmah.

The interrelationships between these three flooding mechanisms make it difficult to quantify a design flood.

The township of Barmah is situated on the Victorian bank of a stretch of the Murray River upstream of the Bama Sandhills. In times of major floods, the pooling of Murray River flood flows upstream of the Bama Sandhills has sometimes caused the Murray River to flow backwards through the Barmah-Millewa forest.

Although the hydrology of major floods at Barmah is complex, making it hard to estimate a design flood, the incremental change in flood level with flow is relatively small due to the large width of

SKM

the floodplains. However the topography at Barmah is relatively flat so a small change in flood level has the potential to inundate a much larger area.

Three previous studies have estimated the 100 year ARI flood level at Barmah:

- RWC (1986) estimated that the 100 year ARI flood level was 96.9 m AHD. This was based on the 1975 flood level plus 0.4 m.
- GHD (1994) also estimated that the 100 year ARI flood level was 96.9 m AHD. This was based on a synthetic flood frequency curve. This study questioned the accuracy of gauged flood levels at Barmah, so instead levels were calculated by interpolating between accurate gauged levels at Yarrawonga, Toccumal and Echuca. Assumptions based on anecdotal evidence were also made.
- MDBC River Mapping adopted a 100 year ARI flood level of 96.9 m AHD. This level is now declared under the Water Act.

In the past the Nathalia Shire has adopted 96.7 m AHD as the 100 year ARI flood level at Barmah, setting minimum floor levels 0.3 m higher at 97.0 m AHD. It must be noted that these past 100 year ARI flood level estimates are based on Murray River floods, so are not necessarily Goulburn River dominated, like the floods we are looking at in this study.

2.3 Previous Flooding Events

GHD (1994) includes a summary of historic flood levels at Barmah, along with a discussion of the accuracy of the measurements, and where required have estimated the flood levels from anecdotal evidence. These flood levels are summarised in Table 2-1.

- **Table 2-1 Summary of the largest historic floods on record at Barmah, from GHD (1994)**

Year ARI	1870	1867	1917	1993	1916	1975	1956	1974	1931
Flood Levels (m AHD)	97.3*	96.8*	96.7*	96.51	96.5*	96.5	96.3*	96.2	96.1*

* GHD (1994) estimated flood levels (not actual gauged data).

The LGFRS project used the 1993 flood for calibration purposes, and has collated in some detail the sequence of events that led to a flood level at Barmah of 96.51 m AHD. The 1993 flood peaked on the Goulburn River at Shepparton gauge on the 7th of October and was preceded by a smaller flood peak on the 19th of September. The flood at the Shepparton gauge was estimated to be approximately a 27 year ARI flood event (WT & SKM, 2005). Goulburn River levees were breached or damaged at 45 separate locations on the south bank downstream of Coomboona and at eight separate locations on the north bank in the proximity to McCoys Bridge. Levees were also breached at Madowla Park and downstream of Hancocks Outlet. Figure 2-1 shows a section of levee with a number of failures that occurred during the October 1993 floods.

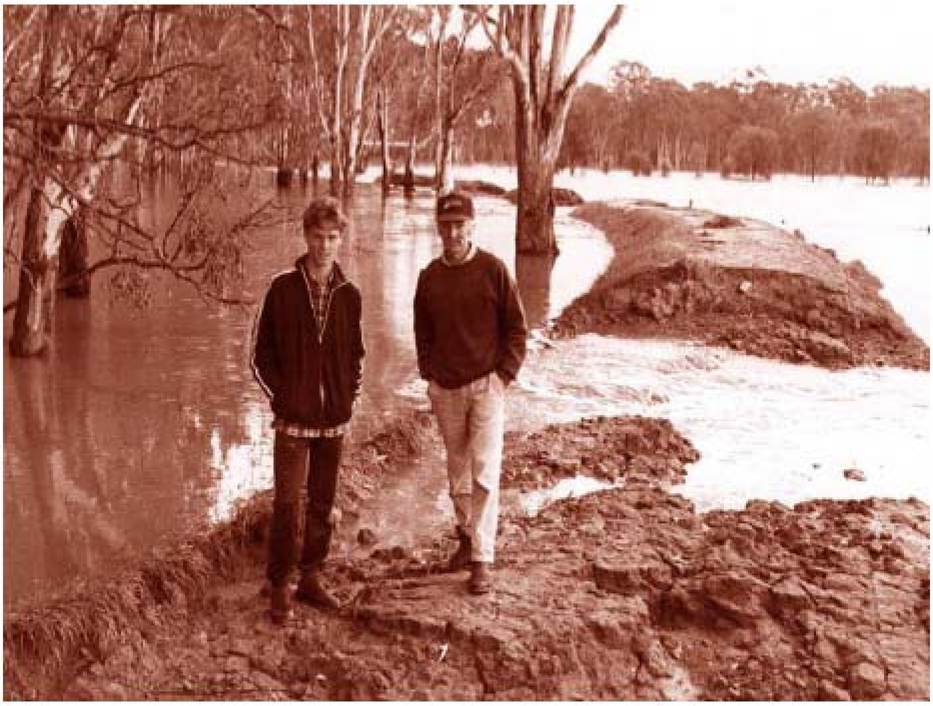
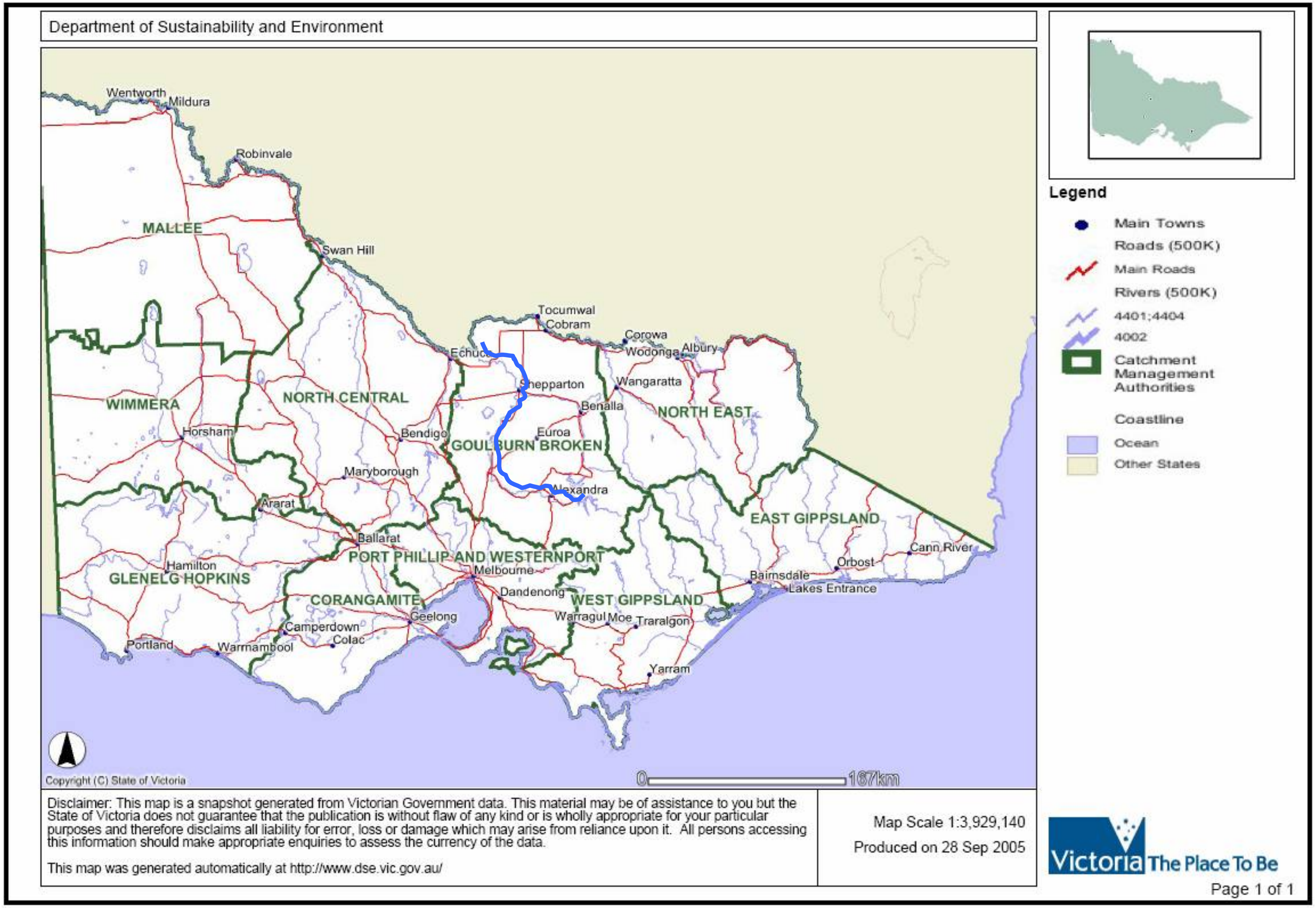
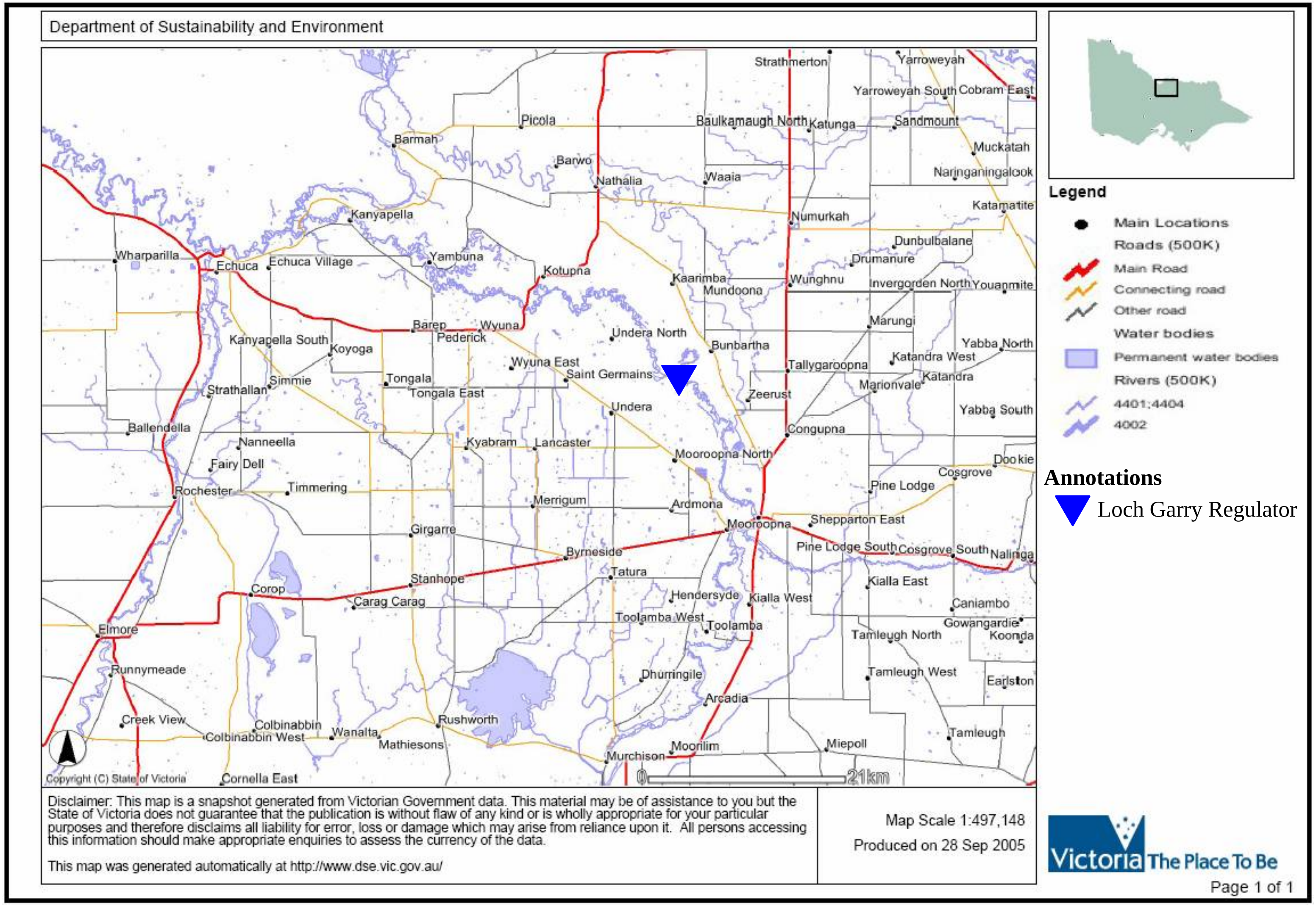


Photo taken from Water Technology and Sinclair Knight Merz (2003), courtesy of the Shepparton News

- **Figure 2-1 Goulburn River levee failures during the October 1993 flood**



- **Figure 2-2 Goulburn River locality map**



- **Figure 2-3 Lower Goulburn River floodplain locality map**

3. Data Availability

A number of key datasets were required to assess flood damage costs and potential mitigation measures for the township of Barmah, including:

- general topography and layout of town,
- location and description of buildings with floor levels and details of other infrastructure,
- existing flood mitigation measures,
- design flood levels; and,
- flood damage costs and mitigation option costs from available literature.

3.1 Topography and Town Layout

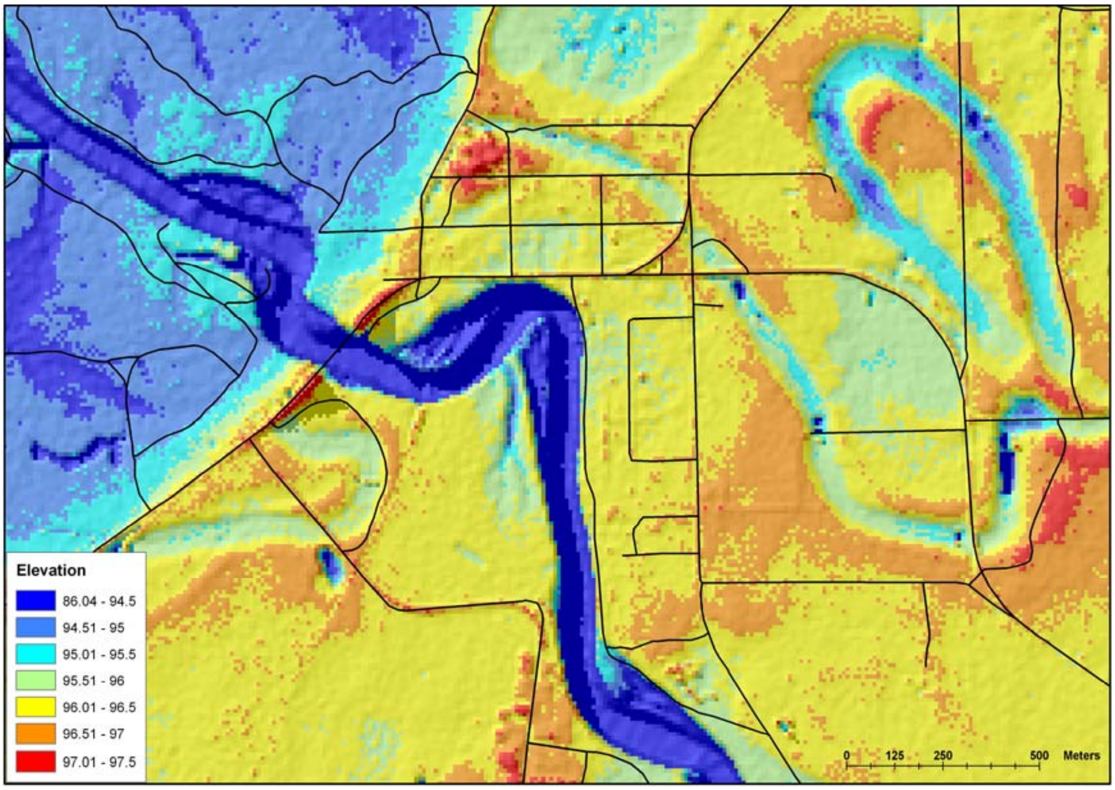
Infrared aerial photography of the township of Barmah taken in 2002 is presented as Figure 3-1. It provides a layout of the river, buildings and roads, aiding in the identification of buildings and infrastructure during the site investigation, and the planning of flood mitigation measures.

- **Figure 3-1 Infrared aerial photograph of the township of Barmah**

The topography of the town and its surrounding area was available as a 10 m digital elevation model constructed for the LGFRS. As can be seen in Figure 3-2 the topography across the town is relatively flat, and is generally between 96.0 to 96.5 m AHD. The digital elevation model was used

SKM

to identify the potential extent of inundation for design floods, confirming that the town is vulnerable to flooding from levels of approximately 96.0 m AHD. It also aided in the alignment and sizing of potential flood mitigation measures. Combined with information on floor level above ground from the site investigation, it was used as a surrogate for floor levels when detailed survey data was not available.



- **Figure 3-2 Digital elevation model of the township of Barmah**

3.2 Property Survey Data

A total of 133 buildings were identified in the township of Barmah, only 13 of which were non-residential. The majority of these buildings were surveyed in detail in the GHD (1994) study. Floor levels, floor types (i.e. concrete slab or timber), building material and general comments were available from this earlier study. Using the topography and the floor level estimates from the site investigation, the survey data was confirmed, and was used where available. Where new buildings had been constructed since 1994, floor levels were estimated by adding the digital elevation model ground level to an estimate of height above ground from photographs and the site investigation.

The residential buildings vary from small fibro sheds and annexes on caravans, to large brick veneer houses built in the last decade.

SKM

In addition to the 133 buildings, a large number of sheds and two separate caravan parks were identified. These sheds and caravan parks were not included in the flood damage cost calculations. The flood damage assessment was limited to the Victorian side of the Murray River, thus the Aboriginal community of Curramugunga was not included.

3.3 Existing Flood Mitigation Measures

During the site investigation the existing flood levees were inspected and found to be generally in poor condition, with large sections removed for driveway access, crests and batters scoured, inadequate tie in with high ground and no consistent standard of protection along the length. It is also considered unlikely, given their visual appearance, that they would have adequate structural integrity to withstand a large flood.

If levee options are to be pursued, new levees would be required, rather than rebuilding of existing levees.

3.4 Design Flood Levels

The 2D MIKE FLOOD model constructed during the LGFRS and Bramah-Millewa studies was developed by Water Technology to estimate flood levels at the township of Barmah for a range of flood magnitudes from a 20 year ARI to a 100 year ARI. Many uncertainties are associated with the complex nature of the hydrology of the Lower Goulburn River during these large design flood events, including the interaction of flooding mechanisms and the increased potential of levee failures. Model results showed that while flood level changes within the forested areas of Barmah-Millewa are negligible under LGFRS conditions, the river reach through the Barmah Township is slightly throttled resulting in a 160 millimetre increase in the 100 year ARI flood level in this area. Figure C-1 in Appendix C shows the approximate extent and depth of flooding in and around the Barmah township during post LGFRS conditions.

The design flood levels predicted by the model at the township of Barmah are presented below in Table 3-1.

- **Table 3-1 Estimates of design flood level at Barmah, from the hydraulic model**

	Design Flood Levels (m AHD)		
	100 year ARI	50 year ARI	20 year ARI
Existing conditions	96.97	96.69	96.56
Post LGFRS conditions	97.13	96.85	96.63
Difference (m)	0.16	0.16	0.07

3.5 Flood Damage and Mitigation Option Costs

Three key sources were used for flood damage cost estimation methodology:

- ‘Rapid Appraisal Method (RAM) For Floodplain Management’ (Read Sturgess & Associates, 2000);
- ‘Economic Costs of Natural Disasters in Australia’ (Bureau of Transport Economics, 2001); and,
- ‘Guidance on the Assessment of Tangible Flood Damages’ (Queensland Government Department of Natural Resources and Mines).

Two additional sources were used for estimates of flood damage costs:

- ‘Australian Construction Handbook Edition 23’ (Rawlinsons, 2005); and,
- ‘www.abs.gov.au’ (The Australian Bureau of Statistics).

Some costing data required for the construction of levees was not available from these sources, and in-house expertise in the design and construction of levees was utilised. These sources are referenced where applicable throughout Section 4.

4. Assessment of Flood Damage Cost

4.1 Existing Conditions

For the purposes of this flood damage assessment, the study area was defined as the urban area of the township of Barmah, with economic costs and benefits outside the town not considered in the analysis (refer to Appendix A for details of flood damage assessment calculations).

4.1.1 Direct Damage to Buildings

Floods can potentially cause a high level of damage to buildings, including structural damage (eg. walls, floors, doors, etc.), contents damage (eg. carpets, furniture, etc.) and external damage (eg. gardens, etc.).

For each building within the township, a depth of above floor inundation was calculated under existing conditions for the design flood levels adopted in Section 3.4, using the floor levels from the property data described in Section 3.2.

Read Sturgess & Associates (2000) recommends that potential flood damage costs be estimated as $20,500 (1999 dollars) per building inundated above floor level. It recommends however that this approach not be used if more detailed stage-damage curves are available.

Stage-damage curves estimate the relationship between the depth of above floor inundation of a building and the potential flood damage cost. This relationship is typically calculated by post-flood survey. ANUFLOOD stage-damage curves for residential and commercial buildings (NRM, 2002), were factored up by 60 % to bring them up to a representative 1999 flood damage cost level, as recommended by Read Sturgess & Associates (2000). They were then factored up to a June 2005 flood damage cost level using Building Price Index (BPI) and Consumer Price Index (CPI) from (Rawlinsons, 2005) and (ABS, website). These values were than factored by the ratio of the June 2008 CPI to the June 2005 CPI to estimate 2008 costs.

The total potential flood damage cost for existing conditions was then calculated by applying the updated stage-damage curves to each building and summing the individual potential flood damage costs.

The total potential flood damage cost represents the flood damage cost if no remedial action is taken. In reality, communities at risk of flooding will usually have some warning and will be able to take steps toward reducing the cost of flood damage (i.e. evacuation, doorstep sandbagging or removing valuable items to a safe level above flood waters). Read Sturgess & Associates (2000), estimated that for a community such as Barmah, having prior flood experience and significant warning time, the ratio of actual to potential flood damage cost could be as little as 0.4. However given that a significant amount of time has passed since the last flood event, the ratio could be as high as 0.7. In this study a ratio of 0.7 was applied to the total potential flood damage cost as a conservative estimate of the total actual flood damage cost.

The total actual flood damage cost along with the number of residential and commercial buildings inundated for the adopted existing condition design flood levels are presented in Table 4-1.

Table 4-1 Total actual flood damage cost for Barmah township for existing conditions

Flood ARI	Flood Level (m AHD)	Total Buildings Inundated #	Potential Flood Damage Cost ($)*	Actual Flood Damage Cost ($)*
5^	95.85	0 (0)	0	0
20	96.56	20(2)	370,000	260,000
50	96.69	34(5)	680,000	470,000
100	96.97	76(8)	1,920,000	1,340,000

Total buildings inundated with commercial buildings in brackets.

^It has been assumed that no flood damage costs would be incurred as a result of the five year ARI flood event.

*Note that these costs are for property damage only and do not include road repairs or indirect clean up costs.

As presented in Table 4-1 the estimated actual flood damage cost for buildings under existing conditions is approximately $1,340,000 for the 100 year ARI event. However, it should be noted that the Barmah region is susceptible to large variations in flood damage costs due to the flatness of the topography and the small range of floor levels within the township of Barmah, and as such it is advised here that actual flood damage costs could vary significantly depending on actual flood levels.

4.1.2 Direct Damage to Roads

Floods can potentially cause significant damage to roads and other inundated infrastructure. Roads can suffer initial damage from flooding as well as accelerated deterioration due to water intrusion under the pavement. Roads are the only major infrastructure in the township of Barmah that is at risk of significant flood damage, and can be readily estimated.

BTE (2001) provides estimates of the cost required to repair flood damaged major, minor and unsealed roads in 1999 dollars. This was factored up by CPI to March 2008 dollars.

The length of inundated major, minor and unsealed roads was calculated for the adopted existing condition design flood levels, and used to estimate the total cost of flood damage to, Table 4-2.

SKM

- **Table 4-2 Roads flood damage cost for existing conditions**

Flood ARI	Flood Level (m AHD)	Roads Flood Damage Cost ($)
5^	95.85	0
20	96.56	120,000
50	96.69	140,000
100	96.97	180,000

^It has been assumed that no flood damage costs would be incurred as a result of the five year ARI flood event.

4.1.3 Indirect Damages

Indirect flood damages are damages sustained as a consequence of a flood but are not due to the direct impact of a flood (eg. emergency services, clean-up costs, alternative accommodation, disruption to business, etc.). Indirect costs are much harder to quantify than direct costs, so only the more readily estimated costs are usually included.

Read Sturgess & Associates (2000) recommend estimating indirect costs as 30% of total direct costs (depending on population density). This is a fairly coarse approximation and has not been adopted in this case. Instead a more detailed analysis has been undertaken, using methodology from BTE (2001).

Included in the estimate of indirect flood damage costs are residential and commercial clean-up, alternative accommodation and relocation of household goods, and emergency response costs, Table 4-3.

- **Table 4-3 Indirect flood damage cost for Barmah township for existing conditions**

Flood ARI	Flood Level (m AHD)	Clean-up Costs ($)	Alternative Housing and Relocation Costs ($)	Emergency Response Costs ($)	Total Indirect Costs ($)
5^	95.85	0	0	0	0
20	96.56	110,000	10,000	10,000	130,000
50	96.69	190,000	20,000	20,000	230,000
100	96.97	400,000	50,000	20,000	470,000

^It has been assumed that no flood damage costs would be incurred as a result of the five year ARI flood event.

4.1.4 Total Existing Condition Damages

The total flood damage cost for the township of Barmah under existing conditions is a sum of the actual flood damage cost of buildings, the road flood damage cost and the indirect flood damage cost, Table 4-4.

SKM

Table 4-4 Total flood damage cost for Barmah township for existing conditions

Flood ARI	Flood Level (m AHD)	Actual Flood Damage Cost to Buildings ($)	Road Flood Damage Cost ($)	Total Indirect Cost ($)	Total Flood Damage Cost ($)
5^	95.85	0	0	0	0
20	96.56	260,000	120,000	130,000	510,000
50	96.69	470,000	140,000	230,000	840,000
100	96.97	1,340,000	180,000	470,000	1,990,000

^It has been assumed that no flood damage costs would be incurred as a result of the five year ARI flood event.

4.2 Post Proposed Lower Goulburn Floodplain Rehabilitation Scheme

The flood damage cost assessment for post LGFRS conditions followed the same process as that for existing conditions, the only difference being the elevated flood levels.

The total flood damage cost for post LGFRS conditions are presented in Table 4-5.

Table 4-5 Total flood damage cost for Barmah township for post LGFRS conditions

Flood ARI	Flood Level (m AHD)	Actual Flood Damage Cost to Buildings ($)	Road Flood Damage Cost ($)	Total Indirect Cost ($)	Total Flood Damage Cost ($)
5^	95.94	0	0	0	0
20	96.63	360,000	130,000	170,000	660,000
50	96.85	930,000	170,000	370,000	1,470,000
100	97.13	2,140,000	200,000	630,000	2,970,000

^It has been assumed that no flood damage costs would be incurred as a result of the five year ARI flood event.

4.3 Effect of LGFRS on Flooding at Barmah

The average annual damage (AAD) for the existing and post LGFRS scenarios was calculated. Table 4-6 shows a comparison of the AAD for the existing and post LGFRS scenarios. The AAD figures shown here represent the total annual damages for all events up to the 100 year ARI flood event.

Table 4-6 Average annual damages for existing and post LGFRS conditions

Existing 100 year ARI Flood Level (m AHD)	Existing AAD ($)	Post LGFRS 100 year ARI Flood Level (m AHD)	Post LGFRS AAD ($)	Difference (Post LGFRS – Existing) AAD ($)
96.97	50,000	97.13	80,000	30,000

In terms of the number of over the floor flooding for the existing and post LGFRS refer to Table 4.7

- **Table 4-7 Comparison of numbers of buildings inundated for existing and post LGFRS conditions**

Flood ARI	- Existing - Flood Level (m AHD)	- Existing - Buildings Inundated	- Post - Flood Level (m AHD)	- Post – Buildings Inundated	Difference (Post LGFRS – Existing)
5^	95.85	0 (0)	95.94	0 (0)	0 (0)
20	96.56	20 (2)	96.63	26 (4)	6 (2)
50	96.69	34 (5)	96.85	59 (6)	25 (1)
100	96.97	76 (8)	97.13	102 (11)	26 (3)

Total buildings inundated with commercial buildings in brackets.

^It has been assumed that no flood damage costs would be incurred as a result of the five year ARI flood event.

SKM

5. Assessment of Mitigation Measure Benefit

5.1 Mitigation Options

A number of flood mitigation measures were considered by GHD (1994), including do nothing, raise floor levels, construct levees, purchase flood prone land, planning controls and combinations of the five mitigation measures. GHD concluded that a levee alignment with a crest level of 0.6 m above the 100 year ARI flood level of 96.9 m AHD along with planning controls was the most viable flood mitigation measure.

The raising of floor levels is expensive and not considered viable as many buildings are built on concrete slabs. A 100 year ARI flood under existing conditions could potentially inundate between 28 to 71 buildings (depending on the adopted 100 year ARI flood level), the purchase of flood prone properties as a standalone flood mitigation measure is hence not considered viable. Planning control whilst providing protection for future development cannot protect against flooding for existing development, hence it too is not considered a viable stand alone flood mitigation measure. The construction of levees are considered the best viable flood mitigation measure for the township of Barmah, with planning control and perhaps minor purchasing of flood prone properties if required.

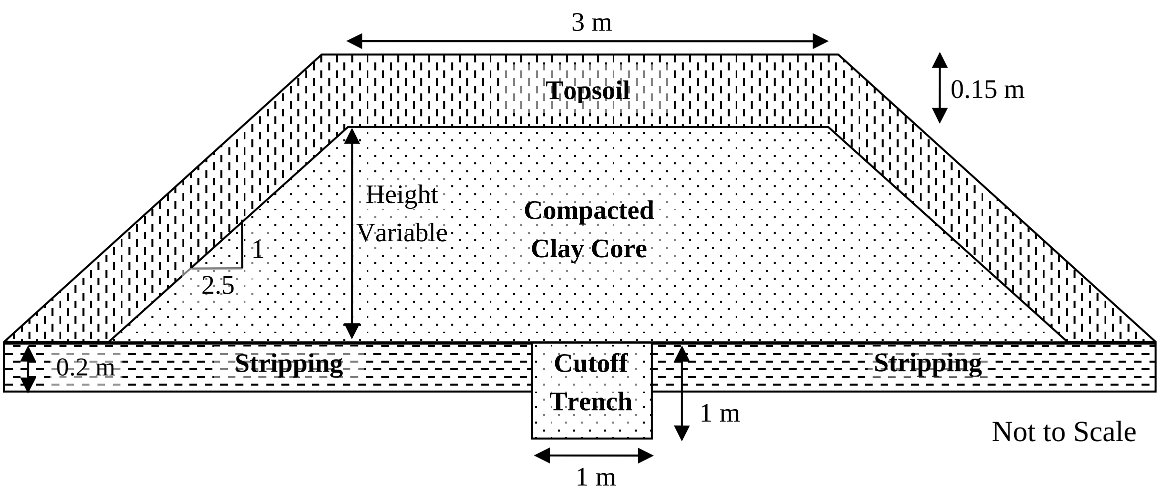
Two levee alignments were considered in this study, as presented in Figure 5-1 and Figure 5-2.

Levee alignment 1 utilises existing roads all the way along its course. It ties in with the Murray River bridge ramp at both ends. Initially raising the road levels was considered, but this option is seen as prohibitively expensive, instead a levee running alongside the road provides a more cost effective option. Levee alignment 1 is approximately 4.2 km long with a crest height of 0.6 m plus the 100 year ARI flood level. Levee alignment 1 is perhaps the simplest alignment, protecting the majority of buildings in the township of Barmah. However levee alignment 1 does not protect the caravan park beside the river, the 6 residential buildings and 1 commercial building to the north of Corry Street, the 5 residential buildings to the east of Moor Street and Barmah Tip Road, or the four residential buildings on the low lying area south of Murray Street.

Levee alignment 2 runs the same course as that of levee alignment 1 except for the northern and eastern boundaries. Levee alignment 2 is approximately 4.4 km long with a crest height of 0.6 m plus the 100 year ARI flood level. Levee alignment 2 protects the same area as that of levee alignment 1 with the addition of protecting 5 of the buildings to the north of Corry Street and the five buildings to the east of Moor Street and Barmah Tip Road.

Both levee alignments cross existing roads at four locations. These locations must remain open to traffic, either the roads must be raised to the equivalent levee crest level, a drop bar arrangement installed or sandbagging (perhaps the cheapest alternative) carried out in times of flood.

- **Figure 5-1 Proposed levee alignments for Barmah township flood mitigation (alignment 1: red solid line; alignment 2: green dotted line)**



- **Figure 5-2 Proposed typical levee cross-section for Barmah township flood mitigation**

SKM

5.2 Cost of Mitigation Options

The two levee alignments were evaluated for all the existing and post LGFRS condition adopted 100 year ARI flood levels.

The levee crest heights were calculated by subtracting the ground level (from the digital elevation model), from the levee crest level (adopted 100 year ARI flood level + 0.6 m freeboard), at 1m intervals along the levee alignment. All other levee parameters are given in Figure 5-2.

The volume of material for the levees compacted clay core, cut-off trench, topsoil and stripping were calculated from the levee parameters.

The volume of material for each of the levee components was then multiplied by an indicative cost per unit volume, Appendix B to calculate the cost of each component. A 35% contingency cost was added to the total of the component costs to allow for increases in required volumes, increases in unit volume costs and any unexpected project related costs. Another $100,000 was also added to the total construction cost to allow for culvert extensions, drainage modifications, levee bank tie-ins and any drop bar structures if required. An annual operation and maintenance cost of $6,000 was also factored in; $2,000 per year for annual inspections and reports, $2,000 per year for minor works and $20,000 per 10 years for major works. The total construction costs were factored up by the ratio of the June 2008 CPI to June 2005 CPI (excluding operation and maintenance costs). The estimated total construction costs are presented in Table 5-1.

- **Table 5-1 Proposed levee construction costs for Barmah township flood mitigation**

Scenario	100 year ARI Flood Level (m AHD)	Levee Alignment 1 Total Cost ($)	Levee Alignment 2 Total Cost ($)
Existing	96.97	1,090,000	1,130,000
Post LGFRS	97.13	1,250,000	1,300,000

5.3 Benefit Cost Analysis of Flood Mitigation Schemes

To assess the economic viability of the proposed mitigation measures a benefit cost analysis was conducted as part of this study. A benefit cost ratio greater than one (1) indicates that benefits outweigh the cost of implementing a scheme. A benefit cost ratio below one (1) indicates that costs outweigh benefits. In the latter case the option becomes difficult to justify on economic grounds. The ratio provides a means by which the options can be ranked on economic grounds. For the economic analysis, a 30 year project life and 4% and 8% discount rate were used. The steps taken in computing benefit cost ratio are:

B = average annual benefit ($)

SKM

= average annual damage for existing situation – average annual damage for a given mitigation option.

N = net annual benefit ($)

= B – annual maintenance cost for a given mitigation scheme

P = present value of benefits ($). This is a capitalised value computed by discounting N over the life of the works (Y years) at a discount rate of i, such that:

$$P = \left(\frac{(1+i)^Y - 1}{i(1+i)^Y}\right)N$$

Benefit cost ratio = P/C, where C = the present value of costs

Table 5-2 shows the benefit cost ratios for the two alignment scenarios under existing and post LGFRS conditions.

- **Table 5-2 Benefit cost ratio of levee options for Barmah township flood mitigation**

Scenario	Benefit Cost Ratio of Levee Alignment 1		Benefit Cost Ratio of Levee Alignment 2	
	Discount Rate 4%	Discount Rate 8%	Discount Rate 4%	Discount Rate 8%
Existing	0.66	0.46	0.69	0.48
Post LGFRS	0.96	0.67	0.98	0.68

From Table 5-2 it is apparent that the proposed flood mitigation works are not economically viable under existing or post Lower Goulburn Floodplain Rehabilitation Scheme conditions.

6. Conclusions

The purpose of this study was to address one of the additional project tasks arising from Monash International's review; assessing the flood risk to the township of Barmah. This study assessed the incremental increase in flood risk and flood damage costs associated with the implementation of the Lower Goulburn Floodplain Rehabilitation Scheme, and assessed the costs and benefits of flood mitigation measures for the township of Barmah.

The hydrology of flooding at Barmah is extremely complicated with widespread Murray River flooding, Goulburn River flooding and back door flooding from Cobram all possible and all interrelated. For large Goulburn River floods it is uncertain where levees will be breached, and what floodplain will become active. The complicated hydrology and uncertainty of levee breaches makes it extremely hard to estimate design flood levels at Barmah.

The average annual damage is a measure of the flood damage per year averaged over an extended period. The Lower Goulburn Floodplain Rehabilitation Scheme is estimated to increase average annual flood damage costs to Barmah by $30,000 for all events up to the 100 year ARI event.

A levee scheme was thought to be the most viable flood mitigation measure for the township of Barmah. Two levee alignments were considered, both providing protection for the majority of the buildings within the township of Barmah, the second alignment protected 10 extra buildings. The levee alignments were between 4 and 4.5 km long with crest levels equal to the adopted 100 year ARI flood level plus 0.6 m of freeboard. Levees were costed for the existing and post LGFRS 100 year ARI flood levels. The total construction cost of the levees analysed ranged from an estimated $1,090,000 to $1,300,000.

The potential costs and benefits of the levees under existing and post Lower Goulburn Floodplain Rehabilitation Scheme conditions were analysed. The economic assessment showed that levee alignments one and two were not economically justifiable under existing or post LGFRS conditions.

It should be noted that the Victorian State Government has subsequently resolved not to proceed with the Lower Goulburn Floodplain Rehabilitation Scheme.

7. Recommendations

It is important to note that this study was an economic assessment of flood risk to the township of Barmah, and has not considered the many relevant social and political issues. This includes the cost sharing and equity issues that arise when changes in floodplain management increase the risk associated with flooding for affected communities. The economic costs and benefits able to be quantified indicate that the flood mitigation options when considered in isolation from the broader costs and benefits of the Lower Goulburn Rehabilitation Scheme, are generally uneconomic (i.e. costs exceed benefits). As such, it is recommended that equity concerns and cost sharing be considered alongside the economic costs and benefits described in this report before making any decision regarding the suitability of potential mitigation measures to alleviate flood risk at Barmah.

8. References

Australian Bureau of Statistics, www.abs.gov.au

Bureau of Transport Economics (2001), 'Economic Costs of Natural Disasters in Australia', Canberra, Australia.

Water Technology & Sinclair Knight Merz (2005), 'Lower Goulburn Floodplain Rehabilitation Scheme – Hydraulic Modelling Report', for Goulburn Broken Catchment Management Authority.

Gutteridge Haskins & Davey (1994), 'Barmah Flood Mitigation Study', for Nathalia Shire.

Monash International (2003), 'Review of the Lower Goulburn Floodplain Rehabilitation Project', for the Department of Sustainability and Environment.

Queensland Government Natural Resources and Mines (2002), 'Guidance on the Assessment of Tangible Flood Damages'.

Rawlinsons (2005), 'Australian Construction Handbook: Edition 23',Rawlhouse Publishing PTY LTD, Bassendean WA, Australia.

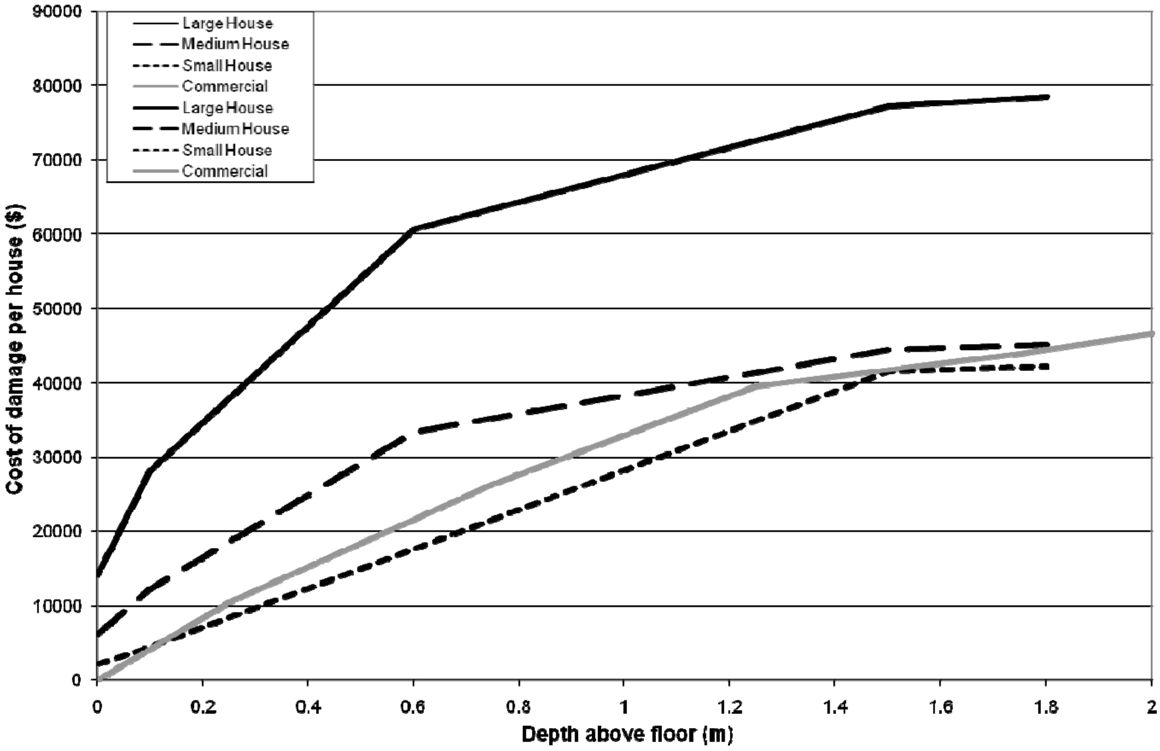
Rural Water Corporation (1986), 'Murray River Floodplain Management Study'.

SKM

Appendix A Flood Damage Cost Estimation Data

A.1 Stage-Damage Curves

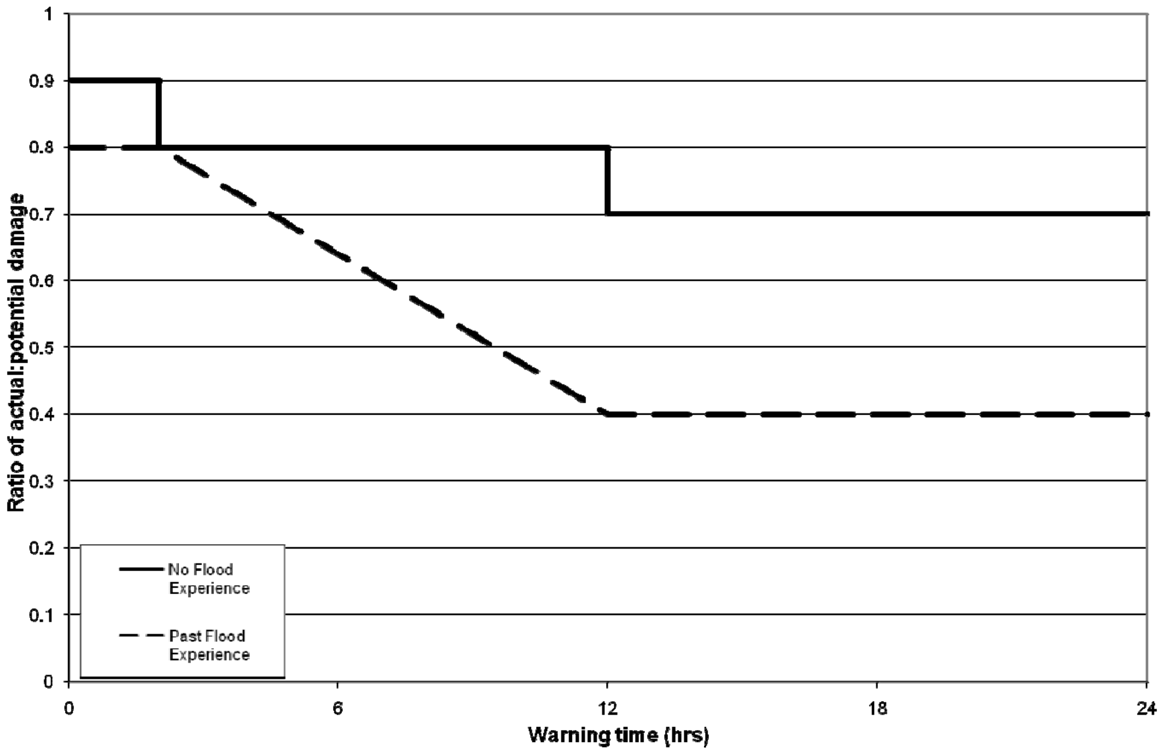
ANUFLOOD stage-damage curves for residential and commercial buildings (developed in 1992) were obtained from (NRM, 2002), and were factored up by 60 % to bring them up to a representative 1999 flood damage cost level, as recommended by Read Sturgess & Associates (2000). They were then factored up to a June 2005 flood damage cost level using Building Price Index (BPI) and Consumer Price Index (CPI) from (Rawlinsons, 2005) and (ABS, website). These values were than further adjusted by factoring them up by the ratio of the June 2008 CPI to the June 2005 CPI. The commercial buildings in the township of Barmah are relatively small and the ANUFLOOD stage-damage curve of a small commercial property of value class ‘2’ has been used. The stage-damage curves shown in Figure A-1 have been factored as described above.



- **Figure A-1 Stage-damage curves used in flood damage cost assessment**

A.2 Ratio of actual to potential flood damage

The total potential flood damage cost represents the flood damage cost if no remedial action was taken. In reality communities at risk of flood will usually have some warning and will be able to take steps toward reducing the cost of flood damage (i.e. evacuation, doorstep sandbagging or removing valuable items to a safe level above flood waters). Read Sturgess & Associates (2000) have developed a relationship between warning time and the ratio between potential to actual flood damage, Figure A-2. For a community such as Barmah, having prior flood experience and significant warning time, the ratio of actual to potential flood damage cost could be as little as 0.4. However, given the significant amount of time that has passed since the last flood event the ratio could be high as 0.7. In this study a ratio of 0.7 was applied to the total potential flood damage cost, to estimate the total actual flood damage cost.



- **Figure A-2 Relationship between ratio of potential to actual flood damage and warning time**

SKM

A.3 Infrastructure flood damage costs

BTE (2001) provides estimates of the cost required to repair flood damaged major, minor and unsealed roads at a 1999 cost level. This was factored up by CPI to a June 2008 cost level, Table A-1. It was assumed that no damage to bridges was incurred for floods up to the 100 year ARI.

- **Table A-1 Cost of repairs for flood inundated roads**

	Initial Repairs ($)	Accelerated depreciation ($)	Bridge repairs ($)	Total cost ($)
Major sealed roads	43,112	21,556	14,820	79,488
Minor sealed roads	13,472	6,736	4,715	24,924
Unsealed roads	6,063	3,031	2,156	11,250

A.4 Indirect flood damage costs

Included in the estimate of indirect flood damage costs for the township of Barmah is residential and commercial clean-up, alternative accommodation and relocation of household goods, and emergency response costs. Costs were obtained from (BTE, 2000) and were factored by CPI to a June 2008 cost level, Table A-2.

- **Table A-2 Cost of repairs for flood inundated roads**

Indirect Cost Description	Indirect Cost Calculation
Residential clean-up costs -Materials -Labour	 $445 per household inundated average weekly wage (from ABS website) × 4 working weeks ($1,123 × 4 = $4,493) per household inundated)
Commercial clean-up costs	$3,233 per building inundated
Alternative accommodation	Cost of accommodation per person per night × 7 nights × average number of people per household (from ABS website) ($35 × 7 × 2.6 = $637 per household inundated)
Relocation of household items	$71 per household inundated
Emergency Response Labour	The number of volunteer workers required will differ for the severity of the flood. For 50 and 100 year ARI flood assume 50 volunteers working 15 hours (50 × 15 × $1,123/40 = $21,056) For 20 year ARI flood assume 30 volunteers working 15 hours (30 × 15 x $1,123/40 = $12,634) For 10 year ARI flood assume 10 volunteers working 15 hours (10 × 15 x $1,123/40 = $4,211)

SKM

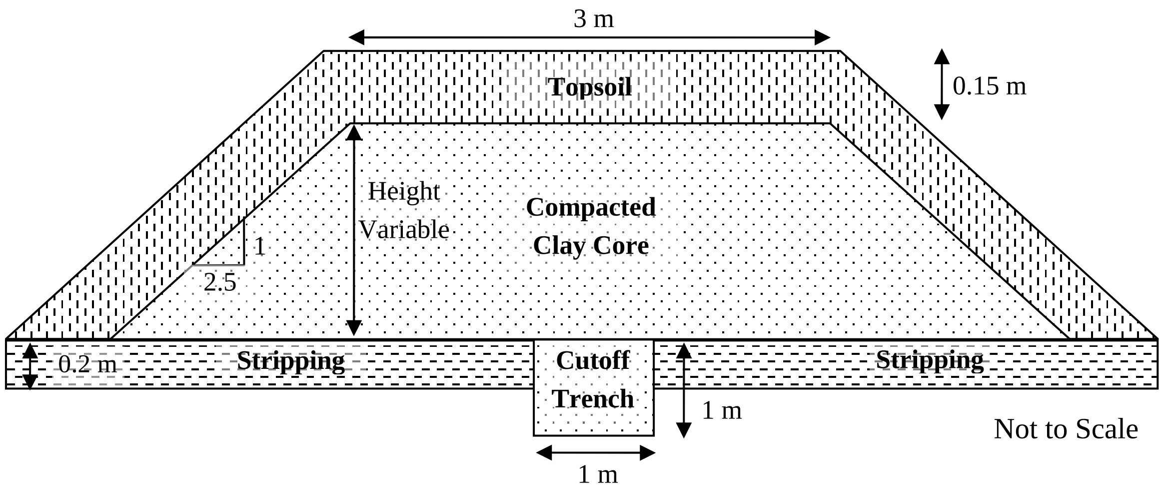
Appendix B Levee Construction Cost Data

Two levee alignments were costed for all the existing and post LGFRS conditions adopted 100 year ARI flood levels.

The levee crest heights were calculated by subtracting the ground level (from the digital elevation model), from the levee crest level (adopted 100 year ARI flood level + 0.6 m freeboard), at 1m intervals along the levee alignment. All other levee parameters are given in Figure B-1.

The volume of material for the levees compacted clay core, cut-off trench, topsoil and stripping were calculated from the levee parameters.

The volume of material for each of the levee components was then multiplied by an indicative cost per unit volume, Table B-1, to calculate the cost of each component. A 35% contingency cost was added to the total of the component costs to allow for increases in required volumes, increases in unit volume costs and any unexpected project related costs. Another $100,000 was also added to the total construction cost to allow for culvert extensions, drainage modifications, levee bank tie-ins and any drop bar structures if required. An annual operation and maintenance cost of $6,000 was also factored in; $2,000 per year for annual inspections and reports, $2,000 per year for minor works and $20,000 per 10 years for major works. The total construction costs were factored up by the ratio of the June 2008 CPI to June 2005 CPI (excluding operation and maintenance costs). Annual operation and maintenance costs were not adjusted.



- **Figure B-1 Typical levee cross-section**

SKM

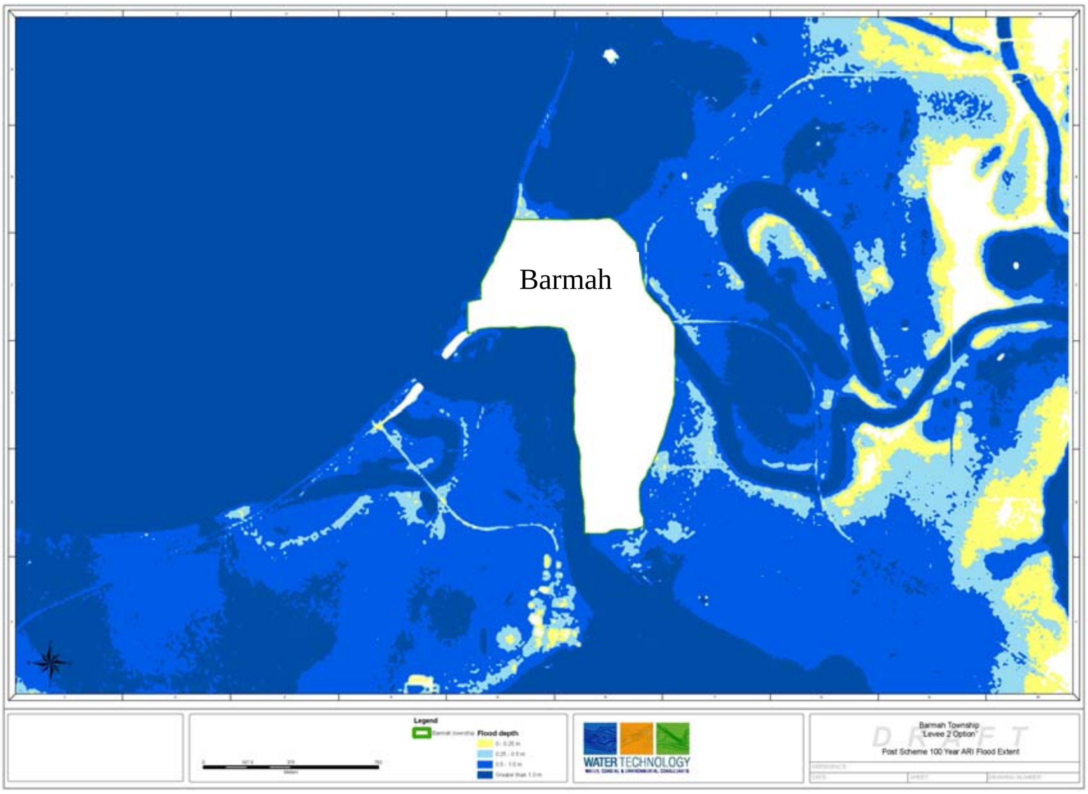
Table B-1 Levee cost per unit volume

Levee Component	2008 Cost per Unit Volume*
Compacted clay core	\$17.75 per m^3
Topsoil	\$2.22 per m^3
Stripping	\$1.66 per m^3
Cut-off trench	\$17.75 per m^3
Contingency	35% of the total cost of the above four components
Other costs (\$)	\$110,916 (for extension of culverts, drainage works, levee tie-ins, drop bar structures if required, etc.)
Annual Operation and Maintenance Cost	\$6,000 total (includes \$2,000 for annual inspection and report, \$2,000 for annual minor works, \$20,000 for major works every 10 years)

*These costs are based on the 2005 construction cost estimates and were factored up from the 2005 value to 2008 prices by the ratio of the June 2008 CPI to the June 2005 CPI. Annual operation and maintenance costs were not adjusted.

SKM

Appendix C Design Flood Levels



- **Figure C-1 Post LGFRS 100 Year ARI Flood Levels (Levee 2 Option) (Flooding Depths at 0.5 Metre Interval and Greater)**