Maribyrnong Flood Mitigation Options

Evaluation of past options

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Contents

Appendices

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1 Executive Summary

Following the significant flooding of the Maribyrnong River in October 2022, Melbourne Water commissioned this investigation to review past flood mitigation studies for the Maribyrnong River. This review has used available information and data to determine if previously considered flood mitigation options should be re-evaluated in more depth in the current context.

This review used the flood information from the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) as its basis. The study was a formative investigation into the flood risk and possible mitigation options for the Maribyrnong River. Much of the information from this report remains highly relevant to the current review. It is noted that the study did not consider the impacts of climate change which is a requirement in the design of contemporary flood mitigation options.

Options Considered

The MMBW (1986) report considered a range of flood risk reduction options including:

- Retarding basins
- Levees
- River channel modifications
- Planning and development controls
- Property acquisition
- Flood resilient homes
- Flood warning systems

The focus of this review is on structural mitigation options. Whilst all other options considered in the MMBW report have risk mitigation value in the current day, other options are either currently implemented as part of Melbourne Water's program of works or are outside the remit of the organisation. A brief discussion of these can be found at Appendix A.

Evaluation of Arundel Retarding Basin Option

Multiple retarding basin options were considered in the MMBW (1986) study. In that study the Arundel Retarding Basin flood mitigation option was considered most effective. The Arundel Retarding Basin option includes a large flood retarding basin on the Maribyrnong River in Keilor North, near the Melbourne Airport. It would reduce the peak flows through the lower Maribyrnong River and thus reduce flood damages. With Arundel Retarding Basin the 1% AEP design peak flow through Maribyrnong Township would be reduced to a flow equivalent to a 20% to 10% AEP under existing conditions. This would reduce the AAD in the Maribyrnong Township area to just $31,000 in today's dollars (from $2.9M). It is noted that the Arundel Retarding Basin would have additional flood risk reduction benefits beyond the Maribyrnong Township.

Whilst effective at reducing flood damages, the cost of the proposed Arundel Retarding Basin is high. Melbourne Water provided indicative comparison costs for similar dam projects across Australia, suggesting that Arundel Retarding Basin could cost in excess of $200M in today's dollars. This high capital cost means the Arundel Retarding Basin option would not be economically feasible, returning a negative Net Present Value (-$144M) and a Benefit-Cost Ratio of 0.3.

Additionally, the retarding basin would have significant impacts on environmental values, cultural heritage values, upstream landholders and the Organ Pipes National Park. Whilst a detailed assessment of these impacts were outside the scope of this review, they are considered significant, and should this option be further investigated, these impacts should be scoped and evaluated in more detail.

Given the high cost (economic, social and environmental), it is considered that the Arundel Retarding Basin is not a viable option for flood mitigation for the Maribyrnong Township, and it is not recommended to pursue this option.

Maribyrnong Township Levee Option

The Maribyrnong Township Levee was also investigated by the MMBW and was found to be the most cost-effective option. The levee would require a significantly high embankment, up to 3 to 4 m in places, which is likely to raise issues with visual and recreational amenity of the area. The levee would require some changes to the road network and MMBW estimated that around 10 properties would need to be purchased for the levee option with 4:1 batter slopes. Increases in flood levels of up to 0.6 m from the levee would require some additional mitigation works on the opposite side of the river, where houses are situated along a low-lying section of The Boulevard in Essendon. To confirm the potential impact of a levee option at Maribyrnong Township, it is recommended that contemporary two-dimensional hydraulic modelling be completed to assess the changed flood behaviour and potential impacts both upstream and downstream.

The levee would be effective at reducing flood risk, protecting the Maribyrnong Township area from floods up to the 1% AEP design magnitude. The average annual damages are reduced to $204,000 in today's dollars. Indicative costs provided by both Melbourne Water and available from published papers suggest that the levee (including property acquisition) would cost in excess of $75M in today's dollars. Within this cost range, an acceptable benefit cost ratio might be achievable. The preliminary analysis suggests a net present value of -$10M and a benefit-cost ratio of 0.87. From an economic perspective this option is worth investigating further. However, it is likely that this would be a contentious issue among the community, and a strong community engagement focus would be required in future investigations of this option.

Effectiveness of Flood Mitigation Evaluated

Both the Arundel Retarding Basin and the Maribyrnong Township Levee options are very effective at reducing the flood risk within Maribyrnong township. A summary of the number of properties impacted by above floor flooding within the Maribyrnong township area is provided in Table 1 below, see Figure 1 for study limits. Despite the fact that the two options evaluated are very effective at reducing the flood risk within Maribyrnong township, the cost, constructability, environmental and cultural impacts of the options must also be considered when determining their feasibility for further consideration.

Table 1 Properties Flooded in Maribyrnong Township

Option	Number of Buildings Flooded Above Floor in 1% AEP event	Average Annual Damage
Existing Conditions	212	$2.9M
Arundel Retarding Basin	1	$31,000
Maribyrnong Township Levee	17	$204,000

This data was extracted from the *Flood Risk Assessment of Maribyrnong Township* (Melbourne Water, 2013)

Evaluation of other options

During this structural mitigation evaluation investigation, the following options were also considered, with the results summarised below:

- Channel modification – not considered a feasible option due to the impacts on the built environment including major infrastructure like bridges and roads, environmental impact, contamination of dredged

sediments, etc. This translates to a high-cost option with questions on feasibility, and not providing the same level of benefit as the Maribyrnong Township Levee or Arundel Retarding Basin options.

- Planning provisions – appropriate planning and development is a key strategy for development in a floodplain. Flood related planning controls are already in place over Maribyrnong Township, but it is suggested that if flood mapping data is updated, Council considers updating their Planning Scheme.
- Property acquisition – The purchase of all 212 properties with above floor flooding in a 1% AEP event in Maribyrnong township would be extremely expensive and not feasible for several reasons. It is noted that property acquisition is not part of Melbourne Water's remit. However, it is a mechanism that has been utilised by other governments in Australia e.g., Queensland's $741M voluntary home buy back resilience scheme, jointly funded through the Commonwealth-State Disaster Recovery Funding Arrangements resilience program, and a similar $800M Resilient Homes Program through the Northern Rivers Reconstruction Corporation in NSW.
- Relocation – Similar to property acquisition, community relocation is outside the current remit of Melbourne Water. Relocation schemes have been implemented around the world, with one of the most successful occurring in Grantham, NSW. A similar scheme is currently being investigated for parts of Lismore. Whilst similar to a property acquisition scheme, relocation generally looks to keep the community together and move them to a nearby area using a land swap mechanism.
- Flood resilient homes was investigated as an option in the 1986 MMBW report. It is noted that this is a key strategy in place in other locations affected by riverine flooding, with a successful scheme in Brisbane running since their 2011 floods. Melbourne Water has developed a Flood Resilient Guide to Retrofitting Your Home and is available online https://www.melbournewater.com.au/water-and-environment/flooding-advice/prepare-flooding. It is recommended that the Maribyrnong community is made aware of this information so they can better prepare for future flooding.
- Flood Warning Systems – Melbourne Water has a flood warning system in place which was operational in the October 2022 flood event. After-action reviews are commonplace in disaster management, it is important to learn from every flood event and continually improve flood warning systems.

Recommendations

The following recommendations are made.

- It is recommended that, pending community support and further hydraulic analysis being completed, that further investigation of a levee is warranted.
- It is recommended that any future modelling investigations of flood risk on the Maribyrnong River should consider the impacts of climate change.
- It is recommended that the Arundel Retarding Basin option is not considered further, with the cost of the option, and the environmental, cultural heritage and upstream impacts rendering the business case unviable.
- It is recommended that the Maribyrnong and Moonee Valley Planning Schemes be updated following the development of new flood modelling along the Maribyrnong River.
- It is recommended that the non-structural options of property acquisition, community relocation and flood resilient design be considered further, but it is noted that this is not currently within Melbourne Water's remit and would require other organisations to take a leading role.
- It is recommended that costing of any further options investigated, be conducted by an experienced cost estimator and economist using any updated flood modelling information, to provide a higher level of certainty on the likely economic outcome of the business case for mitigation.

2 Introduction

2.1 Background

The Maribyrnong River is one of Melbourne's largest river systems. The river network (including tributaries of the Maribyrnong) flows for over 160 km from the slopes of the Macedon Ranges through to the lower Yarra River before discharging to Port Phillip Bay, Figure 1.

The Maribyrnong River's name comes from the Aboriginal phrase *Mirring-gnay-bir-nong*, meaning 'I can hear a ringtail possum'. The Wurundjeri people have a close connection to the river and the land within the Maribyrnong catchment.

The headwaters of the catchment are forested, with the upper catchment giving way to cleared agricultural land, before transitioning into a partly urbanised catchment at Sunbury and then a fully urbanised catchment downstream from Taylors Lakes and Keilor.

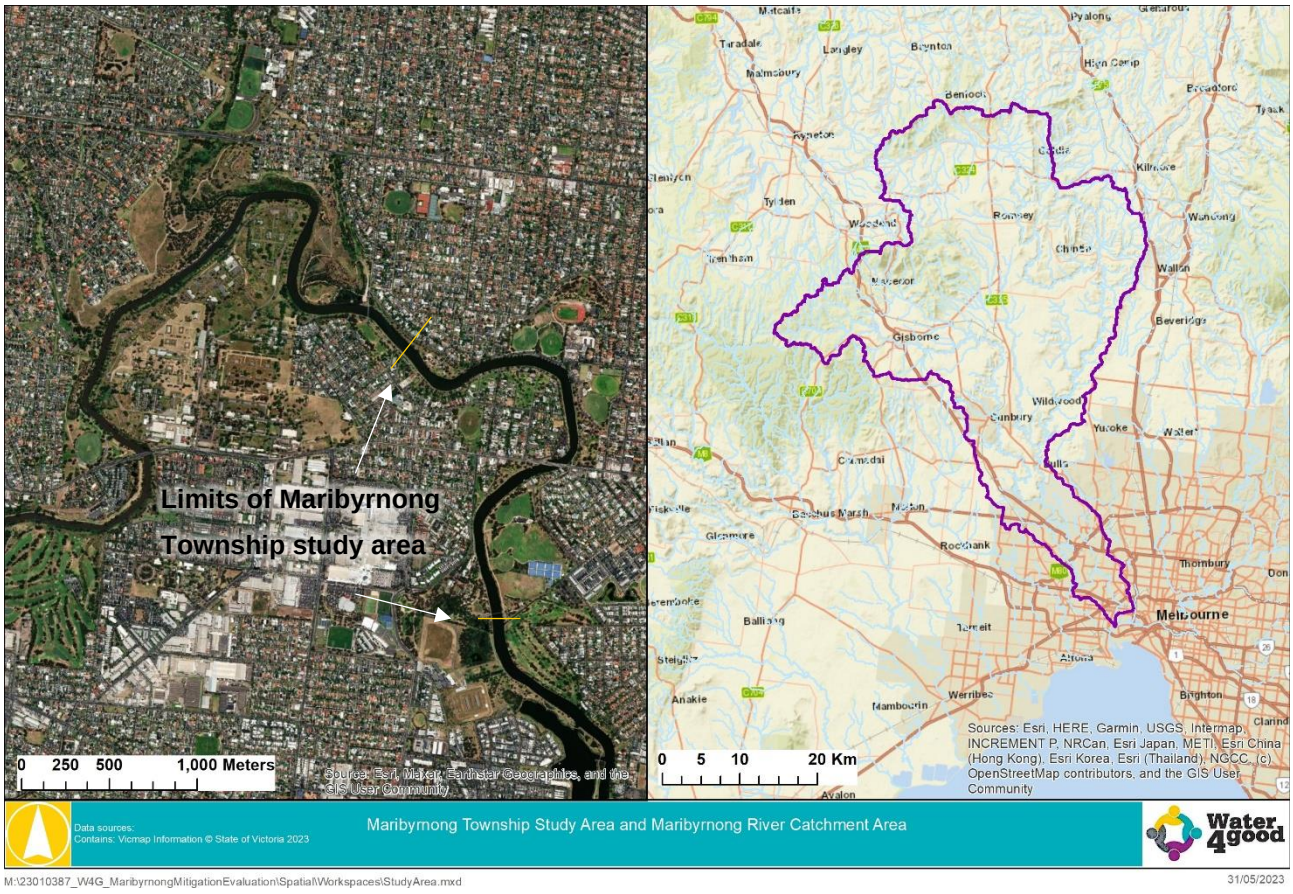

Figure 1 Maribyrnong Township Study Area (left) and Maribyrnong River Catchment (right)

Flooding along the Maribyrnong River is a natural and relatively frequent occurrence. The Maribyrnong township area was first subdivided in the mid 1800s, with further subdivision occurring into the early 1900s. Despite the understanding that the area was known to be vulnerable to flooding at the time of subdivision, there were no regulations governing the development of flood prone land. Throughout the 1920s through to the 1960s the Melbourne and Metropolitan Board of Works (MMBW) had communicated their concern with the Braybrook Council regarding the development of the Maribyrnong township area and asked for it to be restricted. Development of the land proceeded despite the flood risk concerns.

Following one of the Maribyrnong River's largest floods on record in 1974, resulting in significant damage and upheaval to the Maribyrnong community, MMBW implemented a flood warning system in 1975. The

MMBW later began investigations into the *Maribyrnong River Flood Mitigation Study*, completed in 1986. That study investigated the efficacy of a range of potential mitigation measures including retarding basins upstream, a levee system protecting the Maribyrnong township, river channel modifications, property acquisition, flood proofing, and insurance mechanisms.

In October 2022 the Maribyrnong River peaked at 4.2 m AHD at the Maribyrnong gauge, a very similar level to the 1974 event, but slightly lower than floods in 1906 and 1916. The *Maribyrnong Storm and Flood Emergency Plan* (SES, 2018) estimates the 1% AEP design flood level at 4.4 m AHD at the Maribyrnong gauge. The October 2022 flood event again caused devastation through the Maribyrnong River valley with community members still displaced 6 months after the event.

2.2 Project Objectives

This report, commissioned by Melbourne Water, is to review past investigations and evaluate previously identified mitigation options for their potential to reduce flood risk in the Maribyrnong township, shown in Figure 1. In the examination of the value these options may provide to the community, the evaluation is to consider:

- The reduction in the numbers of flood prone properties and buildings for a range of design flood events.
- The reduction in flood damages using standard approaches.
- The likely change in flood hazard.
- High level risks and opportunities relating to constructability, heritage, environmental and social impacts.

The evaluation is focussed on structural mitigation measures. Whilst other options contribute significantly to reducing flood risk, many are either part of Melbourne Water's current program or they are not within the organisations remit. The structural mitigation options considered will not include detailed costing of mitigation options as this was not available within the timeframe required for this report. Rather, this assessment will make qualitative and comparative statements regarding previous mitigation cost estimates.

3 Review of Past Studies

The most relevant study for this review is the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986).

The Arundel Retarding Basin option was first discussed in 1976 and 1981. Then after being considered in detail in the 1986 study, it was again raised in 1989, 1996, 2003 and 2006.

Melbourne Water conducted a Flood Risk Assessment of the Maribyrnong township in 2013 which quantified the flood damages for existing conditions and included the likely reduction in damages due to improved community awareness due to the flood warning system.

These studies are reviewed in more detail below, focussing on the key components of the studies relevant to this review and an options evaluation investigation.

3.1 Maribyrnong River Flood Mitigation Study (MMBW, 1986)

This was a comprehensive flood study, following industry standard practice at the time of publication. As was the case in similar studies of the era, it provides thorough commentary of the catchment characteristics, the land use context, hydrology and hydraulic flood behaviours of the study area, and then presents a detailed investigation into a series of flood mitigation options.

The hydrology for the study used a combination of flood frequency analysis and rainfall runoff modelling using RORB. The RORB model was well calibrated to 5 historic storm events. RORB was also run using standard design estimation techniques at the time, including MMBW (1981) and Australian Rainfall and Runoff (1977), for events ranging from the 20% AEP through to the Probable Maximum Flood (PMF). Design flow estimates using the flood frequency analysis and rainfall runoff modelling approaches are provided in Table 2, showing a very close comparison between the two flood estimation approaches.

The methods adopted for the hydrology in the 1986 study, while broadly consistent with today's approaches, require updating. The flood frequency analysis techniques of today use improved fitting algorithms and the gauges have more data since the previous analysis was conducted. Interim work suggests that the design flood quantiles may be increased by between 5-10% using new techniques, Jacobs (2022).

Table 2 Design Flood Estimates for Maribyrnong at Keilor

Annual Exceedance Probability (%)	Flood Frequency Analysis (m^3/s)	Rainfall Runoff Modelling (m^3/s)
20%	270	272
10%	400	404
5%	530	531
2%	710	708
1%	840	836
0.1%	-	1,300
0.01%	-	1,850
PMF	-	7,410

Hydraulic modelling was undertaken using a one-dimensional hydraulic modelling approach solving the St. Venant equation and the continuity equation. The model was run using both a steady-state design tide level as the downstream boundary and a dynamic tidal downstream boundary. Bridge loss coefficients were calculated for each structure and checked against the United States Bureau of Reclamation approach to estimating bridge losses (1975). While bridge loss equations may have slightly changed, this approach is still considered good practice today. Estimates of scour depth were also made based on the fine silt bed material and empirical scour depth equations. The model was calibrated to the 1974 and 1983 floods, with bridge losses, scour and roughness values altered to provide appropriate calibration results, generally within 0.2 to 0.3 m of observed levels. Design water surface profiles were modelled for a range of design flows. The modelled 1% AEP design flood levels were predicted to be around 4.15 m AHD at Raleigh Road, and 4.4 m AHD at the Maribyrnong River at Chifley Drive streamflow gauge (just upstream of Plantation Street).

The approach to the hydraulic modelling is not consistent with current methods and requires updating, however this does not impact on the findings of this mitigation evaluation study. The one-dimensional hydraulic modelling is likely to predict the overall flood levels across the broader floodplain reasonably well, but modern techniques provide enhanced details of flow paths and flood behaviour at a lot-scale. Since the 1986 study, improvements in technology and computer hardware has led to topographic data such as LiDAR, and complex two-dimensional hydrodynamic modelling software becoming available. As such, todays hydraulic modelling approaches are very different to those available in 1986.

The impacts of climate change were not considered in the 1986 study. Climate change is likely to result in increased tailwater levels due to sea level rise and increased peak flows in the river due to increasing rainfall intensities in rare storms. These impacts of climate change on flood risk should be considered in future investigations. It is understood that Melbourne Water have commissioned a study to update the flood modelling of the lower Maribyrnong River.

The 1986 flood study considered a series of mitigation options and modelled these in the hydrology and hydraulic models to test their potential benefits.

3.1.1 Retarding Basins

Four different locations for retarding basins were investigated, with the Arundel Retarding Basin location the preferred location. The three other options considered were located at Wildwood, Konagaderra and Beveridge West. These other three retarding basin sites were not preferred because they were located further upstream in the catchment and were not able to reduce the downstream peak flows to the same extent as Arundel.

The concept design for the Arundel Retarding Basin option considered the ANCOLD (1984) guidelines determining that the spillway should be designed for a 1 in 10,000 AEP flow. The Arundel Retarding Basin was designed to reduce the peak flow in a 1% AEP design flood from 840 m^3/s to 350 m^3/s, which results in only nuisance flooding through Maribyrnong township. The proposed spillway width was 60 m wide, with the spillway crest at 59 m AHD. The dam wall was designed at 65 m AHD. The proposed retarding basin was not intended to permanently hold water and a pipe of 5.4 m diameter was included in the design to drain the impounded water after the flood. The cost of the Arundel Retarding Basin was estimated in 1985 at just over $16M.

The 1% AEP design flood level in the Maribyrnong River at the Arundel Retarding Basin site would increase by 14 m in elevation. The area inundated and the duration of inundation would be increased significantly upstream of the retarding basin.

Downstream at the Maribyrnong township and through Kensington, the 1% AEP design flood flow would be reduced significantly, with the potential reduction in flood damages estimated in 1985 to have a benefit of just over $8.5M in a 1% AEP magnitude flood.

3.1.2 Levees

The study considered a series of levees including protecting the Maribyrnong township area. The levee was designed to have 4:1 batters and a 3 m top width. To protect to the 1% AEP design flood level with 0.3 m of freeboard, the height of the levee would be at or slightly greater than 3 m above ground. It is noted that the freeboard requirements should be reviewed in any future design. The levee would result in increased water levels on the river side of the levee of up to 0.6 m, this would have some impact on properties on the other side of the river (Essendon). There is limited room for the levee in some locations, meaning road access would be compromised. Ten private properties would require acquisition and several Council owned land parcels would be impacted.

The cost was estimated in 1985 to be $6M for the Maribyrnong Township Levee, and the reduction in flood damages in a 1% AEP magnitude flood would have a benefit of $2.5M.

3.1.3 Channel Modification

Widening and deepening the river was considered. The analysis showed that the significant amount of earthworks, and disruption to existing services requiring relocation means that the cost of such works would be higher than that of constructing the Arundel Retarding Basin or Maribyrnong Township Levee. Channel modifications were then ruled out of any further mitigation option investigation.

3.1.4 Summary

The study concluded that to protect the Maribyrnong township from flooding, the levee with 4:1 batters was the most cost effective option. The study also stated that the levee would not protect other areas of the floodplain, and the most effective way to do that would be via the Arundel Retarding Basin option.

The costings of the mitigation options from the 1986 study are no longer applicable. To produce a more relevant cost estimate it is recommended that contemporary review of costs be undertaken. For the purposes of this investigation we have provided indicative costs comparisons based on information provided by Melbourne Water.

3.2 Maribyrnong Township Flood Risk Assessment (Melbourne Water, 2013)

In 2013 Melbourne Water completed a flood risk assessment for the Maribyrnong township area, inclusive of the floodplain between Afton Street pedestrian bridge across the Maribyrnong down to the Frog's Hollow Wetlands, see Figure 1 for a locality map. This process used data from the 1986 MMBW study and floor level survey of buildings to assess the flood damage at each property for a range of design floods. Flood information for design floods ranging from 20% to 2% AEP were considered in the assessment. Using this information, Average Annual Damage (AAD) due to flooding was calculated for the study area using an early version of the Melbourne Water Flood Risk Reduction Economics Tool. The AAD represents the damage cost per year from flooding, averaged out over a long period of time. This was combined with some social and safety hazard metrics to provide an overall risk rating for Maribyrnong township. The AAD for the Maribyrnong township was estimated at just over $1.9M. Factoring in the impact of the flood warning system, providing early warning to allow community members to prepare their property for flooding and remove themselves from the hazard, the risk rating was stated as "high". The process described above followed the Melbourne Water Flood Risk Assessment Framework (2010).

4 Existing Flood Risk

It is understood that flood mapping is currently being updated for the Maribyrnong River. This data was not available at the time of writing this report, therefore information on existing flood risk is based upon the flood modelling undertaken in the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986). This study, whilst not the most current for the river, provides the most comprehensive information, some of which is not available in later studies.

The Maribyrnong township has long been recognised as a flood prone area, even prior to subdivision. Figure 2 below shows the peak water levels experienced over the historic record, indicating the area is frequently inundated and on occasions is inundated to significant depths. Since gauge records began in 1891 the major flood level has been exceeded eleven times.

Jul-1891 3.32m	Oct-1976 1.59m	Mar-2010 0.65m
Apr-1901 2.22m	Apr-1977 2.74m	Sep-2010 0.98m
Sep-1906 4.50m	Jun-1977 1.58m	Nov-2010 1.50m
Jun-1911 2.16m	Jul-1977 1.87m	Jan-2011 2.21m
Sep-1916 4.26m	Sep-1977 -	Feb-2011 0.72m
Mar-1919 2.16m	Jul-1978 -	Dec-2011 0.61m
Aug-1924 2.98m	Aug-1978 2.94m	May-2012 0.84m
Aug-1932 2.37m	Aug-1978 1.34m	Aug-2012 1.09m
Feb-1946 2.13m	Sep-1978 1.26m	Jan-2016 0.45m
Nov-1954 2.83m	Sep-1978 -	Sep-2016 0.95m
Dec-1954 2.98m	Nov-1978 1.74m	Feb-2017 0.66m
Jul-1963 2.10m	Oct-1983 3.37m	Apr-2017 0.81m
Nov-1971 2.52m	Dec-1985 1.89m	Oct-2022 4.18m
May-1974 4.20m	Jul-1987 3.16m	**Flood Class Levels**
Sep-1975 2.67m	Jun-1989 2.25m	Minor 1.7m
Oct-1975 1.43m	Jul-1990 1.97m	
Oct-1975 1.75m	Sep-1993 3.83m	Moderate 2.3m
Oct-1975 2.61m	Oct-2000 1.90m	
Nov-1975 1.59m	Mar-2001 1.36m	Major 2.9m
Sep-1976 1.39m	Feb-2005 2.21m	

Figure 2 Maribyrnong Flood Pole (corner of Chifley Drive and Plantation Street) left; historic water levels right

The *City of Maribyrnong Storm and Flood Emergency Plan* (2021) provides a good summary of past flooding, and it describes a detailed list of consequences likely to be experienced over a range of design flood conditions. The onset of flooding is typically fast, with travel times between Keilor and Maribyrnong township ranging between 1 and 6 hours. Duration of inundation is typically 24 to 48 hours, although some larger historic floods have spanned up to a week.

Flood damage is limited within the Maribyrnong township for Minor and Moderate floods, with only the lowest lying properties impacted such as The Anglers Tavern. When flood waters reach above the Major flood level of 2.9 m at the Maribyrnong River at Chifley Drive (230106) gauge, many homes begin to flood above floor.

In a 1% AEP design flood the *City of Maribyrnong Storm and Flood Emergency Plan* (2021) suggests the following consequences are likely for the Maribyrnong area shown in Figure 3:

- 456 properties inundated including 449 residential, 3 commercial and 4 public land. These statistics include multi-level apartments that may be above the flood level but would be isolated.
- 1 place of worship inundated
- 3 major roads inundated including Farnsworth Avenue, Raleigh Road and Van Ness Avenue
- 2 tram routes inundated including trams #57 and #82
- 2 bus routes inundated including routes #468 and #952
- 5 sewerage emergency relief points inundated
- 1 sporting facility at Maribyrnong Reserve inundated
- 4 recreational reserves inundated

The red dots indicate the buildings inundated, demonstrating that the majority of the flood damage in this area is concentrated in the Maribyrnong Township area.

The flood inundation mapping for the 1% AEP design flood from the *City of Maribyrnong Storm and Flood Emergency Plan* (2021) is provided in Figure 3.

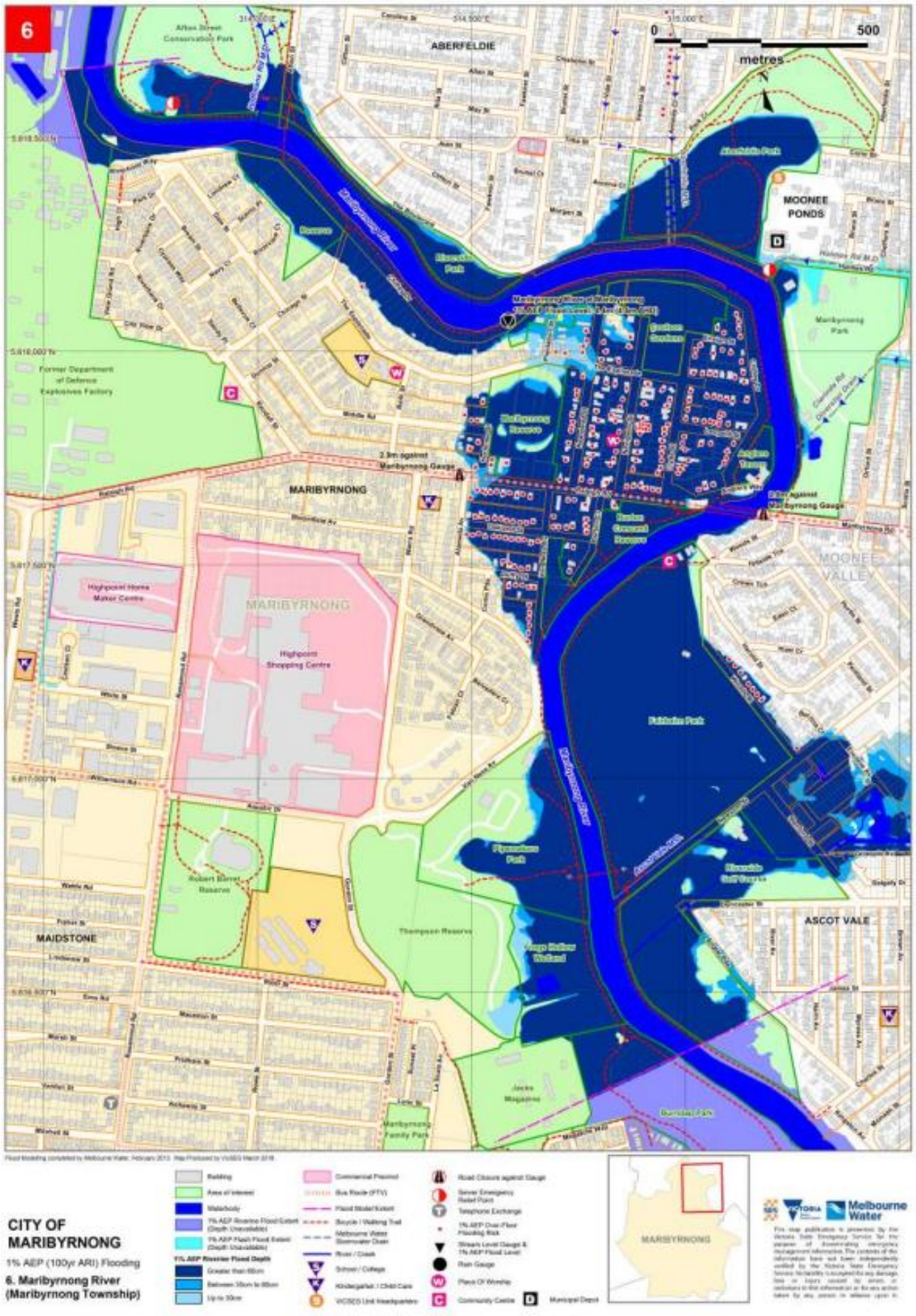

Figure 3 Design Flood Mapping for the 1% AEP event for Maribyrnong Township (Source: City of Maribyrnong Storm and Flood Emergency Plan)

5 Evaluation of Previously Considered Mitigation Solutions

The *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) identified two preferred mitigation options, the Arundel Retarding Basin and the Maribyrnong Township Levee. Other options were considered and are summarised in Section 3.1 of this report. These other options have not been considered in detail by previous studies, and whilst there is not sufficient information to evaluate them quantitatively in this report, they have been discussed qualitatively.

The evaluation has utilised the *Melbourne Water Flood Risk Reduction Economics Tool* (Jacobs, 2019) to evaluate flood mitigation options. This standardised approach means that options can be compared within and between catchments, assisting in prioritisation of flood mitigation projects across Melbourne. The evaluation has used data made available from the 2013 Flood Risk Assessment completed by Melbourne Water for the Maribyrnong township area. It includes 305 properties with building floor levels within the mapped flood inundation area between Chicago Street in Maribyrnong township and the Pipemakers Park pedestrian footbridge downstream, see Figure 1 for location map. This means that some flood damages and benefits in the broader catchment are not included in the analysis. However, it is recognised that the bulk of economic and social impacts are contained within the Maribyrnong township area and hence this provides a sound basis for the mitigation option assessment.

The cost of damage for a range of design floods was estimated. These damage costs were integrated to provide an estimate of the average annual damage (AAD) of flooding to the Maribyrnong Township in today's dollars. Cost estimates were provided by Melbourne Water and comparisons were made to other similar projects around Australia. The *Melbourne Water Flood Risk Reduction Economics Tool* (Jacobs, 2019) uses the flood damages and the mitigation cost to complete an economic benefit-cost and net present value analysis. This information is then used to evaluate if the mitigation options should be further investigated.

It is noted that the existing flood mapping information from the MMBW (1986) report does not include the impacts of climate change. The inclusion of climate change considerations is an important factor in contemporary flood mitigation studies. For both the levee and the retarding basin options, the required assets will likely need to be both higher and wider, making them both more costly and have greater impact within the landscape. The quantification of the increase in size due to climate change, the flood protection efficacy and economic return on the assets cannot be estimated until the revised flood modelling of the Maribyrnong River, currently underway, is complete.

5.1 Existing Conditions Flood Damages

Using the flood level information from the 2013 Flood Risk Assessment for the 305 properties within the Maribyrnong Township area, the flood damages using the *Melbourne Water Flood Risk Reduction Economics Tool* (Jacobs, 2019) were calculated. This uses stage damage curves that provide a damage cost estimate per building for different flood heights above and below floor level. The average annual damage is then calculated by integrating the flood damage costs and the probability of those floods occurring to provide a measure of the cost of flood damage per year over a long period of time.

Table 3 Flood Damages for the Maribyrnong Township in Existing Conditions (today's dollars)

AEP	20%	10%	5%	2%	1%
Building Damage (Tangible Direct)					
Residential	$ -	$ 479,689	$ 5,936,989	$ 17,199,866	$ 25,487,980
Commercial	$ -	$ -	$ 46,269	$ 94,972	$ 136,926
Industrial	$ -	$ -	$ -	$ -	$ -
Vehicles	$ -	$ 47,599	$ 523,479	$ 3,809,302	$ 6,891,225
Sub-Total	**$ -**	**$ 527,289**	**$ 6,506,737**	**$ 21,104,139**	**$ 32,516,132**
Road Damage (Tangible Direct)					
Minor	$ 5,887	$ 95,371	$ 122,314	$ 236,837	$ 259,773
Major	$ 10,365	$ 50,953	$ 65,630	$ 86,280	$ 88,580
Unsealed	$ -	$ -	$ -	$ -	$ -
Sub-Total	**$ 16,253**	**$ 146,324**	**$ 187,944**	**$ 323,116**	**$ 348,353**
Totals					
Tangible Direct	$ 16,253	$ 673,612	$ 6,694,680	$ 21,427,256	$ 32,864,485
Tangible Indirect (30%)	$ 4,876	$ 202,084	$ 2,008,404	$ 6,428,177	$ 9,859,346
Intangible	$ 16,253	$ 673,612	$ 6,694,680	$ 21,427,256	$ 32,864,485
Total Damage (combined)	**$ 37,381**	**$ 1,549,309**	**$ 15,397,765**	**$ 49,282,688**	**$ 75,588,316**
Average Annual Damage (AAD)					**$ 2,859,064**

5.2 Arundel Retarding Basin

To estimate the damage cost of the various design floods, Figure 11.9 from the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) was used, reproduced as Figure 4 here.

This shows that a 10% AEP flood with the Arundel Retarding Basin would have a peak flow similar to the 20% AEP for existing conditions. Thus, to estimate the flood damages for the Arundel Retarding Basin option 10% AEP, the damages from existing conditions 20% AEP were used. A 1% AEP flood with the Arundel Retarding Basin would have a peak flow between the 20% and 10% AEP flood for existing conditions. Hence the damages for the Arundel Retarding Basin 1% AEP flood were interpolated between the 20% and 10% existing conditions flood damages. The same process was followed for all other design floods.

The flood damages for the Arundel Retarding Basin mitigation option are summarised in Table 4, noting that these damages are for the Maribyrnong township area only.

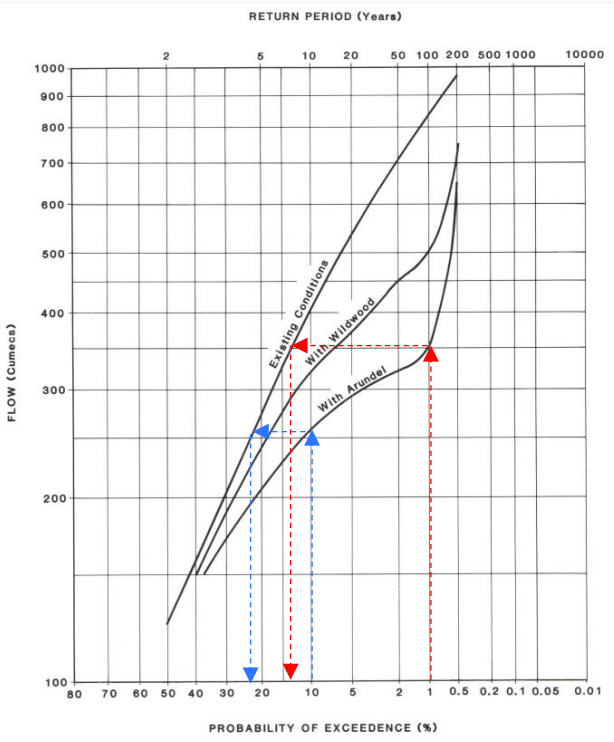

Figure 4 Flood Frequency Curve for Maribyrnong Township

Table 4 Flood Damages for the Maribyrnong Township in Mitigated Conditions with Arundel Retarding Basin (today's dollars)

AEP	20%	10%	5%	2%	1%
Building Damage (Tangible Direct)					
Residential	$ -	$ -	$ 67,710	$ 108,099	$ 116,506
Commercial	$ -	$ -	$ -	$ -	$ -
Industrial	$ -	$ -	$ -	$ -	$ -
Vehicles	$ -	$ -	$ 4,237	$ 7,682	$ 25,001
Sub-Total	**$ -**	**$ -**	**$ 71,948**	**$ 115,782**	**$ 141,507**
Road Damage (Tangible Direct)					
Minor	$ -	$ 5,887	$ 25,315	$ 50,629	$ 75,944
Major	$ -	$ 10,365	$ 15,330	$ 30,659	$ 45,989
Unsealed	$ -	$ -	$ -	$ -	$ -
Sub-Total	**$ -**	**$ 16,253**	**$ 40,644**	**$ 81,288**	**$ 121,932**
Totals					
Tangible Direct	$ -	$ 16,253	$ 112,592	$ 197,070	$ 263,439
Tangible Indirect (30%)	$ -	$ 4,876	$ 33,778	$ 59,121	$ 79,032
Intangible	$ -	$ 16,253	$ 112,592	$ 197,070	$ 263,439
Total Damage (combined)	**$ -**	**$ 37,381**	**$ 258,961**	**$ 453,261**	**$ 605,910**
Average Annual Damage (AAD)					**$ 31,316**

The Arundel Retarding Basin option is effective at reducing peak flows downstream on the Maribyrnong River, with a reduction in the AAD cost in the Maribyrnong township from $2.9 million to $31,000 (adjusted to 2023 dollars). To return a positive Net Present Value (NPV) over a 100-year period with a discount rate of 4%, would require a retarding basin cost less than approximately $65M in today's dollars. This assumes an annual maintenance cost 0.35% of capital cost, based on research of 33 dams in Australia (Petheram, C & McMahon T, 2019).

As a comparison, GHD completed detailed costings for the Arundel Retarding Basin in 1996, estimating a roller compacted concrete dam would be the most cost-effective design and would cost $35.5M, in 1996 dollars. Using the RBA inflation calculator online, this cost increases to approximately $68M in today's dollars. It is noted that this inflation adjustment does not reflect other likely changes in the cost of construction projects, other than inflation, that have occurred over time and would impact present day costs and this is therefore not an appropriate approach for estimating the likely cost of the Arundel Retarding Basin.

Melbourne Water provided indicative comparison costs for similar dam projects within Melbourne Water's area of jurisdiction and others from interstate. Their initial comparison costs suggest that Arundel Retarding Basin may cost in excess of $200M in today's dollars.

Assuming a capital cost in the order of $200M, the Arundel Retarding Basin option would not be economically feasible, returning a negative Net Present Value (-$144M) and a Benefit-Cost Ratio of 0.3.

It is noted that the economics for the Arundel Retarding Basin option would likely be more favourable with the inclusion of damages that would be prevented in other areas along the Maribyrnong River. A more comprehensive assessment of the retarding basin option would also need to consider additional impacts upstream of the Arundel Retarding Basin due to increases in flood levels. This would tend to offset any additional economic benefit from a broader analysis. A more detailed understanding of the full social and

economic costs and benefits of the Arundel Retarding Basin option under present conditions would require further investigation.

To provide more certainty around this analysis a professional cost estimator and an economist should further investigate the economics of this mitigation option. Further discussion regarding the assumptions of this economic evaluation is provided in Section 7.

In terms of social outcomes, the Arundel Retarding Basin option is far removed from the impacted urban area, so disruption to the community is minimised. There would be impacts to private land owners in the area of construction and along the waterways upstream of the retarding basin. The *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) identified 26 properties affected upstream of the retarding basin, several of which would require purchasing, and others would likely require compensation. Social impacts also include increased inundation through low lying areas of the Organ Pipes National Park, which is a popular place for visitors.

Environmental impacts would be significant within the construction footprint, with the riparian corridor having high biodiversity values. It is noted for example that observations of threatened flora and fauna species are recorded in the area on the NatureKit online map provided by DEECA. Given the outlet is proposed to be a 200 m long 5.4 m pipe at the base of the dam wall, passage of fish, platypus, turtles and other aquatic fauna would likely be a major environmental impact.

The Aboriginal Cultural Heritage Register and Information System (ACHRIS) online mapping shows many areas of cultural sensitivity in the expected footprint of the proposed Arundel Retarding Basin and would require detailed investigation into cultural heritage impacts. Consideration of Traditional Custodian's views and impact on cultural values must be included in any future investigation

5.3 Maribyrnong Township Levee

The Maribyrnong Township Levee as proposed in the *Maribyrnong River Flood Mitigation Study* (MMBW 1986) would include approximately 1.7 km of levee. The majority of levee was proposed to be an earthen levee with 4 to 1 batter slopes, 3 m wide top width and 0.3 m of freeboard above the 1% AEP flood profile. The proposed levee would be up to 4 m high in some locations. Some sections where space was limited were proposed to incorporate retaining walls, and it is expected that headwalls with flood gates would be required across road crossings.

The *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) suggested that, should a levee be constructed, the increase in 1% AEP flood levels on the riverside of the levee would be up to 0.6 m, increasing inundation extent and depth for areas outside of the levee.

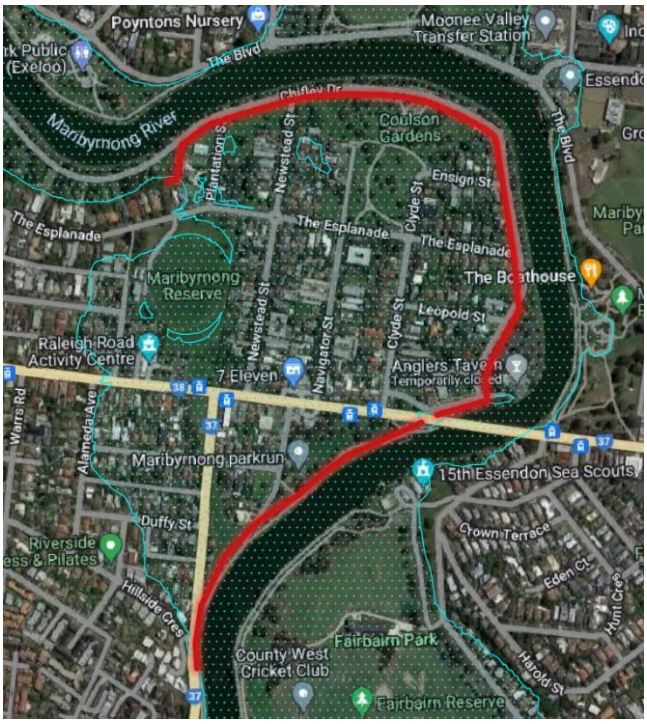

Figure 5 Proposed Maribyrnong Township Levee Alignment

Should this option be considered for further investigation it is likely that an optimised alignment would be considered, to avoid clashes with existing development and infrastructure, increase public amenity, and reduce storage volume removed from the floodplain in public open space.

The flood damages for the Maribyrnong Township Levee mitigation option are summarised in Table 5.

The levee excludes flooding from the Maribyrnong township up to the 1% AEP design flood. The water level is increased outside the levee, raising levels on some private property, including inundating an estimated additional 6 properties above floor on The Boulevard in Essendon (on the opposite side of the river). The inundation extent is not increased significantly given the steep floodplain margins on the opposite bank of the Maribyrnong River. Potentially, a small local flood wall could be considered to protect the additional houses inundated along The Boulevard due to the levee.

The Maribyrnong Township Levee significantly reduces the AAD cost from $2.9 million to $204,000 in 2023 dollars. To return a positive NPV over a 100-year period with a discount rate of 4%, would require a levee cost less than $65M. This assumes an annual maintenance cost of $50,000, which is close to $30/m, and considered conservative compared to other levee projects around Australia. To provide more certainty on this analysis a professional cost estimator and an economist should further investigate the economics of this mitigation option. Further discussion regarding the assumptions of this economic evaluation is provided in Section 7.

As a comparison, the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) estimated the levee to cost $6M in 1985 dollars, which would cost $20M in 2023 dollars if adjusted for inflation. A simple inflation calculator will not represent the true change in cost of building the levee today compared to 1985. The costs when factoring in disruption to the community, the road network, private property access etc, are likely to result in a project cost more than the $20M estimate obtained from the 1985 cost with inflation adjustment.

Comparison costs were obtained from other large levee systems across Australia from available literature, and as a rough guide, the cost of these levees ranged between $5-10k per linear metre. Given the size of the levee required for the Maribyrnong township and the difficulty with the proximity of several private properties and road infrastructure, Melbourne Water advised that a conservative estimate may be $20k per linear meter, which would see the levee cost in the vicinity of $35M in today's dollars with additional expenditure of approximately $20M required to make good other impacts arising from construction of the levee. To build the levee acquisition of up to 10 private properties maybe required, adding approximately $20M in today's dollars to the cost. Using these comparative costs of other large levee systems, the cost of the levee may run close to returning a positive net present value and benefit-cost ratio of 1. The preliminary analysis suggests a net present value of -$10M and a benefit-cost ratio of 0.87. This suggests the option is worth considering further, and that along with levee design, detailed costings performed by an experienced estimator are worth pursuing.

Table 5 Flood Damages for the Maribyrnong Township in Mitigated Conditions with Maribyrnong Town Levee (today's dollars)

AEP	20%	10%	5%	2%	1%
Building Damage (Tangible Direct)					
Residential	$ -	$ 114,402	$ 245,199	$ 762,762	$ 1,812,171
Commercial	$ -	$ -	$ -	$ -	$ -
Industrial	$ -	$ -	$ -	$ -	$ -
Vehicles	$ -	$ 39,600	$ 45,619	$ 128,819	$ 375,685
Sub-Total	**$ -**	**$ 154,002**	**$ 290,818**	**$ 891,581**	**$ 2,187,856**
Road Damage (Tangible Direct)					
Minor	$ 5,887	$ 40,889	$ 57,795	$ 129,306	$ 145,073
Major	$ 10,365	$ 10,365	$ 10,365	$ 10,365	$ 10,365
Unsealed	$ -	$ -	$ -	$ -	$ -
Sub-Total	**$ 16,253**	**$ 51,254**	**$ 68,160**	**$ 139,671**	**$ 155,439**
Totals					
Tangible Direct	$ 16,253	$ 205,256	$ 358,978	$ 1,031,252	$ 2,343,295
Tangible Indirect (30%)	$ 4,876	$ 61,577	$ 107,693	$ 309,376	$ 702,988
Intangible	$ 16,253	$ 205,256	$ 358,978	$ 1,031,252	$ 2,343,295
Total Damage (combined)	**$ 37,381**	**$ 472,090**	**$ 825,650**	**$ 2,371,879**	**$ 5,389,578**
Average Annual Damage (AAD)					**$ 204,190**

Levees can be somewhat divisive in a community, particularly if there are people outside the levee who are not going to benefit from the levee and/or be negatively impacted. In this case, the levee option proposed protects the full Maribyrnong township community. There are a small number of houses on the opposite side of the river on The Boulevard in Essendon that would be exposed to increased flood levels that would need to be protected for this levee option to proceed. The impact on visual amenity and community connection to the River is also a factor that would need to be further evaluated.

The environmental impact of the option is not likely to be as significant as the Arundel Retarding Basin option given the highly disturbed and built-up urban environment. The levee construction footprint would require the removal of several trees.

There are several areas where space is limited, and constructability would be an issue. The *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) identified that around 10 properties would require acquisition for the levee with 4:1 batters to be constructed.

6 Evaluation of Other Potential Options

There are several other possible structural and non-structural mitigation options that could potentially reduce flood risk in Maribyrnong township that have been considered in the past. The structural option of channel modification is discussed below, with non-structural options discussed briefly in Appendix A.

6.1 Channel Modification

The *Maribyrnong River Flood Mitigation Study* (MMBW, 1986) assessed the potential to deepen and widen the Maribyrnong River to reduce flood levels. The findings at the time were very clear and are summarised below.

The report concluded that the extensive social disruption, capital cost and poor benefit-cost ratio of channel modifications meant that it was not a viable option to reduce flood risk at the Maribyrnong township. With today's level of development and infrastructure costs, it is likely that this option is even less viable today than it was in 1986.

6.1.1 Channel Widening

It was estimated that to carry a flow of 500 m^3/s (< 5% AEP) without flooding out-of-bank, the river would need to be widened 20 m, requiring around 700,000 m^3 of earth removal and around 8 km of rock beaching to protect the exposed bank. The previous report lists out the challenges with widening the river by 20 m, which includes realignment of roads, moving of power lines, widening and replacement of bridges, purchase of residential and commercial properties, restoration of parkland, etc. The benefit-cost of this option in the previous report was far below that of the Arundel Retarding Basin or levee options. Widening the river further to accommodate the 1% AEP flow increased the impacts exponentially.

6.1.2 Channel Deepening

Deepening of the channel by 1 and 2 m was considered in the 1986 report. It was estimated that deepening the channel by 1 m would require removal of around 377,000 m^3 of material, increasing to 627,000 m^3 for a 2 m deepening scenario. The 1 m deepening would see flood levels lowered by around 0.3 m and a 2 m deepening would lower flood levels by around 0.5 m. The deepening would have impacts on several bridges and services passing under the river and would also require extensive bank stability works. At the time it was considered that the material would be dumped in Port Phillip Bay.

This option poses significant risk related to the potential contamination of the dredged material to be removed and the difficulty and costs for disposal. Large-scale dredging also brings other environmental risks related to turbidity, aquatic ecosystems and geomorphic impacts along the river upstream and downstream.

7 Limitations on Findings

The scope of this investigation was limited to evaluating potential mitigation options for Maribyrnong township as the location with the highest concentration of flood affected properties and is based on previously available information. The following are limitations to the investigation:

- No new flood modelling was conducted, previous flood levels and flood mapping from the 1986 (MMBW) study and the 2013 (Melbourne Water) Maribyrnong Township Flood Risk Assessment was used.
- Existing floor levels were utilised, with no additional data collated. Floor levels for properties along The Boulevard in Maribyrnong were estimated based on LiDAR ground levels and Google Streetview imagery.
- Melbourne Water's Flood Risk Reduction Economics Tool (Jacobs, 2019) was utilised for the economic analysis of the Arundel Retarding Basin and Township Levee options.
- No costings on the potential mitigation options were completed. This evaluation has considered previous estimates and has commented on the capital cost that would return a positive Net Present Value over a 100 year period. It is noted that a relatively low 4% discount rate has been adopted, which is typical for flood risk reduction projects, but is lower than what is used in other infrastructure sectors.
- No experienced cost estimators or economists contributed to the economic analysis, as agreed with Melbourne Water given the available timeline for this project. We recommend that if any mitigation options are to be further investigated that cost estimation be carried out using contemporary cost estimation techniques, and be based on contemporary designs of the mitigation infrastructure.
- No cultural heritage assessments have been conducted.
- No environmental impact assessments have been conducted.
- No detailed feasibility or constructability assessments have been conducted other than reviewing what has already been investigated in relation to mitigation options in the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986).
- The impacts of climate change on flood risk were not considered in the 1986 modelling and have therefore not been considered in this evaluation.

8 Recommendations

This investigation has rapidly evaluated potential mitigation options for the Maribyrnong township. It has relied on existing information and past studies, with no new flood modelling investigations conducted.

The following recommendations are made.

1. The Maribyrnong Township Levee option would be effective at preventing flooding, would have manageable impacts on private property outside of the levee, and is the most likely of all options to return a positive economic business case. This option requires further testing with the community.
2. To support further investigation of a levee mitigation option updated flood mapping of the Maribyrnong River should be completed, including consideration of the impacts of climate change on flood behaviour. When complete, information from this flood study should be used within Maribyrnong City Council and Moonee Valley City Council, including the consideration of a Planning Scheme amendment.
3. The Arundel Retarding Basin option while effective at preventing flooding, is a costly infrastructure project, that would not be an economically viable business case. Given the many issues associated with building and operating new dams, including the impact on the environment, the change in the hydrological regime of the river, the impacts on cultural values and the Organ Pipes National Park, it is recommended that this option is not considered further. If the option is to be considered further, additional evaluation of the environmental impacts and legislative obligations of a retarding basin or dam within the river network should be undertaken.
4. It is recommended that the non-structural options of property acquisition, community relocation and flood resilient design be considered further, but it is noted that this is not currently within Melbourne Water's remit and would require other organisations to take a leading role.
5. It is recommended that costing of any further options investigated, be conducted by an experienced cost estimator and economist using any updated flood modelling information, to provide a higher level of certainty on the likely economic outcome of the business case for mitigation.

9 References

ANCOLD (1984), Guideline on dam safety referenced in the MMBW (1986) report, but full reference not available.

Institution of Engineers Australia (1977), Australian Rainfall and Runoff : flood analysis and design

Jacobs (2019), Melbourne Water Flood Risk Reduction Economics Tool

Melbourne Water (2010), Melbourne Water Flood Risk Assessment Framework

Melbourne Water (2013), Flood Risk Assessment of Maribyrnong Township – *data provided in spreadsheets and GIS files, not documented in a report*

MMBW (1981), Internal MMBW guideline on flood hydrology referenced in the MMBW (1986) report but full reference not available.

MMBW (1986), Maribyrnong River Flood Mitigation Study

SES (2018) Maribyrnong Storm and Flood Emergency Plan: A Sub-Plan of the Municipal Emergency Management Plan, prepared for Maribyrnong Council.

United State Bureau of Reclamation (1975), Flood Hydrology Manual

Appendix 1 – Evaluation of Other Potential Non-Structural Options

Planning Scheme

The majority of the Maribyrnong township is currently zoned General Residential, with Public Park and Recreation and Public Use areas, and small pockets zoned Commercial. The Maribyrnong River itself is Urban Flood Zone.

A Land Subject to Inundation Overlay (LSIO) is in place covering the 1% AEP design flood extent. This means that applications for development in the LSIO may trigger a referral to Melbourne Water as the Floodplain Authority, and that certain conditions must be met for the application to be approved.

The LSIO is a planning instrument that is not aimed at preventing development, but to guide appropriate development in a floodplain. The purpose of the LSIO is to:

Identify flood prone land

- Maintain free passage and temporary storage of floodwaters such that development does not give rise to increases in flood levels and velocities.
- Minimise flood damage and risk to life, health and safety.
- To protect water quality and the health of our waterways and floodplains.

The LSIO is appropriate for this area, the extent appears to be based on the most recent flood levels and extent produced from the *Maribyrnong River Flood Mitigation Study* (MMBW, 1986).

It is understood flood mapping is being updated for the area and it is recommended that a planning scheme amendment be considered when the new mapping becomes available. This will provide an opportunity to consider if a Floodway Overlay should be introduced into the Planning Scheme that could better reflect the level of flood risk in the Maribyrnong township area.

Flood Resilient Design

Flood resilient design includes the use of materials, construction methods, and house design that enables a building to withstand being flooded, to reduce the impact and provide the ability to recover quickly.

In many developed floodplain communities across Australia, existing dwellings have tended to make improvements that result in significant increases in flood damage cost over time as renewal/renovation occurs. In many cases this has neglected to consider the flood prone nature of these buildings and has ignored basic flood resilient design principles.

One strategy for retrofitting flood resilient design could include wetproofing the building construction by removing built in and hollow spaces that may retain moisture after inundation leading to mould, water damage and weakening of the structural integrity. Dry proofing is another strategy which aims to keep water outside the building by sealing the house with waterproof membranes or barriers, raised windows and flood doors. Raising the floors and vulnerable services to be above flood level is another strategy if the house design allows.

Given the number of properties and the many different building types impacted by flooding in Maribyrnong township, it is likely that flood resilient design will not be suitable for all properties and is not something that Melbourne Water would investigate further. Further information can be found here: https://www.melbournewater.com.au/water-and-environment/flooding-advice/prepare-flooding.

A successful flood resilient design program has been running in Brisbane since the 2011 floods and has continued to gain exposure and acceptance.

Community Relocation

Flooding is a natural occurrence on our waterways. Flooding serves an environmental purpose, and our floodplains need regular floods to maintain a healthy ecosystem. However, flooding can have disastrous consequences when, for historic reasons, communities and infrastructure are located in areas of high flood hazard.

In other high hazard floodplains across Australia, where flooding impacts are considered intolerable (particularly when there is a significant threat to life), community relocation has been implemented. Grantham in NSW is a very good example of a community relocation program. A similar scheme is currently being considered for parts of Lismore. This can be incredibly disruptive to a community, and one of the major issues with other relocation programs has been finding suitable land to relocate people to. If the land availability issue can be solved, other critical success factors include having a community champion/advocate for relocation to help gather a majority proportion of the community to embrace the option, and then building and maintaining momentum during implementation of the relocation scheme.

Regarding land availability, the nearby Department of Defence site located 2 km to the west of the Maribyrnong township area has been identified as a location with potential to be remediated and utilised as a relocation point. It is understood that urban renewal on this site has been considered in the past.

A community relocation would most likely require significant cooperation from many different government organisations/authorities and significant funding to be made available. A community relocation of this size would likely cost more than the Maribyrnong Township Levee discussed previously, but further investigation would be required to understand the economics of this option. In addition, the community are well into the rebuild phase of the recovery, so relocation after the significant investment of the recovery is unlikely to be accepted.

Flooding of the Maribyrnong River will continue to re-occur in the future, and it is recommended that this option be considered as a longer-term means of reducing exposure of the community to future floods. This would require a significant investment and coordinated approach from all levels of government and the community. If it was to be implemented, this would be a landmark relocation scheme that would provide a globally-significant example of how flood prone communities can adapt to increasing flood risk.

It is noted that both the New South Wales and Queensland governments currently have home resilience programs running to support community relocation and property buy back schemes valuing around $800M in each State.