

MARIBYRNONG RIVER

FLOOD EVENT

INDEPENDENT REVIEW

August 2023

The Hon GT Pagone AM KC
Chair

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Systems
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INTRODUCTION

1. In January 2023 Melbourne Water announced, in its capacity as flood manager as prescribed under the *Water Act 1989 (Vic)*, that there would be an independent review into the flooding of the Maribyrnong River which had occurred on 14 October 2022 (the **Flood Event**).
2. The Flood Event was the third highest flood on record for that catchment. Melbourne Water heard through community forums, stakeholder discussions and direct communication of its significance to those impacted.
3. The final composition of the Review Panel, after a process including extensive consultations and detailed probity inquiries, was announced in May 2023 to be as follows:

Chair: The Honourable G T Pagone AM KC

Members: Mr Mark Babister RPEV, Director, WMAwater Pty Ltd

Professor Holger Maier, Director, Systems Cooperative Limited

Mr Tim Peggie MVPELA, Director Planning, Ethos Urban

TERMS OF REFERENCE

4. The Terms of Reference for the Review Panel were published on 17 January 2023, they were updated on 11 July 2023 and is Attachment A to this report.
5. The Terms of Reference constitute the Review Panel to undertake a **technical** review to report on:
 - the causes and contributors of the Flood Event in the urban catchment, including any potential impacts of the Flemington Racecourse Flood Wall on the extent and duration of the Flood Event;

- any impact of prior works or activities in the urban catchment on the flood levels and extent during the Flood Event; and
 - whether any other matters may have significantly contributed to the Flood Event.
6. The scope and matters to be considered in that technical review were further identified in the Terms of Reference as:

OVERALL

The Review should:

1. Describe the specific effects of the Flood Event.
2. Confirm duration and extent of this riverine Flood Event.
3. Identify and describe any predictions or modelling relevant to the Flood Event.
4. Provide analysis of the impact of the Flood Event compared with predictions or modelling, and the basis for any potential differences.
5. Consider other matters relating to hydrology, topography and population that may have made a material contribution.

THE FLEMINGTON RACECOURSE FLOOD WALL

The Review should:

6. Examine whether the Flemington Racecourse flood protection wall contributed to the extent and duration of the Flood Event.
7. Review the efficacy of Melbourne Water's proposed conditions of approval and mitigation measures relating to the wall and their implementation.

THE RAINFALL AND FLOOD EVENT

The Review should assess:

8. The characteristics of the rainfall event(s) across the catchment leading to the Flood Event, including consideration of how these compared to:
 - i. Historical records.
 - ii. The Australian Rainfall and Runoff Guidelines (2019).
 - iii. Flood predictions or modelling that accounts for climate change.

PLANNING FOR THE FUTURE

The Review may provide recommendations in relation to any matter associated with:

9. Melbourne Water's approach to flood modelling and prediction.

OUT OF SCOPE

The following matters are outside the scope of the Review:

1. Any specific policy responses.
2. Future potential mitigation measures such as additional flood walls, levees or dams.
3. Overall emergency responses including warnings and evacuation procedure.
4. Flood recovery.
5. Broad planning matters including decisions, frameworks and processes.

THE REVIEW PROCESS

7. The review process was established to be independent and transparent. In that context it is important, however, to note that it is a review for a report to Melbourne Water: the Review Panel is established by Melbourne Water and had no formal or statutory basis other than as an inquiry established by Melbourne Water to receive a report.

8. The Review Panel also had no power to compel participation or to compel anyone to provide evidence or information. Submissions, participation, and communications to or with the inquiry conferred no special protection from suit or liability for participation and in such circumstances, it may not be surprising that some people and bodies might be reluctant to participate in the inquiry if there were any adverse risk to insurance or other legal claims. However, many submissions were received, and many people provided helpful information, although it was a mixed level of co-operation and assistance, leaving many questions unanswered and many issues not fully explored. It should also be noted that the conclusions for a technical review depended upon some technical analysis which had been undertaken by Melbourne Water, but which had not yet been completed and, therefore, was not available to the Panel. We understand that it will be available in April 2024 and are willing to review it when available if thought desirable. This report was prepared on the information and material available to us as at 14 August 2023.

9. The Review Panel was constituted with the independent technical members referred to above with expertise in hydrology, town planning and forensic analysis and evaluation. The Review Panel was also provided with an independent Panel Administrator working at the direction of the Review Panel to assist in general administration, typing, co-ordination with Melbourne Water and interfacing with submitters and members of the public. Melbourne Water also allocated a member of staff as Review Co-ordinator to liaise with the Panel Administrator and to support the review as required.

Stage 1 – Set-up

10. Six stages in the review process were contemplated in the terms of reference. The first was the project set-up described above. It included the establishment of a secure database for the panel to store information and documents received. The information stored on the Panel's database has not been available to Melbourne Water.

11. The Terms of Reference require the Chair, as Review Lead, to produce a written report providing:
 - an assessment of the matters to be considered as outlined in the Terms of Reference,
 - a list of persons who made submissions considered by the Review Panel, and
 - a list of persons consulted or interviewed by the Review Panel.

The assessment of the matters to be considered as outlined in the Terms of Reference is in this document. It is provided by the Review Lead as a joint report that has been written jointly by the members of the Review Panel after consideration of the information available and discussions between the Panel members. A list of the persons who made submissions considered by the Review Panel is in Attachment B. The list of persons consulted or interviewed by the Review Panel is in Attachment C.

Stage 2 – Public Submissions

12. The second stage of the Review was undertaken by Melbourne Water before the Review Panel was established and involved the receipt by Melbourne Water of submissions for the Review Panel. A total of 63 submissions were received during the submission stage between 17 January and 17 March 2023 and one late submission was received in April. These submissions were from individual residents, Moonee Valley City Council, City of Melbourne, Maribyrnong City Council, Brimbank City Council, Victorian Racing Club Limited, TIGcorp Riverview Retirement Village (TIGcorp) and Melbourne Water. Unredacted copies of these submissions were made available to the Panel by Melbourne Water and are located in the panel’s database in a folder marked “unredacted copies of initial submissions”, but are also attached to this Report as Attachment D.

Stage 3 – Information and Submissions Review

13. The third and subsequent stages occurred after the Review Panel was established and was organised by the Review Panel through the Panel Administrator with the assistance of the Panel Co-ordinator.
14. An initial understanding by the Review Panel of the sites affected, of the issues and of the subject matter was obtained by site visits and informal preliminary consultations over the period 1 – 3 May 2023 as follows:

‘Day 1:

- A tour itinerary of impacted locations was arranged for the Review Panel by the Review Co-ordinator and incorporated the following key locations:
 1. Brimbank Park;
 2. Townhouses at Flora Street, Keilor;
 3. Canning Street/Cordite Avenue bridge area, also showing the view over Rivervue Retirement Village from River Park Terrace;
 4. Fairbairn Park, Woods Street, Ascot Vale;
 5. Maribyrnong Township, Corner Chifley Drive and Plantation Street;
 6. Fairnsforth Avenue/Fisher Parade Bridge;
 7. Corner Dynon Road, West Melbourne and Kensington; and
 8. Hobsons Road Kensington.
- The Review Panel met informally with [REDACTED] (Submitter #23) at his premises at [REDACTED] and were told what had happened at his premises.
- The Review Panel was not able to visit the site at Rivervue Retirement Village (which was then still in part undergoing repair construction); however, there were several submissions of the impact upon the residents at Rivervue and many of the submissions included detailed

descriptions. The Review Panel members were able to drive to the site and inspect it visually from the outside and were subsequently able to visit the site on 8 August 2023.

Day 2:

- The Panel held formal preliminary discussions with representatives of Melbourne Water at their premises. Those present from Melbourne Water were: Mr Craig Dixon, Executive General Manager, Service & Asset Lifecycle, Mr Tim Wood, General Manager, Service Programs, Dr Wendy Smith, Senior Manager, Waterways, Drainage & Catchments, Ms Kirsten Shelly, Executive General Manager, Service Futures, Ms Rachel Lunn, General Manger, Urban Planning and Development, Ms Kerrie Homan, Senior Manager, Statutory Flood Amendments and Engineering Assessments and Ms Heidi Ryan, General Manger, Government and Water Sector Strategy. Melbourne Water provided two documents to the Panel on the occasion, namely:
 - (1) Presentation to the Maribyrnong River Flood Review Panel dated 2 May 2023. Mr Craig Dixon, Executive General Manager Service & Asset Lifecycle spoke to this paper; and
 - (2) Melbourne Water Submissions to the Maribyrnong River Flood Review’.
- The Review Panel met at Flemington Racecourse with Victorian Racing Club Limited representatives, Ms Jo King and Mr Alex Watson, and were taken to inspect the Flemington Wall.
- The Panel met with [REDACTED], at that time a representative from Moonee Valley City Council, who informally informed the Review Panel of the events during and after the Flood Event.

Day 3:

- On the third day the Review Panel met with Ms Laura-Jo Mellan (representative from Maribyrnong City Council).
 - The Review Panel members then conferred to plan their work to undertake the tasks required by the Terms of Reference including those undertaken through the Panel Administrator as outlined in the following paragraphs.
15. The Panel Administrator next contacted each submitter inviting each of them to be considered amongst those who might be asked to participate in public consultations with the Review Panel and whether they wished to add anything further to their previous submission. Copies of the correspondence inviting submitters to be considered to participate at public consultations with the Panel and inviting them to add to their submissions is Attachment E.
16. Of those individual submitters:
- Seven provided extra information;
 - Nine indicated they did not want to confer with the Panel;
 - Thirteen indicated they would like to consult with the Panel; and
 - Four indicated a possibility of being willing to consult with the Panel.

Additional information was also received subsequently, and a list of the additional information received from the submitters is located in the Panel's database and a copy of that information is Attachment F.

17. Further information was also requested from:
- Melbourne Water;
 - Moonee Valley City Council;
 - Maribyrnong City Council;
 - Bureau of Meteorology;
 - Victorian Racing Club Limited;

- TIGcorp ; and
- [REDACTED]

Those requests extended over the period of the review with responses from time to time. Some information was also provided without specific request. A list of the requests seeking further information is Attachment G and a list of the responses to those requests, and of other information provided, is Attachment H.

Stage 4 – Public and Expert Sessions

18. Public consultations as contemplated by the Terms of Reference were scheduled by the Review Panel for the week of 17 July 2023. A proposed programme for consultations during that week was set out and a number of persons and organisations were notified to meet with the Panel for public consultations. Copies of those invitations are in Attachment I.
19. A number of those invited to participate in the public consultations declined to participate. Moonee Valley City Council declined to participate but made available its facilities for the public consultations to take place, and also provided submissions and information in response to requests from the Panel. [REDACTED], a former employee of Moonee Valley City Council, who had had direct involvement in responding to the flood event, had initially agreed to attend (on his own behalf and not as a representative of the Moonee Valley City Council) at a scheduled time of the public consultations. However, [REDACTED] informed the Panel Administrator late on the day before the time scheduled for his participation that he was unable to do so without explanation. [REDACTED] was invited to participate on another occasion during the week and to make further submissions, but he did not do so. A copy of that request is Attachment J.

20. TIGcorp, as the Managers and Developers of the Rivervue Retirement Village development, also declined to participate in the public consultations but had made a submission, provided information as requested and on 8 August arranged for the Panel to inspect the site with a formal presentation and tour of the site. The representatives from TIGcorp present on that occasion were Mr David Thurin, Chief Executive Officer, Mr Greg O’Brien, General Manager – Development, Mr Darren Lewis, General Manager - Finance and Ms Angela Buckley, General Manager - Retirement. There were also present Mr Tony Goddard in his capacity as Secretary of the Residents’ Association and Mr Rob Blachford whose property had been affected by the Flood Event. The Review Panel were shown the extent of the Flood Event at the site and were able to visit two of the residences which had been affected by the flood.
21. The public consultations that took place were as follows:

Date	Time	Attendance	Location
Monday 17 July	9:00 a.m. – 3:00 p.m.	Melbourne Water Dr Nerina Di Lorenzo, Ms Rachel Lunn, Dr Wendy Smith, Mr John Woodland.	Clocktower Events Centre
Tuesday 18 July	9:00 a.m. – 10:00 a.m.	Moonee Valley City Council The Panel convened to inform the observers that [REDACTED] was not able to attend as expected and that Moonee Valley City Council had provided written submissions but declined to participate at the public consultations.	Clocktower Events Centre
	1:00 p.m. - 3:00 p.m.	Brimbank City Council Ms Leanne Deans, Mr Tom Razmovski.	Clocktower Events Centre
Wednesday 19 July	9:00 a.m. – 11:00 a.m.	Victorian Racing Club Mr James Reid, Ms Abby Gill.	Medway Golf Course
Thursday 20 July	9:00 a.m. – 11:00 a.m.	City of Melbourne Mr Bandara Rajapaske, Mr Sanjeeva Rajapaske, Mr Cintia Dotto.	Clocktower Events Centre
	1:00 p.m. – 3:00 p.m.	Maribyrnong City Council Ms Laura-Jo Mellan.	Clocktower Events Centre
Friday 21 July	9:00 a.m. – 12:00 noon	Rivervue Residents’ Committee & Rivervue Residents Mr Tony Goddard, assisted by Mr Rob Blachford, Mr Colin Waters.	Clocktower Events Centre

	1:00 p.m. – 4:00 p.m.	Melbourne Water (Continuation from Monday) Dr Nerina Di Lorenzo, Ms Rachel Lunn, Dr Wendy Smith, Mr John Woodland.	Clocktower Events Centre
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22. Observers from the public or interested parties were able to attend each of the public consultation sessions. Advance notice of the proposed sessions was published on the Melbourne Water website in a section dedicated to the Independent Review and anyone wishing to attend as an observer was able to register with the Panel Administrator to attend. Observers who attended included journalists, representatives of interested parties, persons affected by the Flood Event and some members of the public. A list of observers by reference to each of the sessions is in Attachment K.

23. The public consultations were transcribed and additional information, or copies of presentations, were made available. The transcript of the public consultations is in the Panel’s database in a folder labelled “Transcripts” and a copy is in Attachment L. The documents referred to during the public consultations and marked for identification for the purposes of the transcript are in Attachment M.

OVERALL

24. The first two matters for the Review Panel are to describe the specific effects of the Flood Event and to confirm its duration and extent.

25. The Flood Event occurred in the Maribyrnong catchment region after four days of above average rainfall in an already saturated catchment. The flooding followed significant rainfall across the catchment in the preceding days. The resulting river flows exceeded the capacity of the river channel and evolved into a major flood. Floodwater inundated over 500 homes, businesses and assets in the Maribyrnong catchment.

26. The catchment is large. The Maribyrnong River has a total length of 160 kilometres, including Deep Creek and Jacksons Creek and is the second major river system in the Port Phillip and Westernport Region. The catchment begins on the southern slopes of the Great Dividing Range, in the Cobaw Ranges, and Deep Creek and Jacksons Creek are the two main tributaries that join to form the Maribyrnong River at Keilor North. These creeks have the biggest impact on downstream flows.
27. Much of the Maribyrnong floodplain is zoned for public park and recreation use, with some zoned for residential use. The floodplain extent in the lower catchment is narrow at Keilor and gradually widens to 800 metres at Maribyrnong.
28. Melbourne Water's review of the Flood Event shows that this was the third highest flood event on record for this area. It was assessed as a 2 in 100 year flood event which means that there was a 2% chance of a flood event of that magnitude or larger occurring in any one given year. The location and intensity of the rainfall, the conditions of the catchment it falls onto, and the changes in urban development mean that every flood event is unique. In the lead up to the Flood Event, the Maribyrnong catchment was already saturated due to high and sustained rainfall throughout September and early October which meant that the runoff levels were high.

1. Specific effects

29. The specific effects of the Flood Event have been far reaching, resulting in damage to homes and businesses, community infrastructure groups and council assets across four local government areas, including Brimbank City Council, Moonee Valley City Council, Maribyrnong City Council and the City of Melbourne. The severity of the effects of the Flood Event varied significantly in different locations, ranging from minor damage to people being dislocated for nine months and businesses having to close permanently. In addition, the

event had significant impact on people's health and well-being that are ongoing.

30. The following examples from submissions by residents affected by the Flood Event are representative of the experiences of many of the affected residents:

**Rivervue Retirement Village, Moonee Valley City Council
(Submission #33):**

"... Some stood around stunned and simply bewildered, a few remained in their homes, others parked mobile homes or caravans in the street. ... Others seemed unable to act or chose to do nothing. This span of reactions was understandable given the number of properties impacted and the differing degrees of property damage. Affected residents had a wide variation in individual circumstances: health, age, availability of family support, and financial status, while some were absent from their property. ... by day four we were physically exhausted. We started to struggle mentally and we simply could not effectively process information ... it took some time for us to ... work through the trauma. The mental and emotional impact still lingers ... We also witnessed the impact of the flood on village residents whose homes were not damaged. Their community had been dislocated, facilities damaged and they wanted to and did help but were often unsure of how best to do so."



Figure 1: Photo of flooding at Rivervue Retirement Village.
(Source: Submission #33).

Navigator Street, Maribyrnong City Council

(Submission #02):

“This flood has completely devastated my life and my finances. The strata (sic) building insurance does not cover flood and I have had to spend my life savings to repair my property. ... Too many lives have been destroyed!”



Figure 2: Photo of example flood damage in Navigator Street, Maribyrnong City Council. (Source: Submission #02).

Chifley Drive, Maribyrnong City Council

(Submission #56):

“... I was extremely anxious of not knowing why this had become so dangerous that I could not stop shaking ... We were taken to the community centre. I was dazed uncertain, anxious, angry, lonely, lost, shaking and I wanted answers. ... This is when anger was starting to creep up I remember thinking I cannot believe this got to this stage and nobody knows anything we were not told of any warning that this was going to happen is that this was going to be so bad so huge so devastating. ... I arrived home and I just stood there. there was not one bit of greenery around me everything was black anyway I looked down the road round the corner everything was just black it was all mud at least 4 inches high and higher in other places.”

Esplanade, Maribyrnong City Council

(Submission #31):

“The flood left river mud on everything it touched and about 50mm thick in places...” The clean-up “... was very difficult and emotional.” “... the water had been highly contaminated with sewerage and heavy metals ...”... “... we lost control of what was happening, the helpers, bless them, just carted it all out the trash and myself and my wife weren’t in a position mentally to grasp the implications. Consequently, we were not sure of what we lost.”

Duffy Street, Maribyrnong City Council

(Submission #35):

“... I slept elsewhere for 56 nights but did not completely move out. Ate here, continued to work from here (sole trader), worked on the clean-up and restoration – which continues to this day. ... Thursday 13th October was a sleepless night with NO WARNINGS from any official body, just a general sense of dread and anxiety.”



Figure 3: Photo of example flood damage in Duffy Street, Maribyrnong City Council.

(Source: Submission #35 and duplicated in Submission #38).

31. The spatial extent of flooding in the lower Maribyrnong River between Aberfeldie Park and Thomson Reserve is shown in Figure 4, with the corresponding classification of flood extents given in Figure 5. The spatial extent of flooding in the mid Maribyrnong River between Canning Street and Plantation Street is shown in Figure 6.

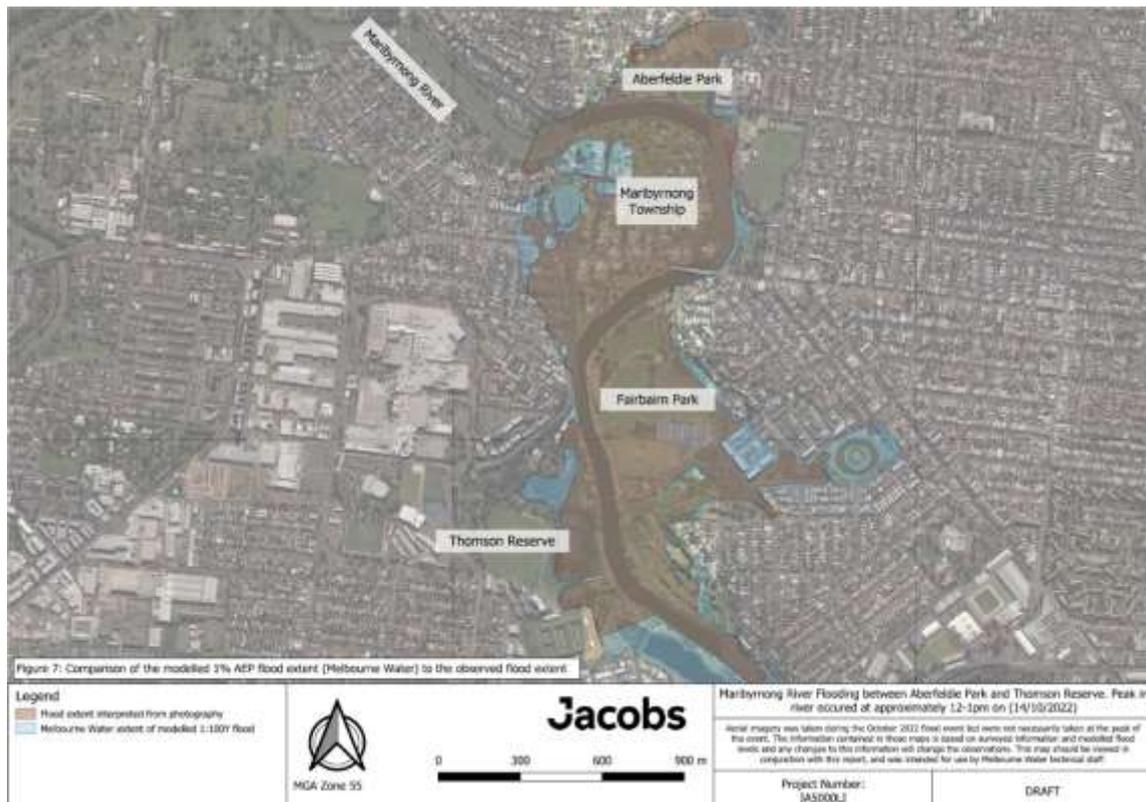


Figure 4: Spatial extent of flooding in the lower Maribyrnong River between Aberfeldie Park and Thomson Reserve resulting from the Flood Event.
 (Source: Jacobs, 2023, Lower Maribyrnong HEC-RAS Model Verification_RevB).

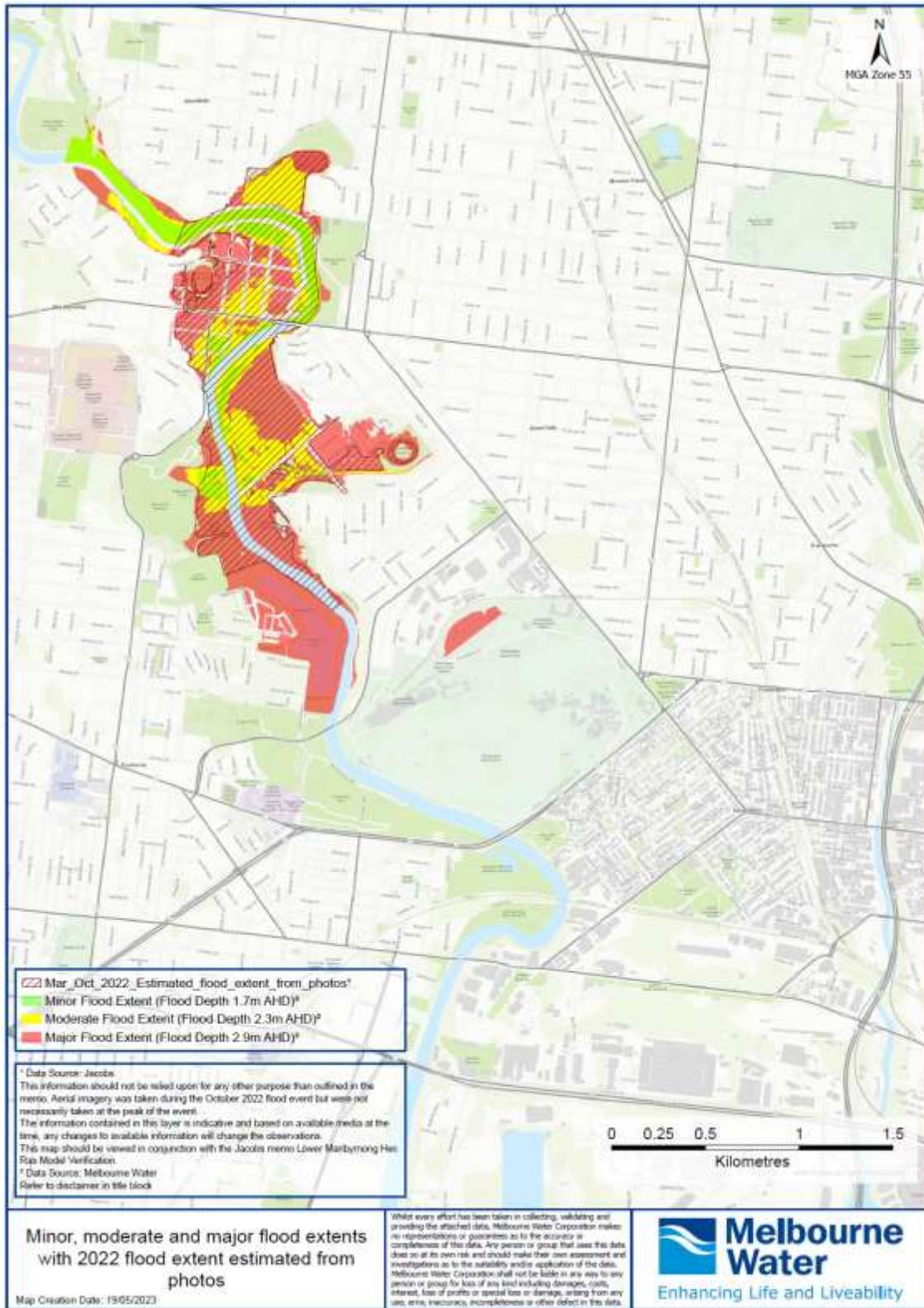


Figure 5: Spatial extent of flooding in the lower Maribyrnong River between Aberfeldie Park and Thomson Reserve resulting from the Flood Event, showing classification of flood extent. (Source: Jacobs, 2023, Lower Maribyrnong HEC-RA Model Verification_RevB).

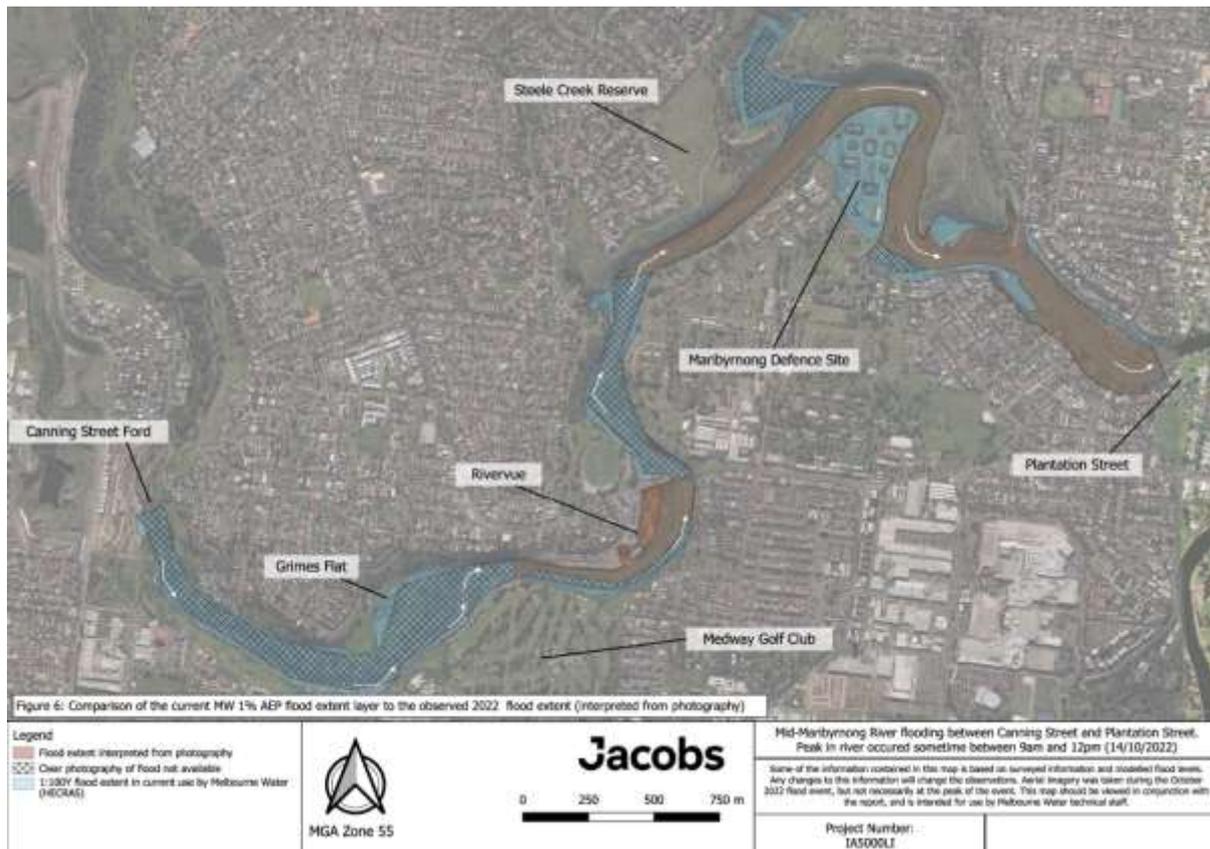


Figure 6: Spatial extent of flooding in the mid Maribyrnong River between Canning Street and Plantation Street resulting from the Flood Event.

(Source: Jacobs, 2023, Mid Maribyrnong HEC-RAS Model Verification_RevB).

32. In the Brimbank City Council area, which is located furthest upstream of the four local government areas affected, there was significant impact on a range of private and public properties, some of which were outside the area included in the Terms of Reference of this Review. Within the area defined by the Terms of Reference Brimbank City Council indicated in their submission that they were aware of 10 private properties that were impacted by the Flood Event. However, private properties along the Maribyrnong River and within the Brimbank Green Wedge (outside the area defined by the Terms of Reference) also incurred losses, including property and equipment damage, as well as equipment being swept away in flood waters. An example of this is given in Submission #32, which stated that there was significant inundation in a property in Keilor, “... causing damage to irrigation infrastructure, loss of topsoil, loss of crops both in the ground at the time and those unable to be planted until 24 January 2023 when the irrigation infrastructure was repaired ...”.

33. Other specific effects of the Flood Event in the Brimbank City Council area included the destruction of the historic Arundel Road Bridge, which is outside of the area included in the Terms of Reference, and the inundation of properties adjacent to the Maribyrnong River with flood waters that could have been contaminated from surrounding aviation, industry and landfills, potentially presenting risks to human health.



Figure 7: Photo of destruction of Arundel Heritage Bridge post Flood Event.
(Source: Submission #60).



Figure 8: Photo of flooding at Flora Street, Keilor, resulting from the Flood Event.
(Source: Submission #60).

34. In the Moonee Valley City Council area, which is located second furthest upstream of the four local government areas affected, a number of residents, businesses, and community organisations were affected by the Flood Event. This included approximately 80 properties in the suburbs of Ascot Vale, Aberfeldie and Avondale Heights, affecting 180 residents, the majority of who were aged over 65 and vulnerable. The emotional trauma of being evacuated from their homes, being socially isolated, experiencing financial stress and requiring temporary accommodation (of up to nine months) because their homes and their possessions had been significantly damaged or destroyed, had a significant detrimental effect on the health and well-being of many of these residents, necessitating ongoing support and advocacy.

35. Council facilities, open spaces and sports and recreational reserves were also significantly affected by the Flood Event. Flooding damaged Riverside Park, Canning Reserve, Maribyrnong River Walking Trail, Riverside Golf Course, and Moonee Valley Athletics Centre. All of these facilities required cleaning, repairing and replacement of damaged assets and infrastructure. General waste from upstream became dislodged and stuck on trails and open spaces across these areas. At the time of making their submission, Moonee Valley City Council estimated the cost of cleaning up this waste to be over \$500,000. Those costs were in addition to estimated costs of over \$860,000

for repairs to council buildings, and estimated costs of more than \$10,000,000 to be borne by residents and community organisations.

36. Residents, community organisations and sporting clubs were unable to access and use council spaces and facilities as a result of the Flood Event for up to three months, with repairs to council assets affected by the Flood Event continuing beyond that time frame. Equipment belonging to sporting clubs was also damaged or destroyed, impacting community well-being, member participation and social events. The Flood Event also affected power, water, and sewerage in Ascot Vale and Avondale Heights and caused public health and environmental risks from contaminated waste, including mould, water-borne diseases, and increased transmission of mosquito-borne diseases.
37. An example of community impact is the damage to the appliances, gym equipment, furniture, internal walls, partitions, and fixtures that occurred at the Essendon Canoe Club. After the flood subsided, a large amount of sediment, and an unknown number of contaminants, remained in the club, which were eventually cleaned by club volunteers. In addition, internal walls, toilet cubicles, fixed shelving and larger appliances had to be replaced.
38. The biggest effects in the Moonee Valley City Council area were at the Rivervue Retirement Village in Avondale Heights (Figure 9), where significant amounts of inundation occurred (see Figures 10 to 17). Overall, 47 properties were affected, including the village's Community Centre (Figure 17). Impacts varied significantly, with some residents losing a little and others losing a lot, with some having insurance and others not, and with some being back in their homes soon, while others had to wait up to nine months, causing significant anxiety, discomfort and expense (e.g. displaced residents reported of having to pay in the order of \$500 per week for rent). There is also ongoing emotional, physical, social, and economic impact associated with a lack of ability, or concern about whether it would be possible, to obtain insurance, an increase

in insurance premiums where insurance could be obtained, and potential reductions in the value of the residents' 99 year leases of their properties.



Figure 9: Photo of flooding of Woods Street, Fairbairn Park, and Riverside Golf Course, Ascot Vale – Fire Rescue Victoria.

(Source: Moonee Valley City Council Submission #40).

39. The following recollections provide a more detailed insight into the effects of the Flood Event on residents:

**Rivervue Retirement Village
(Submission #33):**

"... My partner and I live in the Rivervue Retirement Village, Avondale Heights, adjacent to the Maribyrnong River. On 14 October 2022 our home was inundated with flood waters. ... By 7.45 am our street was inundated and by 8.00 am the street behind ours was flooded as well. Inside our house water began spouting from the sinks due to backflow pressure and by 8.30 am the house was enveloped by flood water. ... The water initially breached the house from the rear, the opposite side to the river, at 9.10 am. Shortly thereafter our home was inundated to a depth of 100mm. ... When water appeared in the street, we knocked on our neighbour's doors to alert them. Some people were asleep, others difficult to raise, a few occupants were away and one thought that she had spilt a glass of water on her carpet when getting out of bed. ... The flood waters trapped our wheelchair bound neighbour in our driveway with our dog. ... At 11.00am, directed by Rivervue management, we evacuated to the community centre located on higher ground. From there we could see the river; its height, size, and speed took us aback. By early

afternoon we waded back in knee deep water to recover some more personal effects. ... For the first week we frequently lost power and vehicle access to our property. Access to our street, one of the few two-way streets in Riverview, quickly became problematic. ... Household contents, including sodden carpets, were dumped at the front of properties or driveways, as garages were now crammed with household effects. As such the street was often impassable. This confused congestion mirrored people's reactions to the flood. Some stood around stunned and simply bewildered, a few remained in their homes, others parked mobile homes or caravans in the street. People shipped all their effects to storage, or refilled their freezers, or ripped out sodden carpets, or hung rugs out to dry. Others seemed unable to act or chose to do nothing. This span of reactions was understandable given the number of properties impacted and the differing degrees of property damage. Affected residents had a wide variation in individual circumstances: health, age, availability of family support, and financial status, while some were absent from their property. There were also a surprising number of people without, or with inadequate, contents insurance.

... Another issue complicated by insurance was temporary accommodation. Where to stay, for how long and who should pay became an increasingly challenging issue. We had nine moves after the flood before we able to secure a longer-term rental. Short term accommodation was scarce due the Spring Racing Carnival, and we were not attractive tenants to rental agencies. Because of the high demand short term accommodation cost more than \$2,500 a week. ... Riverview advised us that rebuilding could take six months. Residents' meetings became heated at times as people vented their frustrations over a range of issues, most pointedly whether our homes were built on a flood plain, insurance coverage, floor coverings and temporary accommodation. ... by day four we were physically exhausted. We started to struggle mentally and we simply could not effectively process information, something of a brain fog set in. Our minds felt like a series of mixed up whiteboards and spreadsheets. This was symptomatic of delayed shock, and it took some time for us to acknowledge it and work through the trauma. The mental and emotional impact still lingers ...

... We also witnessed the impact of the flood on village residents whose homes were not damaged. Their community had been dislocated, facilities damaged and they wanted to and did help but were often unsure of how best to do so. ... Five months after the flood there are still challenges ahead as we deal with the rebuild/refit of our home and continue our dance with the insurers."



Figure 10: Photo of Rivervue Retirement Village (prior to the Flood Event), showing the constructed retarding basins in the area of the site close to the river corridor land. Canning Street is seen at the right of photo.
(Source: Submission #44).



Figure 11: Aerial photo of Rivervue Retirement Village, Friday 14 October 2022.
(Source: Submission #40).



Figure 12: Estimated extent of inundation at Rivervue Retirement Village for the Flood Event. (Source: Jacobs 2023, Mid_Maribyrnong_2022_Flood_Extent_Observations, provided by Melbourne Water in folder “1. Mapping”).



Figure 13: Photo of the flood affected Rivervue Retirement Village on 14th October 2022. (Source: Submission #44).



Figure 14: Photo of the flood affected Rivervue Retirement Village on 14th October 2022.
(Source: Submission #44).



Figure 15: Photo of the flood affected Rivervue Retirement Village on 14th October 2022.
(Source: Submission #44).



Figure 16: Photo of Blue Ridge Close, Rivervue Retirement Village – Friday 14 October 2022.
(Source: Submission #40).



Figure 17: Photo of the flood affected community centre at the Rivervue Retirement Village
on 14 October 2022.
(Source: Submission #44).

40. In the Maribyrnong City Council area, which is located third furthest upstream of the four local government areas affected, a number of homes and businesses were impacted. In total, 512 residential properties were damaged, 177 of which were considered uninhabitable. In addition, six businesses were affected, including one medium/large business that is still closed for repairs, one small

business, the tenant of which has not returned, and four that have reopened.



Figure 18: Photos of example impacts of the Flood Event in Maribyrnong City Council.
(Source: Submission #57).



Figure 19: Photos of example impacts of the Flood Event in Maribyrnong City Council.
(Source: Submission #61).



Figure 20: Photos of example impacts of the Flood Event in Maribyrnong City Council.
(Source: Submission #26).

41. Examples of specific effects in the Maribyrnong City Council from the submissions include the following:

**Chifley Drive, Maribyrnong City Council
(Submission #24):**

“As a residence [sic] of Maribyrnong it is the worse flood that I have encountered since the 1974 flood. We have been through a few floods in the past but nothing could compare to October 2022 floods, nothing. We are a household of 4 adults my elderly father and mother and my partner and myself. It’s impossible to understand the flood disaster unless you have been affected by the floods only these people like myself can only tell you of the devastating affects the October 2022 floods had on each and everyone of the Maribyrnong resident and community. We lost everything clothes, furniture, computers, garden equipment and structural damage to the house.”

**Duffy Street, Maribyrnong City Council
(Submission #35):**

“I slept elsewhere for 56 nights but did not completely move out. Ate here, continued to work from here (sole trader), worked on the clean-up and restoration – which continues to this day. ... had we known that the water would inundate our house to waist level and completely submerge the back yard, we would (a) have put a LOT MORE stuff upstairs and/or (b) hired a truck and thrown all our beds, office furniture, filing cabinets and equipment, the piano, libraries full of books and countless other personal items of clothing, memorabilia in it and driven the truck up to Highpoint.

Thursday 13th October was a sleepless night with NO WARNINGS from any official body, just a general sense of dread and anxiety.”



Figure 21: Photos of example impacts of the Flood Event in Maribyrnong City Council.
(Source: Submission #35).

**Duffy Street, Maribyrnong City Council
(Submission #39):**

“I was at first concentrating on watching the front yard and watched the water slowly rise to the level of our front deck as other properties were inundated. I had raised the floor level prior to undertaking a renovation in 2012. From the front deck I heard the gurgling of water rising through the toilet, bath, shower & sink ... it was then I noticed the back yard was totally inundated with our back shed with a metre of water through it and the outdoor fridge and my prized electric smoker floating. The water came through the front door as I scrambled to get my musical instruments and computers to the 2nd story. I grabbed photos, documents, clothing and put them on beds with my partners words ringing in my ears that all her memorabilia should be moved up stairs, just in case. ... Eventually waste high water was throughout the downstairs area of the house and almost above my head in the back yard. After saving as much as possible I sat on the stairs and contemplated the mammoth task ahead. I stayed in the house that night and watched as the water receded leaving the full extent of the catastrophe. My piano, drum kit, mattresses, bedding... everything you take for granted in a comfortable home covered in mud.”



Figure 22: Photos of example impacts of the Flood Event in Maribyrnong City Council.
(Source: Submission #39).

**Raleigh Street, Maribyrnong City Council
(Submission #55):**

“... On Friday the 14th of October my life undoubtedly changed forever, literally in front of my eyes and without warning. ... For the next 2 hours, we constantly approached the SES members asking do we need to evacuate, only to be told no, you don’t need to and it’s only going to be a minor to moderate flood, don’t worry. At 8.50 am we notice water about to enter the rear of our property our property(sic) — this is the moment we knew we were in trouble, despite talking to the SES again less than 5 minutes prior, who again reassured us we were fine. By the time we urgently evacuated 3 kids (2, 4 and 7 in age) and 2 cars, as we drove out in water over ankle deep (only 10 minutes later). Within 30 minutes, our yard was knee deep in water and within 1 hour, water started to enter our house and over knee deep in our yard. Working frantically with my partner to save as much as we could, we walked out of our place, near crutch deep in water — no need to panic says the SES you’ll be right mmm!”

42. The Flood Event also had marked effects on community infrastructure and groups, including two religious and ten community groups, within the Maribyrnong City Council, with ongoing effects on one youth group, as well as council assets, including 31 kilometres of roads, 30 kilometres of stormwater drains, 70 kilometres of footpaths, eight kilometres of walking trails, three playgrounds, public toilets, public BBQs, park lighting infrastructure and two sports pavilions. The council has also removed approximately 150,000 cubic

meters of mud, silt, household material and other flood debris from private property and public land.

43. In the City of Melbourne, which is the most downstream of the four local government areas affected, the Flood Event caused damage to infrastructure, properties and businesses, however, the proactive measures taken by the City of Melbourne, as well as the topography of the area, reduced flood impact. Three businesses were severely impacted, five businesses had light to medium impact and there was one residential apartment block in Hobsons Road, Kensington, where “... the carpark flooded to a depth of 40cm which destroyed many cars and damaged many items in the lock-up cages.” (Submission #42).
44. One example of a specific effect on a small business in the City of Melbourne included the damage caused to Aftershock PC from decisions to allow vehicles to travel through the flood waters (Submission #23, Figure 23), as described below:

Aftershock PC

Submission #23:

“Aftershock PC employs over 80 staff on the corner of Dynon and Kensington road in West Melbourne, to manufacture and assemble custom computers. The Maribyrnong flood came with no warning to us at all. We lost around \$1.5 million in the flood and our insurance company has since told us we will not be covered due to specific clauses. This put our business on the brink of bankruptcy. ... During the flood event, Dynon road was closed from both ends, as well as Kensington road. As such, we were able keep some of the water at bay from inside the building. Hours after the road was closed, someone on the CBD side of Dynon Road decided to let a cement truck through ... making a huge tidal wave that smashed out around \$100,000 of our big glass façade windows and sent a wave through our building damaging a heap of extra stock. Then hours later, a b-double was let through from the Footscray end of Dynon Rd, creating another tidal wave when the flood was at its peak. This smashed out a bunch more of the façade windows and wiped out a heap more stock that we had carefully placed up higher.”

45. Flood recovery works completed by the City of Melbourne after the Flood Event included:

- Traffic management services at Kensington Road and Hobsons Road, which re-opened at 7:00 p.m. on the Sunday after the flood.
- Approximately one week of tidying up (scraping silt and clearing debris from roads, footpaths, and public spaces) along the Maribyrnong River.
- Provision of skips to impacted businesses and apartments by Council, so owners and occupiers could clear damaged goods.
- Testing and disposal of material removed from the sites.
- Pit and pipe inspection and cleaning as required.

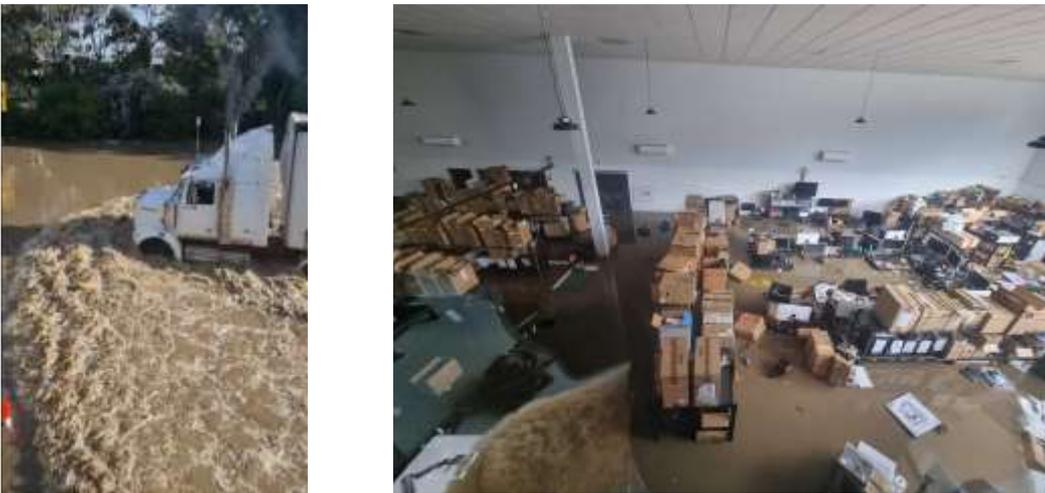


Figure 23: Photos of truck Driving through flood waters producing wave that caused damage to Aftershock PC in the City of Melbourne and of inundation of Aftershock PC warehouse.
(Source: Submission #23).

46. The Flood Event also affected Riverside Park and the adjacent areas because the non-return valves closed, and stormwater could not drain under gravity into the Maribyrnong River because of the high water level in the river. Flooding also occurred in a section of Hobsons Road close to the river, a section of Childers Street adjacent to a newly constructed rain garden and a section of Dynon Road.
47. Flooding impacts at the Flemington Racecourse were limited as a result of the Flemington flood mitigation wall (Figure 24).



Flemington Racecourse avoided major flooding. Picture: David Caird

Figure 24: Photos of limited effect of the Flood Event on the Flemington Race Course as a result of the Flemington wall.

(Source: <http://www.heraldsun.com.au/news/victoria/weather/backlash-over-former-vrc-chief-dale-monteiths-post-about-the-flood-wall-around-flemington-racecourse/news-story/fobe27f01bc868fef5a93dfb3b1557e0>).

Rivervue Retirement Village

48. We have referred above to some of the effects of the Flood Event at the Rivervue Retirement Village, but we need to mention that impact in a little more detail. The Terms of Reference do not expressly identify the Rivervue Retirement Village, but that effect of the Flood Event is an important aspect of our task.

49. The Rivervue Retirement Village occupies the land known as 9 Canning Street, Avondale Heights on a site located adjacent to the Canning Street Bridge with direct frontage to the Maribyrnong River. TIGcorp is the owner and developer of the land and access to the site is via an intersection to Canning Street with traffic signals and the Retirement Village is characterised as a gated community with private roads. The development of the site commenced in 2010 and consists of a mix of attached homes that are generally orientated with views towards the aspect of the Maribyrnong River. The 7.4 hectare site comprises a four-level community centre, 16 apartments, 144 villas, a practice bowling green

and 1.7 hectares of shared gardens. Development is continuing in the western part of the site with a further 45 villas either under construction or planned to be built. When finished, the Rivervue Retirement Village will consist of 205 apartments and villas.

50. The site was impacted by the Flood Event on 14 October 2022 as we have described generally above. Forty-seven homes were flooded, and homes located along Evergreen Avenue and Blueridge Close were directly affected. The Rivervue Community Centre and bowling green were also impacted. The TIGcorp submission (Submission #44) demonstrates those homes affected by the Flood Event in the area of the site as is shown in the plan below.

Maribyrnong River at 6.50 am. 5 metres from backdoor of 31 Evergreen Ave (southern end).



Floodwater at bottom corner (northern end) of Evergreen Avenue at 7.30 am.



Floodwater emerges from drainage pits in Evergreen Avenue (northern end). 7.30 am



Floodwater 3 metres from rear of 31 Evergreen (last villa seriously affected). 7.45 am.



Floodwater from drainage pits starts to enter northern villas in Evergreen Avenue. 7.50 am



Floodwater 1 metre away from rear of 31 Evergreen Avenue (southern end). 8.20 am.



Floodwater from drainage pits (southern end of Evergreen Avenue) at 8.30 am



Maribyrnong River at 8.30 am.



Water from drainage pits on Evergreen Avenue (mid-point looking north) around 8.30 am.



Water from drainage pits in Evergreen Avenue (southern end) at 8.30 am.



SES arrive around 8.30 am after call from Rivervue Management. They left soon after.



Photo of water coming from drainage pits at mid-point of Evergreen Avenue. 8.45 am.



Rear of villas at the low (northern) end of Evergreen Avenue. 8.50 am.



Water from drainage pits entering rear of 16 Evergreen (western side) in Blueridge. 9.00 am.



River water reaches backdoor of 31 Evergreen Avenue (southern end, river side). 9.10 am.



Floodwater at Community Centre. 9.15am.



Photo of drainage water in Blueridge Close, looking towards Evergreen Avenue. 9.15am.



Photo of drainage water from walkway at top of Redfern past Blueridge to Evergreen. 9.20 am.



North corner of Evergreen. Photo from Redfern past Blueridge down to Evergreen. 9.20am.



Water from Blueridge drains enters rear of villa on non-river side of Evergreen. 9.30am.



Water from drainage pits nears front of villa on western side of Evergreen (mid-point). 9.33am.



Water at front of villa (southern end of Evergreen) at 10.00 am.



Floodwater (southern end) Evergreen. 10.30 am



Floodwater in Community Centre 10.45am.



Floodwater peaks around 11.00 – 11.30 am.



Water starts to recede 11.45 am.



Front of 12 Blueridge Close as water subsides. This villa was flooded at back (first) then front.



Photo shows depth of floodwater (post flood) at rear of 25 Evergreen Avenue (mid-point).



Rear courtyard in Blueridge, post flood. Black sludge left by 6" water from backyard drain pit.

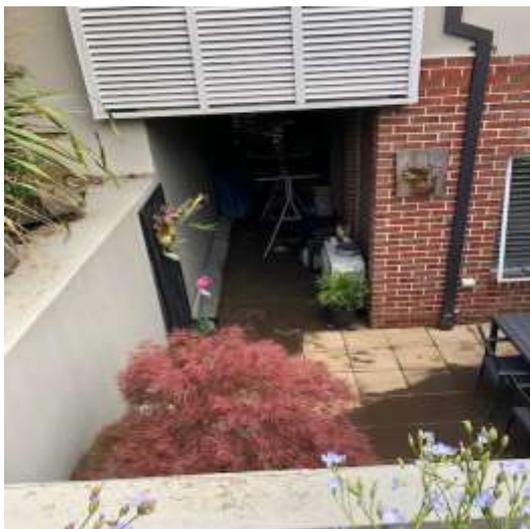


Figure 26: Rivervue Flood Event Timeline.
(Source: Tony Goddard, Secretary Rivervue Residents' Association 6.8.23).

52. TIGcorp provided the Panel on 8 August 2023 with a map of the affected site which showed the extent of the Flood Event and the areas which had been affected. Figure 27 shows the area shown to the Panel on that occasion.



Figure 27: Site tour 8 August of affected areas.
(Source: Rivervue Retirement Village 10.8.23).

2. Duration and extent

53. The second matter for the Review Panel was to confirm the duration and extent of the Flood Event.
54. The key flow gauges for confirming the **duration** of the Flood Event are those for the lower Maribyrnong located at Keilor and Maribyrnong. The Keilor gauge (230150A), which is the key upstream gauge, is located at a river crossing in Brimbank Park in an area known as Horseshoe Bend. At this location all major tributaries have combined so that no major additional inflows are expected beyond this point. Consequently, flow at this gauge is a good estimate of flow in the lower reaches of the Maribyrnong River.

55. The Maribyrnong gauge (230106A), which is the key downstream gauge, is located at Chifley Drive in Maribyrnong. At this location, the smaller tributaries (Thompson and Steel Creeks) have joined the main river channel, the catchments of which are much more urbanised than those of the upstream tributaries.
56. The timing of the key flood warning levels for these two gauges, as well as the corresponding duration of the Flood Event, are summarised in Figure 28 and Table 1. As can be seen in the table, the duration above the major flood level was 14 hours 30 minutes at the Keilor gauge and 14 hours 18 minutes at the Maribyrnong gauge.

Table 1: Minor, moderate and major flood levels at Keilor and Maribyrnong flood gauges and times at which these were reached during the Flood Event.

(Source: Produced by the IRP based on information provided).

Gauge	Minor Level (m)	Moderate Level (m)	Major Level (m)	Time Minor Level Reached (m)	Time Moderate Level Reached (m)	Time Major Level Reached (m)	Time Above Major Level
Maribyrnong River at Keilor	3.5	5.4	6.1	13/10/2022 10:12pm	14/10/2022 1:06am	14/10/2022 1:54am	14h 30m
Maribyrnong River at Maribyrnong	1.7	2.3	2.9	14/10/2022 3:30am	14/10/2022 4:36am	14/10/2022 5:36am	14h 18m

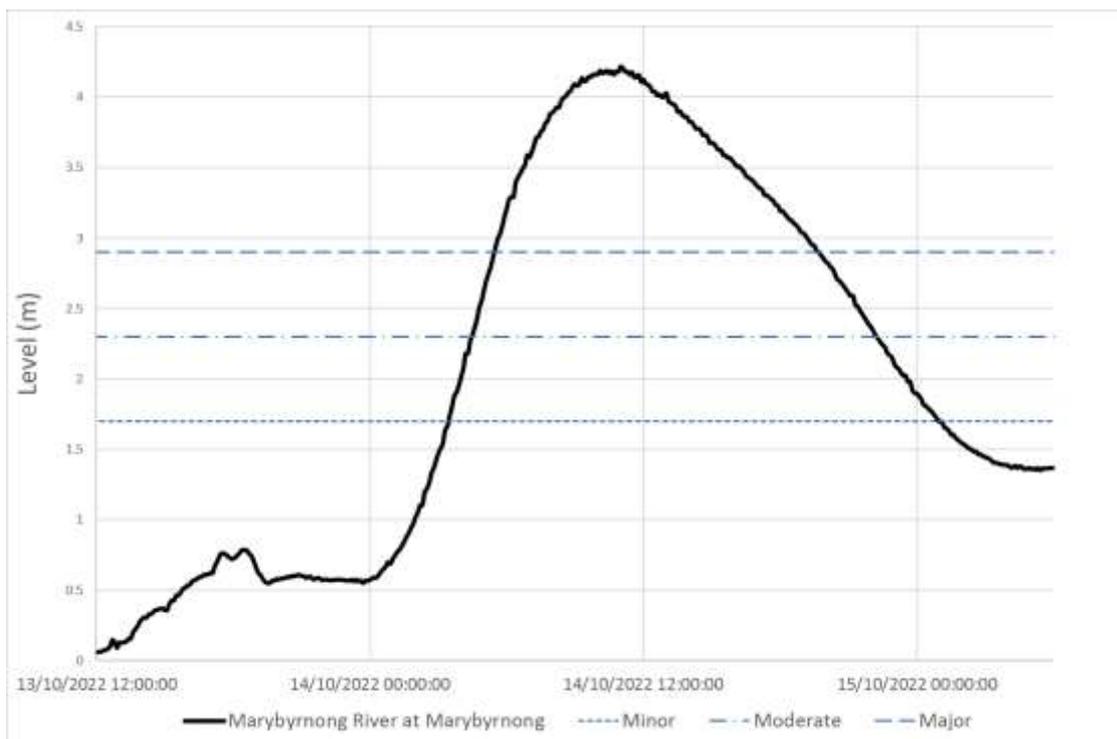
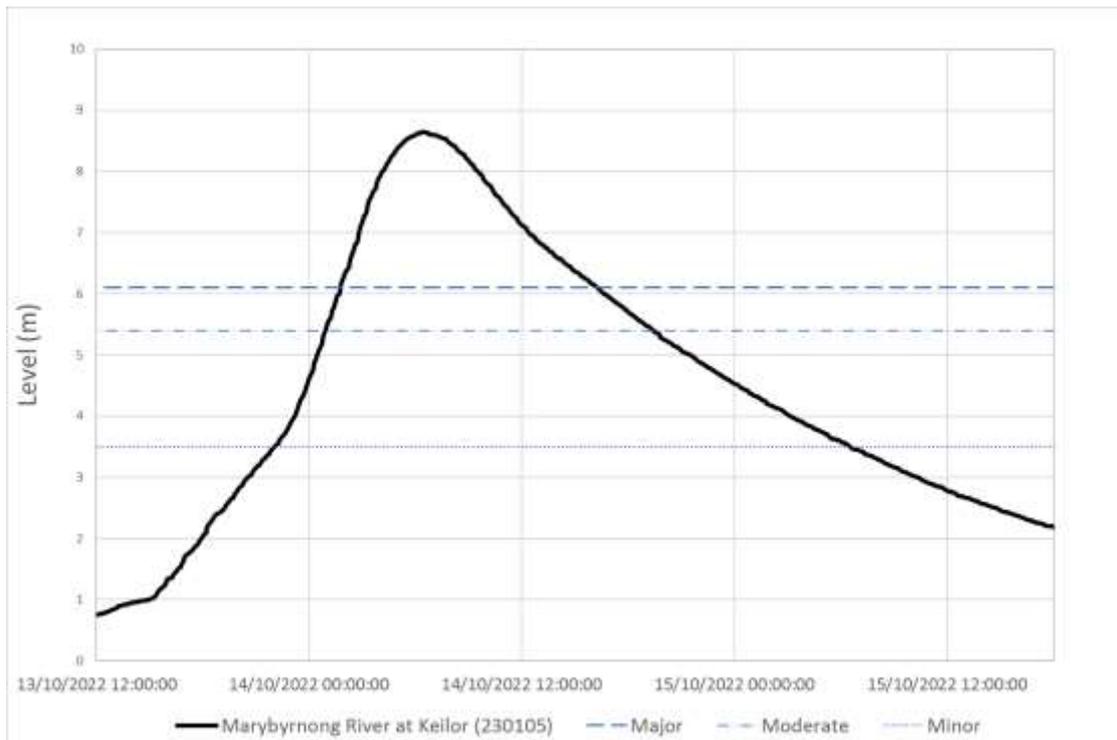


Figure 28: Flood hydrographs for the October 2022 event at Keilor and Maribyrnong gauges showing the duration above minor, moderate and major flood levels. (Source: Produced by the IRP based on information provided).

57. Information on the **extent** of the Flood Event was collected by Melbourne Water and their flood consultants as part of a post flood data collection assessment. This was done with the aid of data on flood levels, flood photos

and aerial flood photography, which has allowed the approximate flood extent to be mapped downstream of Canning Street Ford.

58. The results of the flood extent mapping performed by Melbourne Water and its flood consultants are shown in Figures 29 and 30 for the mid and lower Maribyrnong Rivers, respectively. It is possible to produce reasonably accurate maps of the extent of a flood from limited flood levels and photos because topography constrains the extent of the river.
59. Flood mapping can be used to inform the extent of the floods between known locations but this type of mapping will always have a level of uncertainty of a few hundred millimetres in flood depth estimate because flood and debris levels can be influenced by local factors and aerial photos are rarely taken at the exact time the flood reaches its peak level. In river reaches with steep banks, this uncertainty in estimates of flood depth does not translate to noticeable changes in flood extent. However, this is not the case in flat floodplain areas, where small differences in water depths can result in changes in flood extents of tens of metres or more. For this reason, the primary calibration of flood models is to levels, not to extents.
60. Figure 29 compares the extent of the Flood Event with the 1% annual exceedance probability flood extent for the reach of the river from Canning Street Ford to Plantation Street. Some areas have not been mapped because clear aerial photography was not available. For most of this reach, the extent of the Flood Event was at or within the 1% annual exceedance probability flood extent. The major exception is at Rivervue Retirement Village upstream of the Canning Street bridge where the flood extent exceeded the 1% extent.

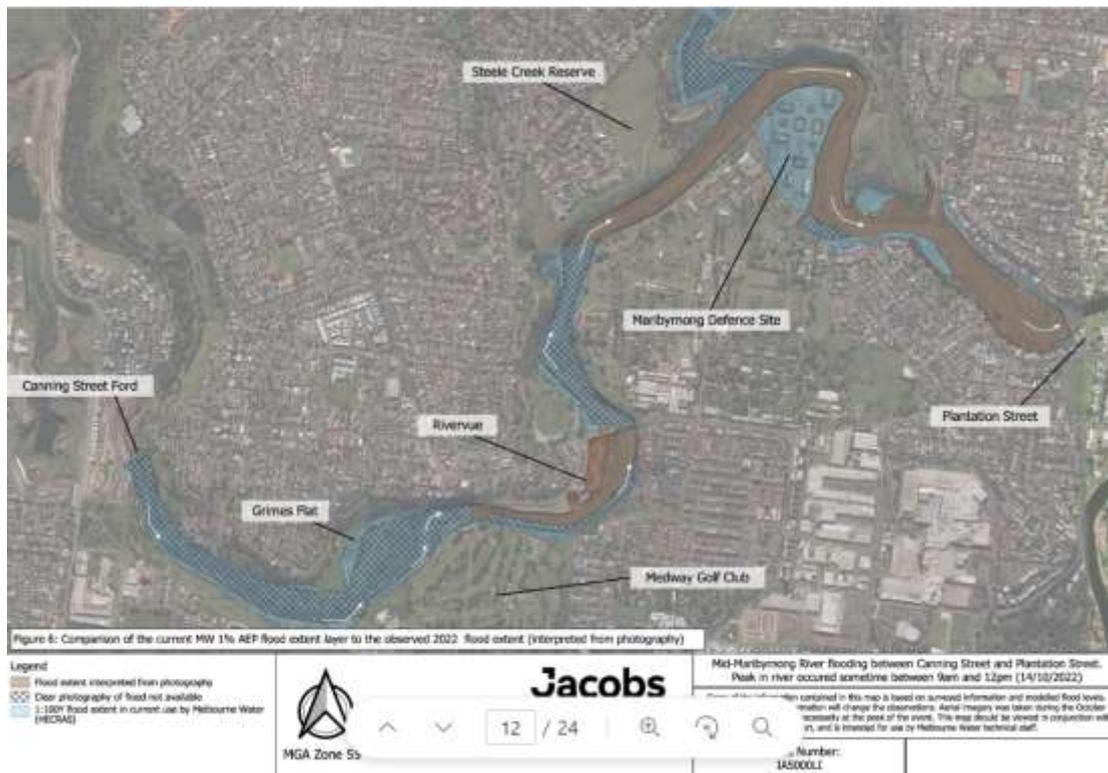


Figure 29: Flood extent mapping for the mid Maribyrnong River.
 (Source: Jacobs memo dated 4 July 2023 titled “Mid Maribyrnong HEC-RAS Model Verification _RevB”).

61. Figure 30 compares the estimated flood extent to the 1% annual exceedance probability design extent from Aberfeldie Park to Thompson Reserve. These photos show that downstream of Aberfeldie Park, the flood extent was just below the 1% annual exceedance probability extent.



Figure 30: Flood extent mapping for the lower Maribyrnong River.

(Source: Jacobs memo dated 17 May 2023 titled “Lower Maribyrnong HEC-RAS Model Verification_RevB”).

3. Prediction and Modelling

62. The third matter for the Review Panel was to identify and describe any predictions and modelling relevant to the Flood Event. In order to enable readers to understand better the relevance, importance and limitations of the available modelling, we first provide a brief overview of the role models play in flood management and how these models work, followed by details of the models used in the Maribyrnong River catchment by Melbourne Water, before providing details of specific modelling that is relevant to the Flood Event.

Role and Function of Models in Flood Management

63. Computer modelling is an essential component of flood management because it enables flood extents and depths to be estimated under current as well as future conditions for which corresponding measured values are not available. Such modelling is generally used for two purposes, namely for the support of

long-term planning decisions and for the support of flood warnings. Modelling for the former is generally detailed and is carried out using a rigorous process to setup, calibrate and validate the model. This typically takes a year and requires using all available flood data. In contrast, modelling for the latter is generally simpler and less rigorous, as the focus is on computational speed and timely predictions of flood level. These predictions are usually processed to produce information needed by response agencies and the public. An example of processed information is the time at which a particular bridge or street, or even individual houses, will be flooded or their access will be cut off.

64. The purpose of the **detailed modelling to support long-term planning decisions** is to obtain estimates of flood extents and depths for “design” flood events, which correspond to flood events that are estimated to be equalled or exceeded with a particular probability in any given year. For example, a design flood with a 1% Annual Exceedance Probability corresponds to 1 in 100 (namely, a 1%) chance of a flood of that magnitude or larger occurring in any given year. These modelled “design” flood extents and depths are used by planning authorities to determine which areas are considered to be affected by flooding (e.g. Land Subject to Inundation Overlay (LSIO)) and what finished floor levels should be required to avoid flooding.
65. In general, more extreme flood events, which result in greater flood extents and depths, and hence which have a greater potential to cause damage, are less likely to be exceeded in any given year than are less extreme flood events. Consequently, more extreme floods have a smaller “annual exceedance probability”, which means that there is a reduced chance that they will be equalled or exceeded in any given year. It follows that the smaller the annual exceedance probability of the design flood event that is used to determine LSIOs and required finished floor levels, the smaller the chances that damage will occur due to flooding.

66. In practical terms there is a necessary trade-off to be made between the measures required or adopted to reduce the possible damage by flooding and the amount of risk to be accepted. The adoption of mitigation measures that cater to design flood events with a smaller annual exceedance probability reduces the chances of flood damage, but also results in increased costs because of the need for these mitigation measures (e.g. raise finished floor levels) to avoid the impact of more severe floods. The trade-off between reducing the chances that flood damage will occur and having increased costs associated with achieving a reduction in damage can be likened to balancing the trade-off between selecting a higher level of insurance cover and the corresponding increase in premiums or selecting a higher level of insurance excess and the corresponding decrease in premiums. Ultimately the trade-off made by public authorities requires a judgment to be made and adopted as a matter of public policy.
67. For example, dams are generally designed to be able to cope with extreme flood events that have a very small annual exceedance probability (of the order of 0.001% to 0.01%) because dam failure is likely to result in the devastation of entire communities downstream. However, this also results in significant expense. In contrast, as the nuisance flooding of roads has far less severe consequences, stormwater systems are generally only designed to cope with much less severe flood events that have annual exceedance probabilities of the order of 5% to 20%. This requires less cost but also has the potential for more frequent flooding.
68. An annual exceedance probability of 1% is generally adopted for buildings in residential areas to determine the 1% LSIO and the required finished floor levels of buildings to avoid damage. However, that does not mean that buildings which are located outside of the 1% LSIO are immune to flooding, but, rather, that the chances that flooding will occur are less outside the area in the LSIO than out of it. More specifically, if the model results are accurate, buildings outside of the 1% LSIO should only flood for events that have an annual

exceedance probability that is less than 1% (i.e. flood events that are more severe, and therefore less likely to be exceeded, than flood events with a 1% annual exceedance probability).

69. The 1% LSIO and required finished floor levels of buildings are determined based on modelled outputs and are therefore not exact because models are only a representation of reality. How uncertain model outputs are, and hence the reliability of the estimates of the 1% LSIO and of the required floor levels, is a function of a number of factors, such as the quality and extent of the data available for model development, the physical characteristics of the system being modelled, the modelling approach used, the process used to develop the model and the assumptions made during the model development process.
70. Two different types of models are generally needed to obtain estimates of design flood extents and levels: one to estimate design flows in the river and the other to convert these flows into corresponding design flood extents and depths. In Australia, this modelling is carried out using the methodology in *Australian Rainfall and Runoff: A Guide to Flood Estimation*, which provides guidelines for flood estimation. The original edition was in 1958, with the current, 4th edition, first published in draft form in 2016 and finalised in 2019.
71. One way to obtain estimates of design flow is by statistically analysing long records of flows at a location, which is a process called “flood frequency analysis”. However, this analysis can only be used when relevant measured flow data are available. As part of this analysis, design flows that correspond to a particular annual exceedance probability are determined with the aid of statistical analysis of the available flood data. This results in a statistical model that provides a relationship between annual exceedance probability and the magnitude of the corresponding design flow.
72. Flood frequency analysis is a relatively old approach but there have been major improvements in the way it can be applied. Modern methods of analysis have

improvements in the statistical fitting, the ability to use historical information, and the use of incomplete records and anecdotal information. They also have the ability to use information from nearby locations to improve reliability. Flood frequency analysis results in a best estimate of design flood levels for a given annual exceedance probability, as well as a degree of confidence around this estimate.

73. Although flood frequency analysis is not precise, with a long record over 50 years, it is considered more reliable than any other method. For this reason, all other methods of producing design flows are either “calibrated”, “parameterised” or “tested” against flood frequency analysis results. An advantage of flood frequency analysis is that it is based on historical records and is therefore able to capture the observed variability of real floods.
74. Estimates of design flows can be obtained with the aid of rainfall-runoff models, where appropriate recorded flood data are not available which convert rainfall values to the corresponding flows or runoff. That method assumes that a design rainfall with a certain annual exceedance probability will produce a flow estimate that has a similar annual exceedance probability. Rainfall runoff models became mainstream modelling tools in the 1980s and have remained relatively unchanged since. There are several rainfall runoff models in use in Australia, but they are all relatively similar.
75. The physical processes underpinning the conversion of rainfall to runoff are very complex and depend on a number of factors, such as how much of the rainfall is intercepted by vegetation before it hits the ground and how this varies spatially, what happens to the rainfall that hits the ground in different locations (e.g. does it sink into the ground?, does it evaporate?, does it flow over the Ground? etc.), which, in turn, is a function of a number of factors, such as whether the ground is impervious (e.g. roofs, driveways, roads etc.) or not (e.g. soil, grass etc.), how this degree of imperviousness varies in space and time (e.g. the degree of saturation of the soil based on previous rainfall etc.),

the topography of the landscape and the presence of any engineering infrastructure (e.g. drains etc.).

76. Due to the inability to support the development of models that represent all physical processes underpinning the conversion of rainfall to runoff (e.g. lack of data, lack of computational resources, lack of financial resources), simplified rainfall runoff models are generally used, which abstract the key physical processes affecting the conversion of rainfall to runoff and are therefore relatively simple and easy to develop. Despite their relative simplicity, such models are generally considered to be very reliable.
77. When rainfall runoff models are used to obtain design flows, the rainfall values they convert to river flow have to be “design” rainfall values. The way in which design rainfall values are obtained is similar to the way design river flow values are obtained, namely by statistically analysing long records of rainfall data, which is a process called “rainfall frequency analysis”. However, this introduces additional uncertainties, especially when determining design rainfall values for rarer events, such as those with a 1% annual exceedance probability. The degree to which this is the case depends on the amount of rainfall data available.
78. When rainfall-runoff models are used to obtain design flows, uncertainties are also introduced by the assumption that on average a rainfall event with a 1% annual exceedance probability will be converted to a flow value with the same annual exceedance probability. However, given the simplified nature of rainfall-runoff models and the large number of assumptions that generally have to be made about catchment conditions etc. this is not always the case for specific events.
79. The conversion of modelled estimates of design flow to modelled estimates of design flood extent and levels is achieved with the aid of hydraulic models, which are complex to set up and require detailed information on the river and

floodplain. This includes detailed surveys of the land and riverbed, the land use and vegetation, as well as the characteristic of all the man-made structures in the river and floodplain, such as bridges, weirs, culverts, levees and roads.

80. There have been three generations of hydraulic models, resulting in significant advancements in flood modelling as computers have become more powerful. First-generation models are one dimensional. They model rivers as a series of cross sections and can only model peak flows to determine flood levels. These types of models became mainstream products in the 1980s and the modelling software HEC-2/HEC-RAS is the most popular example. Second generation models are also one dimensional but model the time series of a flood event and allow for branches, breakouts, and new flow paths. The modelling software MIKE 11 is the most popular example. Third generation models are two dimensional and represent the river and floodplain as a surface enabling the model to determine where flooding occurs directly producing detailed flood maps. These models became mainstream in the 2000s, with the modelling software TUFLOW and MIKE FLOOD becoming the most common examples. In the last decade, the software products have moved to incorporating “finite volume” numerical solutions schemes that have proved very reliable and have made use of high-end graphics cards for faster numerical processing.
81. Hydraulic models need to be setup by an experienced flood modeller and in contrast to rainfall-runoff models, which take on the order of seconds to minutes to run, can take hours to days to run. National guidance on the development of hydraulic models is contained in *Australian Rainfall and Runoff 2019 project 15 report “Two dimensional modelling of rural and urban floodplains”*.
82. A core principle in developing both rainfall-runoff and hydraulic models is model calibration and validation. This is a process where models are fine-tuned to reproduce observed historical events (calibration) and then, where possible,

blind tested on other events that were not used in the fine-tuning process (validation). This process is critical, as it ensures that the model provides a reasonable representation of the real world. Where this process has been carried out, the model is referred to as “calibrated”. The degree to which a model is calibrated is generally a function of the available data, including rainfall and stream flow records, and for hydraulic models, recorded flood levels along the river. The general principle is to use all available data on large floods, although there is generally limited data on such extreme events and only some use can be made of earlier historical floods where there is limited information on rainfall, stream flow and flood levels, and where major changes in catchment conditions have occurred.

83. Rainfall runoff models are relatively easy to calibrate to observed floods. Once they are calibrated to several events, they can be used to estimate stream flow anywhere in the catchment. The calibration process is used to fine-tune the one or two model parameters that describe how runoff travels through the catchment, which do not vary between storm events, and the two storm loss parameters that describe how much rainfall turns into runoff and how much infiltrates into the soil, which does vary between storms depending on how wet the catchment is before a flood event.
84. Uncalibrated models are generally considered unreliable. However, even when there is limited calibration data available, it is possible to test and improve the accuracy of a model. A simple test is to compare design levels, such as the 1% annual exceedance probability flood level with the largest recorded flood level. For a location with 100 years of flood history, it is expected for the highest flood on record to be slightly above or below the design 1% annual exceedance probability level and the second highest flood event to be well below. This simple style of testing removes much of the uncertainty around design levels.
85. The purpose of **modelling to support flood warnings** is to obtain forecast

(future) values of flood depths and extents for a *current* rainfall event to provide information that can be used to support the provision of flood *warnings* for that *specific event*. The models required for this purpose convert forecasts of actual rainfall, which are generally provided by the Bureau of Meteorology, to estimates of corresponding flood extent and depth.

86. The time it takes for these models to provide information that can be used for the purpose of updating flood warnings relative to the time it takes for actual flood levels to change is critical. For these models to be useful for the purpose of providing flood warning, the time it takes to obtain relevant information on impending flood extents and levels from these models has to be significantly less than the time it takes for flood conditions to change from, say, “minor” to “major”. This might require a trade-off between the degree of sophistication and accuracy of these models and the speed with which they can produce outputs.
87. The factors relevant to the trade-off between accuracy and uncertainty is summarised by Australian Institute for Disaster Resilience, 2009 as follows:
 - Predictions based on forecast (pre-storm) rainfall can only be very approximate.
 - Predictions based on amounts of recorded rainfall are likely to be more accurate, but they need to take into account rainfall losses and catchment processes. Given the complexity of the processes involved in transforming rainfall amounts into subsequent river flow, inaccuracies in predictions are likely.
 - Predictions based on measured stream heights upstream of a specified gauge are generally the most accurate, especially in streams with little additional inflow between the two gauges. However, these predictions often do not provide sufficient lead time, particularly in smaller catchments.

88. The time it takes to obtain modelling results is only one factor that affects the utility of flood warning systems, the others being the frequency with which the rainfall forecasts that are used as inputs to the flood models are updated, the frequency with which flood warnings that use the outputs from the flood models are issued, and the extent to which real-time measurements of flood levels are used to supplement the information provided by the models.

Melbourne Water's Modelling Approach in the Maribyrnong River

89. Melbourne Water is the lead agency for floodplain management in the Melbourne area under the Victorian Floodplain Management Strategy. As such, Melbourne Water is responsible for carrying out flood studies and modelling in collaboration with local government and, together with predecessor organisations, has a long history of studying the flood behaviour of the Maribyrnong River.
90. Under Victoria's State Emergency Management Plan, Melbourne Water is also the flood prediction agency for the Melbourne metropolitan catchments but the overall responsibility for the provision of forecasting and warning services for riverine flooding lies with the Bureau of Meteorology which also has responsibility for providing forecasts and warnings for severe weather conditions and heavy rainfall that could lead to flash flooding. The Bureau of Meteorology, however, is not responsible for flash flood forecasting, which is defined as flooding for catchments with response times of six hours or less. The responsibility for flash flood forecasting is with state and territory agencies in partnership with local councils.
91. To **support long-term planning decisions** in the Maribyrnong catchment, flooding extents and levels for an event with a 1% annual exceedance probability are obtained using a combination of rainfall-runoff models to obtain design flows and hydraulic models to convert these design flows to design flood extents and levels. The outputs of these models are used by relevant

planning authorities to determine the 1% LSIO and design floor levels, where required. Design floor levels are the minimum acceptable floor level for residential dwellings and many types of business.

92. The rainfall runoff model used by Melbourne Water to obtain design flows in the Maribyrnong River is RORB, which was developed at Monash University in the 1980s and is used widely throughout Australia. This model has been used by Melbourne Water for all of its rainfall runoff modelling since early in its development and those responsible in Melbourne Water have corporate knowledge about its application.
93. A RORB model for the Maribyrnong catchment was setup and calibrated in the 1980s. This model was calibrated to the May 1974 and October 1983 flood events at the Keilor, Bulla and Sunbury gauges. The calibration fits from this study are given in Figure 31. These fits are reasonably good, considering that there was limited rainfall information available at the time.

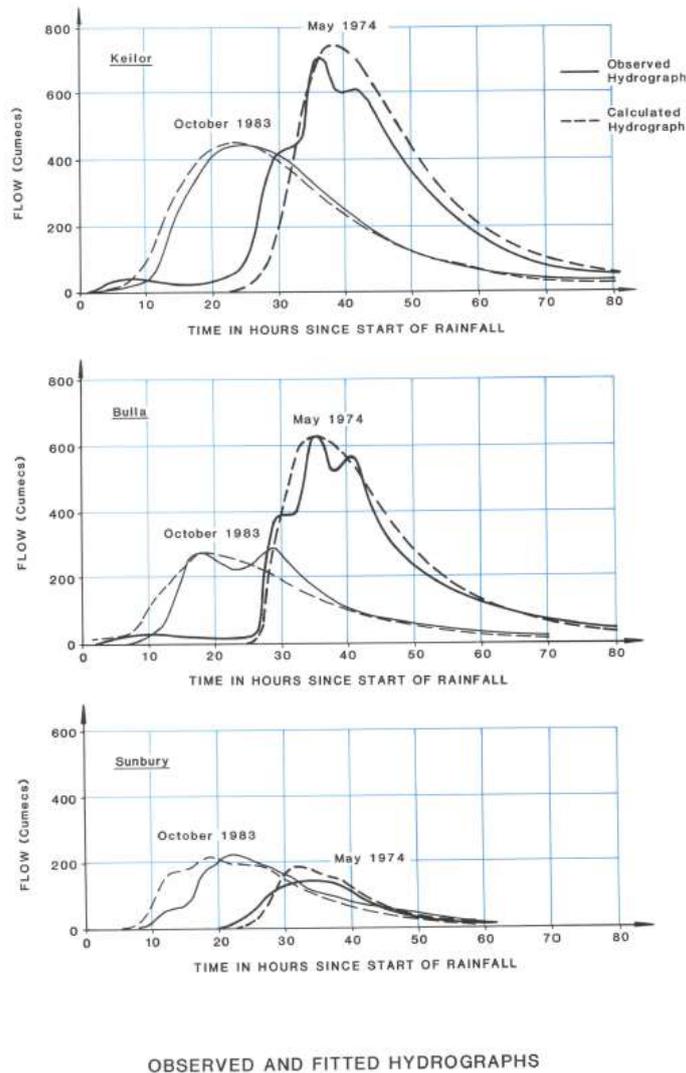


Figure 31: Results of calibration of Maribyrnong RORB model.
(Source: Melbourne and Metropolitan Board of Works (March 1986),
Maribyrnong Flood Mitigation Study).

94. The hydraulic modelling software used by Melbourne Water to convert the design flows obtained from the RORB model into design flood extents and depths is HEC-RAS which was developed by the US Army Corp of Engineers and is an evolution of their HEC-2 software package that was first released in 1968. This software implemented the standard step backwater analysis method that was usually carried out by hand. HEC-2 became one of the most frequently used hydraulic software packages in the early computer era as the code was freely available and could be run on nearly any computer platform. It also had extensive features and documentation and was backed by the US Army Corp of

Engineers. By the 1980s, as computers became more accessible, HEC-2 was used widely throughout the world and by most Australian flood management authorities.

95. The major limitation of HEC-2 is that the software only models the flood level using a steady flow in the river. In a real flood event, however, the flow at any particular location of river changes over time. As the flood wave arrives, the flow increases until it peaks and then recedes again. A HEC-2 model is usually setup with the peak flow represented as a constant value in time and therefore it does not represent the passage or routing of a flood wave down the river network. Additionally, as a flood moves down a river reach, without additional inflows, the peak is slightly attenuated, or reduced, as flood waters fill the river and floodplain and flow out more slowly than they flow in. While this can be indirectly addressed in HEC-2, by the 1990s many authorities started moving to dynamic flood modelling platforms that considered the whole flood, and not just the peak flow, and directly accounted for the attenuation of the flood peak. While HEC-2 can be considered a first-generation model, these newer dynamic models, of which the software MIKE 11 is the most successful in Australia, can be considered second generation models. These types of models were generally commercial products with a significant purchase price that limited their access.
96. In 1995, HEC-2 evolved into the HEC-RAS software package and eventually incorporated dynamic flow behaviour, but for the Maribyrnong studies the final flood surface was obtained using the model's steady state mode, with dynamic mode only used to understand the attenuation. Even today, the HEC-RAS model of the Maribyrnong River is generally only used in the steady state (peak flow).
97. In general, the HEC-RAS software is still used in practice today, but generally only for simple, short reaches of river and for checking or analysing bridge hydraulics. By 2000, most flood authorities had moved away from HEC-RAS for

new studies on larger river systems.

98. There are currently separate HEC-RAS models for the upper, mid and lower Maribyrnong catchments, which were set up and run by consultants GHD Group Pty Ltd in 2003 on behalf of Melbourne Water Corporation. This modelling draws upon the work in the 1986 Maribyrnong River flood mitigation study by the Melbourne and Metropolitan Board of Works and is covered in two separate reports. Development of the model for the lower Maribyrnong is covered in the *Maribyrnong River Hydraulic Model Final Report*; that report is extensive and contains the features of a flood study, including the model setup and calibration to historical flood level with particular attention paid to all the bridges that cross the lower Maribyrnong (as these can have a major impact on flood levels if they constrict flood flows). The setup of the hydraulic models of the upper and middle reaches of the Maribyrnong River is covered in the 2003 GHD *Flood Mapping of Maribyrnong River stages A and B Report – Volume 1*.
99. The HEC-RAS model for the lower Maribyrnong River was calibrated to 14 flood levels along the length of this section of the river, as well as several historical flood photos, using the standard approach of adjusting Manning's 'n' value, which represents the roughness of the riverbed, or restriction to flow, for different reaches. To address the effect of flow attenuation, the model was originally run in dynamic (unsteady) mode and the attenuated flow was then used in the steady state model to obtain the final flood surface. The actual flows used are slightly higher than those in the 1986 flood study, as the hydrologic model produced slightly higher flows, but they nearly perfectly match the results of the 1986 study in the lower reaches modelled.
100. The calibration results for the lower Maribyrnong HEC-RAS model are good, with 10 of the 14 flood levels being within 50 mm of the observed level and the model showing no systematic over- or under- estimation bias, but the calibrated Manning's 'n' values are at the lower end of the range of typically used values.

However, an unusual aspect of the calibration is that the model was calibrated using “total energy” and not the “design water surface”, which correspond, respectively, to two different types of flood levels. The **water surface** represents the average water level across the river, while the **total energy surface** represents the additional level the water will reach if it flows against an obstruction like a bridge pier. This is a function of the one dimensional nature of most first and second generation models. In reality, the water level can be lower in the middle of the river, where water flows faster and the total energy can be higher because of the higher velocity, while surfaces at the edge of the river, where buildings are typically located, can vary between the average water surface and average total energy level. The difference between the water surface can be considered the kinetic energy of the flow, with its value calculated by the formula $v^2/2g$, which is the velocity squared divided by two times the acceleration due to gravity. For a typical velocity of 2 m/s, this equates to 210 mm, while the equivalent value is 460 mm for a relatively high velocity of 3 m/s.

101. The approach used to develop the hydraulic models of the upper and middle reaches of the Maribyrnong River is much simpler than that used for the development of the model for the lower reach of the river. These models were setup and run with the design 1% annual exceedance probability flood flow. Historical floods were not run or used for calibration, nor were design levels compared to any observed flood levels. This seems unusual, because some observed flood levels for the 1974 flood existed and, at the time, that event was known to be the second largest flood in approximately 90 years. As a result, Manning’s ‘n’ values (which were obtained as part of the calibration of the lower Maribyrnong HEC-RAS model) were used in the mid and upper Maribyrnong models, without, it seems, comparing the results of these models against historical data.
102. To **support the provision of flood warnings**, Melbourne Water use their Flood Integrated Decision Support System (FIDSS) to determine whether a rainfall

event is likely to result in minor, moderate or major flooding and provides this information to the Bureau of Meteorology, which then issues warnings.

103. FIDSS uses software known as Delft-FEWS (Flood Early Warning System), which is freely available software that is designed to handle large amounts of forecast data efficiently, to integrate latest observations with meteorological forecasts, and to provide for data quality and standardised work processes, visualisation and reporting. Delft-FEWS is used to prepare input data (rainfall and river levels and forecast rainfalls from the Bureau of Meteorology) and run hydrologic and hydrodynamic models for flood forecasting. Delft-FEWS is industry standard software that is widely used nationally and internationally for flood forecasting applications.
104. As part of FIDSS, rainfall and river data, along with forecast rainfalls from the Bureau of Meteorology, are fed into a hydrologic model. This model converts rainfall into runoff (flow), and models how this runoff moves across the catchment and into the river system, as well as along the river system, to obtain estimates of flows along the length of the river. These estimates of flows are converted into estimates of river heights using a rating curve, representing defined relationships between flow and river height. These relationships are normally fixed in the modelling process and are only updated after additional information becomes available. It is important that rating curves cover the whole range of river heights and flows, including those for large flood events.
105. FIDSS utilises the Unified River Basin Simulator (URBS) as the hydrologic model to convert rainfall into runoff. URBS is also used by the Bureau of Meteorology for their flood forecasting and nearly every agency that does flood forecasting in Australia uses this model. Melbourne Water's URBS models have been calibrated to historic flood events, however, rainfall data and information on how wet the catchment is has to be entered for the specific rainfall event to be modelled because the URBS model is an "event" type model, which means that it is run with rainfall inputs that just cover the period of a rainfall event

(i.e. the flood event for which warnings might have to be issued). Melbourne Water had informed us that FIDSS model runs take between 30 and 90 minutes, with a further 20-45 minutes required to process the information obtained from the model to make it suitable for issuing flood warnings.

106. Forecasts of the rainfall inputs required to enable the URBS model to be run to obtain forecasts of flood extent and levels are based on forecast rainfalls obtained from numerical weather modelling conducted by the Bureau of Meteorology. Given the high degree of uncertainty associated with these forecast rainfalls, particularly for small catchments, the Bureau of Meteorology provides a range of rainfall forecasts to Melbourne Water and advises on which of these are most likely to occur as well as which are credible high rainfall forecasts. In the Maribyrnong River catchment, FIDSS also uses inputs from 21 rainfall and river level gauges that are operated by Melbourne Water, 11 of which measure river height at locations on the river.

Modelling Relevant to the Flood Event

107. With regard to modelling of the Flood Event to **support long-term planning decisions**, Melbourne Water engaged consultants Jacobs Australia Pty Limited (Jacobs) to carry out a post flood analysis of the 2022 event. As part of this study an updated flood frequency analysis was carried out at Deep Creek at Darraweit Guim and Maribyrnong River at Keilor. The Deep Creek record only extends from 1975 but is supplemented with data on the 1964 flood. The analysis of this record by Jacobs indicates that the flood in the upper catchment was close to a 1% annual exceedance probability event and that the Flood Event was the largest flood in the period from 1964 to 2022.
108. The record at Keilor on the Maribyrnong River is much longer, which increases the reliability of estimates. This record is not complete, but all of the large events from 1908 appear to have been recorded. The record has been extended back to 1871 for large events based on newspaper articles.

The analysis of this record is of direct significance for the river reach to where the Maribyrnong River joins the Yarra River.

109. The flood frequency analysis by Jacobs is presented in Figure 32 and shows that the Flood Event is the second largest event in this period and that the Flood Event is just larger than a 2% annual exceedance probability event. There is a slight increase in the 1% annual exceedance probability design flow from the previous analysis in 1986.

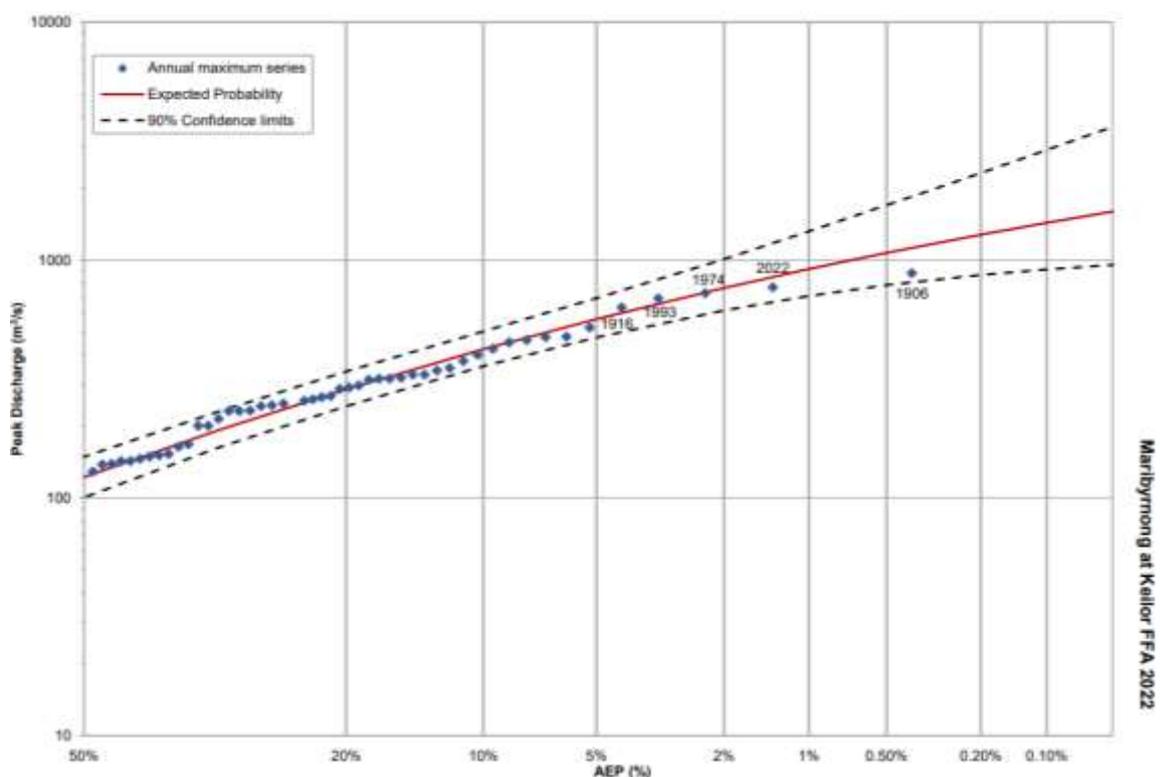


Figure 32: Results of calibration of Maribyrnong RORB model.

(Source: Produced by the Panel using data from Jacobs (2023) Maribyrnong Flood Event October 2022 – Post event analysis).

110. In addition to flood frequency analysis, insight can also be gained from the rank of the flood event at gauges, which both lead to the conclusion that the Flood Event was slightly larger than a 2% annual exceedance probability flood. This means that under historical climate conditions, in each year there is a 1 in 50 chance of this flood or a larger occurring again. On this basis, the 1% annual exceedance probability level should be a reasonable amount above 1974 levels.

111. Melbourne Water also commissioned Jacobs to verify the lower and mid Maribyrnong HEC-RAS models for the Flood Event. For the lower Maribyrnong model, the memorandum provided by Jacobs does not provide a direct comparison between the estimated and modelled extents of the Flood Event, but these two extents look similar, especially with reference to the spatial extent of the 1% annual exceedance probability event modelled by Melbourne Water (see Figures 33 and 34). By comparing the maps in Figures 33 and 34, it can be seen that the modelled spatial extent of the Flood Event is slightly larger than that of the actual event in some locations. However, it should be noted that the map of the estimated spatial extent of the Flood Event does not cover the full extent of the modelled area, as the area around the Flemington Racecourse is excluded (Figure 33). This may be because the HEC-RAS model verification for the Flood Event did not include the Flemington Racecourse wall (i.e. the wall was not included in the model and hence the impact of the wall was not modelled).

112. There is a close match between the modelled and the actual spatial extent of the Flood Event, apart from the area surrounding Flemington Racecourse. The Flood Event had an annual exceedance probability of 2% and is hence less extreme than a 1% annual exceedance probability event. For this reason, the spatial extent of the Flood Event is within the 1% annual exceedance probability design flood event modelled by Melbourne Water, as expected (see Figures 33 and 34).

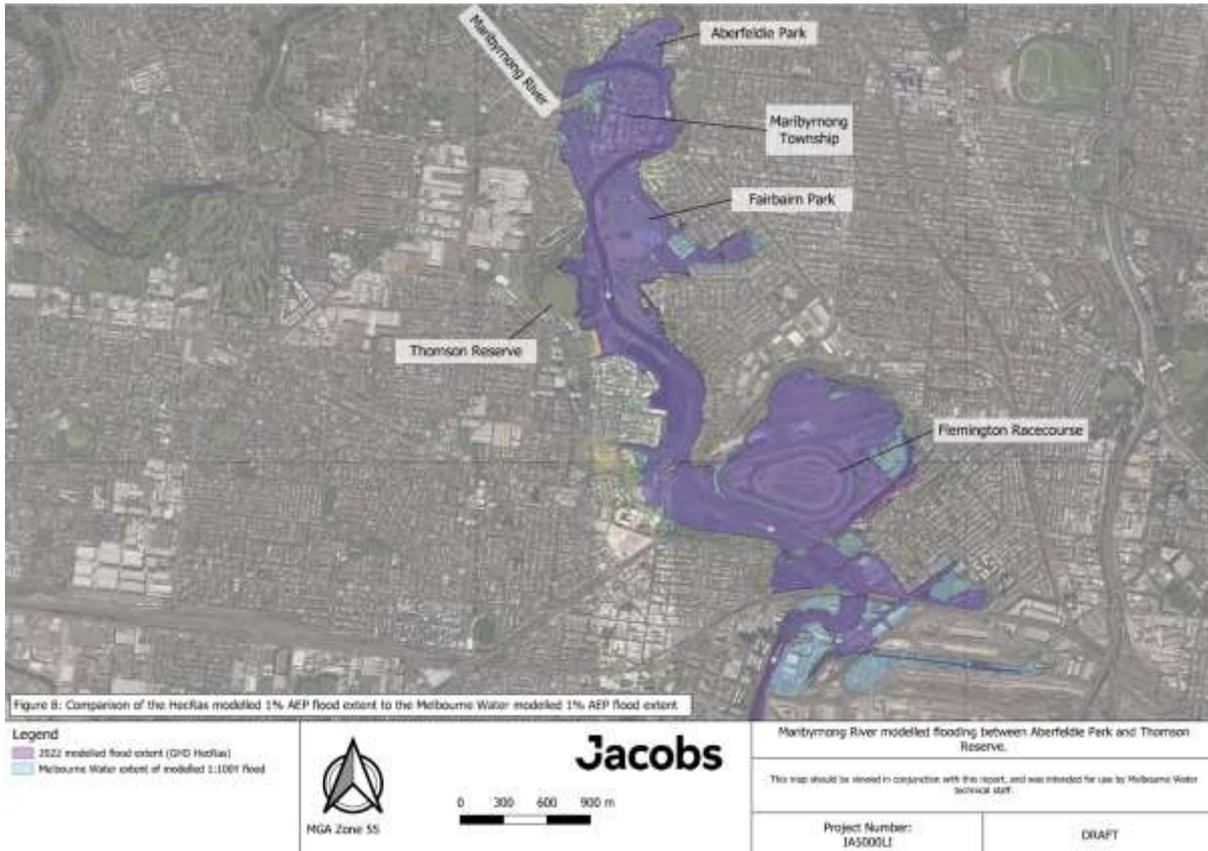


Figure 33: Comparison of modelled spatial extents of the Flood Event and the 1% AEP flood for the lower Maribyrnong model.

(Source: Jacobs (2023) Lower Maribyrnong HEC-RAS Model Verification_RevB).



Figure 34: Comparison of estimate actual spatial extent of the Flood Event and modelled spatial extent of 1% AEP flood for part of the lower Maribyrnong model.

(Source: Jacobs (2023) Lower Maribyrnong HEC-RAS Model Verification_RevB).

113. Based on the work done by Jacobs, for the lower Maribyrnong model, there was also a close match between the modelled and the observed flood depths for the Flood Event, with the model over-predicting flood levels by an average of 55 mm after the influence of spurious flood marks had been removed. The Lower Maribyrnong HEC-RAS verification report (Jacobs, 2023) concluded that the model verification results were acceptable and that the HEC-RAS model “... remains a relevant tool for floodplain management for the Lower Maribyrnong”.
114. However, the same is not the case for the mid Maribyrnong model, which Jacobs suggested “... in its current state is not a suitable tool for floodplain management for the Mid Maribyrnong”. This is because when they tested the performance of the model for the 1974 event there was a very poor fit between the modelled and the observed water levels. In the Canning Street

Bridge/Rivervue area, water levels predicted by the model were between 360 mm and 530 mm lower than corresponding observed values, while further downstream, they were between 420 mm and 570 mm higher. Jacobs also tested the performance of the model against observed values for the Flood Event with results showing even larger discrepancies at Rivervue, where water levels predicted by the model were between 670 mm and 810 mm lower than corresponding observed values, while downstream they were between 340 mm and 440 mm higher.

115. The major cause of this difference is that, along with not calibrating the model, the low surface friction (Manning's 'n') values obtained as part of the calibration of the lower Maribyrnong model were simply transferred to the upstream models without adjustment. The most concerning part of the testing by Jacobs is that it suggests that the difference between the modelled and actual water levels in the Canning Street/Rivervue area will be even larger in a 1% annual exceedance probability flood than they were in the Flood Event.
116. These validation results highlighted the problem with not calibrating a flood model to ensure that it is reproducing real world flood behaviour with reasonable accuracy. This is why it is recommended by Australian Rainfall and Runoff that models be calibrated where relevant data exists. Ideally, flood models should be reviewed every five years and updated at least every ten years. A major flood is often a good trigger for reviewing or updating a model as a new flood event enables model calibration to be tested and any catchment changes, like the addition of infrastructure such as bridges, to be incorporated into the model.
117. Modelling of the Flood Event using Melbourne Water's FIDSS was used **to support the issuing of flood warnings**. A summary of the forecasts and warnings issued by Melbourne Water and the Bureau of Meteorology based on information provided to the Review Panel from these agencies, and hourly gauge data downloaded from Melbourne Water's website, is given in Table 2.

Table 2: Summary of forecasts and warnings issued by Melbourne Water and the Bureau of Meteorology for the Flood Event.

(Source: Constructed by Review Panel from information provided).

Date and time	Agency/Data source	Action or warning type	Comment
11 October at 4:57 p.m. to 13 October at 4:37 p.m.	Bureau of Meteorology	Severe weather warning for heavy rainfall	Issued for districts including Maribyrnong River catchment. Warning included wording that heavy rainfall may lead to flash flooding.
Prior to 11 October at 12:11 p.m.	Melbourne Water	Consulting with Bureau	Melbourne Water consulted with Bureau about the need for an initial flood watch to be issued.
After 11 October at 12:11 p.m.	Melbourne Water	Increased forecasting modelling and daily flood watch updates	Increased flood forecasting, modelling and flood outlook scenario development.
11 October at 12:11 p.m. 12 October at 12:03 p.m.	Bureau of Meteorology	Flood Watch	Includes wording that minor to moderate flooding is expected across the flood watch areas, and that major flooding is likely in some catchments. Maribyrnong River is specifically listed as likely to be affected.
13 October between 11:00 p.m. and 11:59 p.m.	Keilor gauge	Exceeded Minor Flood Level	
13 October at 8:15 a.m.	Melbourne Water	Flood warning to Bureau	First Major Flood warning for Maribyrnong catchment sent to Bureau.
13 October at 8:24 a.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River.
From 13 October at 8:24 a.m. to end of event	Melbourne Water	Provision of 6-hourly updates to the Bureau	Melbourne Water continued to monitor and regularly update modelling and forecasting over course of event.
13 October at 12:50 p.m. 14 October at 1:47 p.m.	Bureau of Meteorology	Flood Watch	Includes wording that minor to major flooding occurring or expected across several Victorian catchments. Major flood warning current for Maribyrnong River.
13 October at 2:24 p.m.	Melbourne Water	Moderate Flood warning for Lower Maribyrnong to the Bureau	Forecast based on revised forecast rainfall data.
13 October at 3:24 p.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River expected to peak around Moderate Flood Level on

Date and time	Agency/Data source	Action or warning type	Comment
			morning of 14 October.
13 October at 3:42 p.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River expected to peak around Moderate Flood Level on morning of 14 October.
13 October at 8:24 p.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River expected to peak around Moderate Flood Level on morning of 14 October.
14 October at 12:30 a.m.	Melbourne Water	Initiated update to predictions	Noted that river was rising faster than model prediction and began updated model runs.
14 October between 1:00 a.m. and 2:00 a.m.	Keilor gauge	Exceeded Moderate Flood Level	
14 October between 2:00 a.m. and 3:00 a.m.	Keilor gauge	Exceeded Major Flood Level	
14 October at 2:16 a.m.	Melbourne Water	Major Flood Warning to Bureau	Included update of major flood warning and that Major Flood Level predicted to be exceeded.
14 October at 2:25 a.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River expected to peak above Major Flood Level on morning of 14 October.
14 October between 8 a.m. and 9 a.m.	Keilor gauge	Flood peak	Peak at more than 2.5m above Major Flood Level
14 October at 8:10 a.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River expected to peak above Major Flood Level on morning of 14 th
14 October at 2:16 p.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River currently exceeding Major Flood Level and falling/steady. It is expected to drop below Major Flood Level on afternoon of 14 October.
14 October at 7:55 p.m.	Bureau of Meteorology	Flood Warning	Major Flood Warning for the Maribyrnong River. Maribyrnong River currently exceeding Moderate Flood Level and falling. It is expected to drop below Moderate Flood Level on evening of 14 October.

Date and time	Agency/Data source	Action or warning type	Comment
15 October at 12:00 a.m.	Bureau of Meteorology	Flood Warning	Minor Flood Warning for the Maribyrnong River. Maribyrnong River currently exceeding Minor Flood Level and falling. It is expected to drop below Minor Flood Level on morning of 15 October.
15 October at 12:19 p.m.	Bureau of Meteorology	Flood Warning	Final Flood warning for the Maribyrnong River.

118. As can be seen, on 11 October, the Bureau of Meteorology issued a flood watch that included advice that major flooding was likely in some catchments from Thursday 13 October, listing Maribyrnong River as one of these catchments. Melbourne Water undertook increased flood forecasting and modelling from that time and sent its first major flood warning to the Bureau of Meteorology on the morning of 13 October. That warning was focussed on the upper catchment. Melbourne Water also issued a moderate flood warning for the lower catchment to the Bureau of Meteorology on the afternoon of 13 October after rainfall forecasts from the Bureau of Meteorology were revised. Both of those flood warnings were sent out by the Bureau of Meteorology.
119. On 14 October Melbourne Water identified that the river height at the Keilor gauge was higher than their models had predicted and revised their forecasts based on the observed data. However, time was required to rerun the models and to process the results before an updated warning was issued to the Bureau Meteorology at 2:16 a.m. on 14 October. The Bureau of Meteorology then issued a major flood warning for the Maribyrnong River at 2:25 a.m. on 14 October.
120. The information in Table 2 indicates that Melbourne Water implemented increased flood forecasting in the lead up to the Flood Event and provided updates to the flood warning every six hours. Of note is that the water height at the Keilor gauge was forecast to be higher than the top of the rating curve for that gauge on 11 October, and the rating curve was extended at that time, ahead of the forecast rainfall.

121. From the information provided, the very rapid rise in water level caused by the catchment being very wet at the beginning of the rainfall event, and the changing rainfall forecasts, had resulted in very little time being available to enable Melbourne Water to rerun models and to update forecasts. We note in that context, however, that the forecast rainfalls provided to Melbourne Water for this event, and the hydrologic model parameters and outputs, have not been provided to us and have not been reviewed by us.
122. The time that Melbourne Water's forecasting tools take to run needs to be reduced by approximately 50% for future forecasts produced by Melbourne Water to provide sufficient flood warning in an event such as the 2002 Flood Event. Reducing the time taken to run forecasting tools could be done by automating some manual and/or time intensive tasks, by enabling the information that is needed by staff to make subjective decisions faster and more efficiently. This would also allow more time for warnings to be disseminated and acted upon. The cost of such improvements should be relatively modest compared with the savings in the cost of damages resulting from people acting on earlier and better targeted warnings.
123. The speed and reliability of forecasts produced by Melbourne Water could also be increased by reviewing the extent of the rating curves at key forecast gauges and ensuring they extend sufficiently to include rare floods and that they have been calculated or extrapolated on a defensible basis. Updated hydraulic models would also help with this task.
124. We note, however, that any further improvements to warnings on the Maribyrnong River will be limited unless the Bureau of Meteorology can provide timely updates to the rainfall forecasts that are needed for Melbourne Water to run models more frequently. The service level agreement with the Victorian government outlines a maximum update frequency for these rainfall forecasts of six hours, but more frequent complete or partial updates would

enable more frequent and timely predictions to be produced. The most recent version of the service level agreement (version 3.4.15) was published in October 2020 and is titled “Service level specification for flood forecasting and warning services for Victoria – Version 3.4”.

125. The Bureau of Meteorology forecasts are based on a set of ensemble forecasts that provide information on a range of possible future rainfalls. It is not uncommon for the forecast rain in some ensemble members to be exceeded midway through a forecast period or some ensembles to show a very poor correlation between when and where rainfall is falling. Consequently, there exists an opportunity to determine which ensemble rainfall forecasts are no longer relevant and which are matching the post forecast rainfall well between formal forecast rainfall updates. By determining which ensemble forecast are performing well, it should be possible to issue an interim update to the forecast based on observed post forecast observed rainfall and well-performing ensemble forecast members.

4. Analysis of impact compared with predictions

126. The fourth matter for the Review Panel was to provide an analysis of the impact of the Flood Event compared with predictions or modelling, as well as the basis for any potential differences. As discussed earlier in this report, the impacts of the Flood Event have been far reaching, resulting in damage to homes and businesses, community infrastructure and groups and council assets across four local government areas, including Brimbank City Council, Moonee Valley City Council, Maribyrnong City Council and the City of Melbourne. Both types of modelling discussed in the previous section of this report, namely modelling to support long-term planning decisions and modelling to support flood warnings, can have an influence on the impact of the Flood Event. The former in relation to whether impact occurred within or outside the 1% LSIO and the latter in relation to how much time was available to take mitigating actions.

127. The differences between observed impacts and those which were expected based on **modelling used to support long-term planning decisions** were different for the lower, mid and upper Maribyrnong HEC-RAS models.
128. For the **lower Maribyrnong** model, the extent of the actual flood event appears to be contained within the boundary of the 1% LSIO, which is as expected, given that the Flood Event was less severe than a 1% event (Figure 35). However, it should be noted that the modelled extents do not include the impact of the Flemington Wall, whereas the actual extents do.

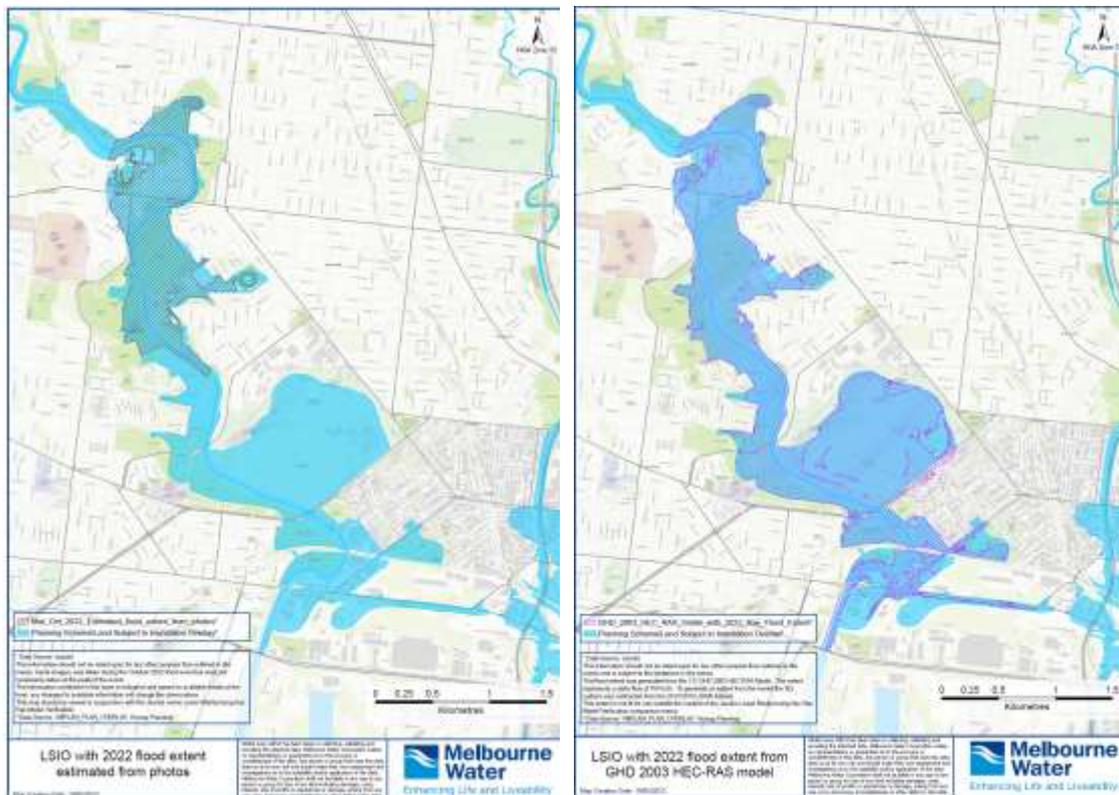


Figure 35: Comparison of the extent of the Flood Event estimated from photos and the 1% LSIO (left panel) and of the extent of the Flood Event estimated using the lower Maribyrnong HEC-RAS model and the 1% LSIO (right panel).

(Source: Left panel Provided to IRP by Melbourne Water (“LSIO with 2022 flood extent estimated from photos”) and right panel Provided to IRP by Melbourne Water (Source: “LSIO with 2022 flood extent from GHD 2003 HEC-RAS model”).

129. The fact that there are no major anomalies as far as impacts occurring in unexpected areas is not surprising, given that the lower Maribyrnong model is calibrated and was found to be suitable for the purpose of floodplain

management in the recent review by Jacobs (2023). However, although impact generally occurred within the 1% LSIO, this was not always the case. For example, in the flood management plan for Maribyrnong City Council, which was developed by council in collaboration with Melbourne Water, only 293 properties were identified as being impacted by a 1% annual exceedance probability flood event, which is significantly less than the 512 properties which were actually impacted by the Flood Event. This is despite the fact that Flood Event was not as severe as a 1% annual exceedance probability event, suggesting that there is room for improvement in the modelling used to support long-term planning decisions for the lower Maribyrnong region, even though this model seemed to perform reasonably well overall.

130. In the Moonee Valley City Council area, impact occurred primarily in the Ascot Vale area and the Rivervue Retirement Village. In Ascot Vale, the 1% LSIO suggests that 248 properties may be affected by a 1% annual exceedance probability flood event, whereas the actual number of properties impacted was approximately 31, primarily in Woods Street, suggesting that the impact in this area was not unexpected. However, the same is not the case for Rivervue Retirement Village, where significant impact occurred outside the 1% LSIO, even though the Flood Event was only estimated to have an annual exceedance probability of approximately 2%. This impact was therefore unexpected based on the outputs from the **mid Maribyrnong** HEC-RAS model.
131. Rivervue Retirement Village, as we have said above, is located on the northern banks of the Maribyrnong River in Avondale Heights and has 150 units, 47 of which were damaged by the Flood Event, with 68 residents displaced (Figure 36, Left Panel). These properties were not identified as being at risk from a 1% annual exceedance probability flood event in the Local Flood Guide developed based on modelling provided by Melbourne Water and are outside of the 1% LSIO (Figure 36, Right Panel). The units located on Evergreen Avenue and Blueridge Close, however, were built on land that was covered by a previous LSIO that was updated and removed from the overlay in

2016 (Figure 37).



Figure 36: Comparison of the estimated extent of the Flood Event at the Rivervue Retirement Village (left panel) and the extent of the 1% LSIO (right panel).
 (Source: left panel provided to IRP by Melbourne Water (“Mid Maribyrnong_2022_flood_extent_observations”) and right panel from Moonee Valley City Council Submission #40).

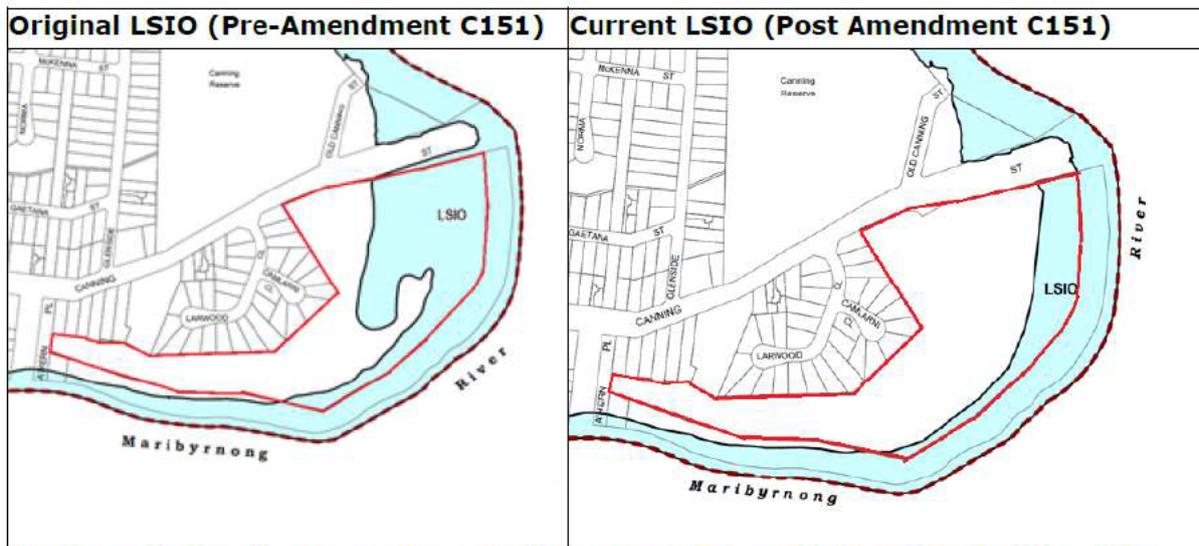


Figure 3. Amendment C151 was gazetted into the Moonee Valley Planning Scheme in August 2016.

Figure 37: Comparison of extent of the 1% Land Subject to Inundation Overlay (LSIO) prior (left panel) and post (right panel) amendment.
 (Source: Moonee Valley City Council Submission 40).

132. The most plausible explanation for the discrepancy between expected and actual levels of inundation in the Rivervue Retirement Village seems to us to be that the 1% annual exceedance probability flood levels were significantly underestimated by the mid Maribyrnong HEC-RAS model. As discussed in the previous section on modelling, the independent validation of the mid

Maribyrnong HEC-RAS model by Jacobs found that the model underestimated river levels at the Rivervue Retirement Village site for the Flood Event by between 670 mm and 810 mm, which is greater than the 600 mm freeboard allowed to account for any modelling errors. As discussed in the previous section of this report, the likely cause for this was that the mid Maribyrnong HEC-RAS model was not calibrated to actual data. In addition, it used low Manning's 'n' values, which were adopted without adjustment from the calibration of the lower Maribyrnong model. Given that the results from that model were used to inform the local flood guide and to set design floor levels for planning approvals, it is likely that the significant underprediction of flood levels by the mid Maribyrnong HEC-RAS model at the Rivervue Retirement Village site was a major reason for the difference between the impact expected based on modelling and the actual impact.

133. Apart from water levels, the other factor affecting the degree of inundation in a flood event is the finished floor level used for the construction of buildings. No inundation will occur if finished floor levels are above the level of the flood waters, whereas the opposite will be the case if the level of the flood waters is above the finished floor level.
134. The value of the finished floor levels required as part of planning approvals for the flood affected properties at Rivervue Retirement Village were changed throughout the planning process, which also had an impact on the level of flooding during the 2022 Flood Event, as detailed below.
135. The site of the Rivervue Retirement Village had been the subject of planning permit application MV/16866/2004 in December 2004 by Retirement Services Australia and Metricon Homes. The site at that stage was subject to a LSIO, which required any planning permit application to be referred to Melbourne Water under Section 55 of the *Planning and Environment Act 1987* as the relevant floodplain management authority.

136. The permit which was issued after proceedings in the Victorian Civil and Administrative Tribunal (VCAT), required, as had been noted in Melbourne Water's referral response, that all finished floor levels be at a minimum of 600 mm above the applicable flood level. This flood level was the average total **energy** level (not the average water **surface** level) obtained with the aid of the flood modelling performed by Melbourne Water and varied between 6.0 and 6.4 metres. The Planning permit referred to this flood level.
137. Section Plans endorsed in January 2008 show *adjusted flood level* of between 6.0 mm and 6.4 metres as can be seen by Figure 38 below. These plans align with the permit requirements that the finished floor levels be 600 mm above total **energy** levels of between 6.0 metres of 6.4 metres. Figure 38 demonstrated finished floor levels of dwellings at the Rivervue Retirement Village above 6.6 metres.

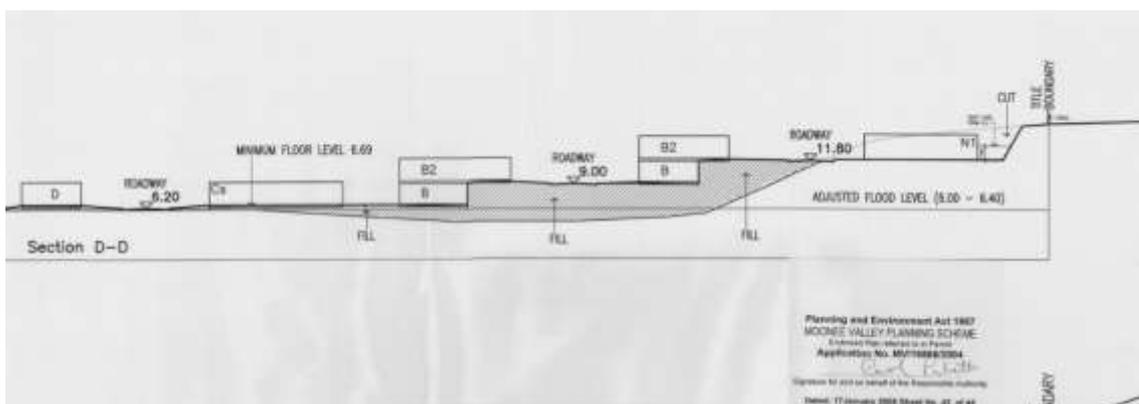


Figure 38: January 2008 Endorsed Plan.

Source: Moonee Valley City Council endorsed plans provided 15.8.23.

138. On 25 March 2009, Retirement Services Australia and Metricon Homes sought and subsequently obtained consent from Melbourne Water **to lower** the proposed finished floor levels for a number of dwellings within the development by a consistent value of 0.22 metres.
139. Plans subsequently endorsing the lower finished floor levels (approved in June 2009 and shown in Figure 39) showed the *flood levels* used to determine the reduced finished *floor* levels were 5.85 metres, 5.81 metres and 5.81 at sections

D-D, E-E and I-I, being below the **average** total energy levels of 6.0 metres to 6.4 metres mentioned above. This change reduced some finished floor levels to below 6.60 metres.

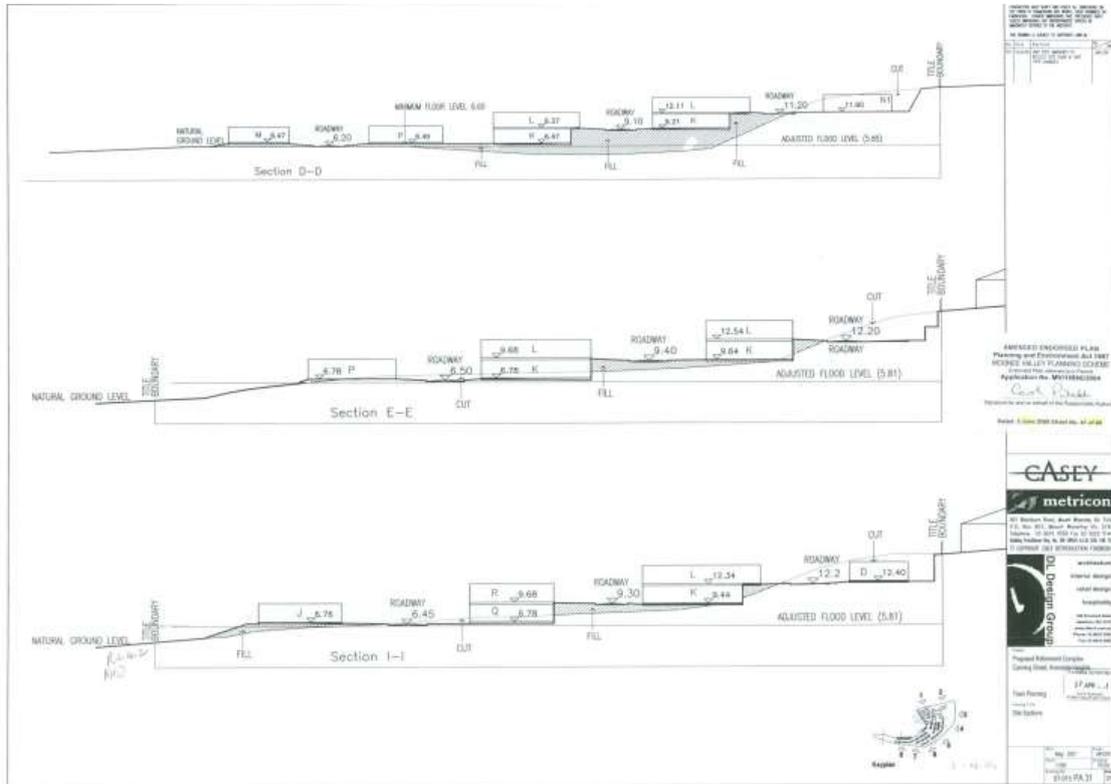




Figure 40: Endorsed plans showing the locations of proposed dwellings at Rivervue Retirement Village, including finished floor levels. The sections identified in this plan are shown in Figure 39.

(Source: TIGcorp documents: MV 2009_06_02 endorsed plans 2 June 2009).



Figure 41: Endorsed plans showing the locations of proposed dwellings at Rivervue Retirement Village, including finished floor levels. The locations of the sections shown in this plan are shown in Figure 39.

(Source: TIGcorp documents: MV 2009_06_02 endorsed plans 2 June 2009).

- 141. These diagrams may be compared with the Rivervue Retirement Village site plans provided by TIGcorp showing the extent of the flooding from which it can be seen that a number of properties built with finished floor levels below 6.60 metres were within the area inundated by the Flood Event.



Figure 42: Rivervue Retirement Village site plan showing extent of flooding.
(Source: TIGcorp Submission #44).

142. A possible explanation for the discrepancy between the endorsed plans used to build the properties and the corresponding permit conditions may lie in the potential uncertainty in the way in which the conditions were initially drafted. It is possible that those considering whether to approve the adjusted (lowered) floor levels in 2009 had not based the approved flood levels upon modelled total **energy** levels (as had been specified initially by Melbourne Water), but on the modelled water **surface** levels as used in the endorsed plans of 2 June 2009 (see Figures 40 and 41).
143. A combination of the under-prediction of design flood levels by the mid Maribyrnong HEC-RAS model and the lower approved finished floor levels, appears to have resulted in the finished floor levels of the flood-affected properties at the Rivervue Retirement Village corresponding to the water levels produced by a flood with a 2% annual exceedance probability rather than a 1% annual exceedance probability. The minimum floor level for residential dwellings at risk of riverine flooding should correspond to the 1% annual exceedance probability level requiring 600 mm freeboard. While the latter does not eliminate flood risk, it usually ensures that finished floor levels are above 1% annual exceedance probability levels to allow for errors in the modelling used to estimate the requisite water levels.
144. Differences in the probabilities of actually being flooded during periods of 10, 15, 20 and 30 years between properties with finished floor levels that correspond to a 2% annual exceedance probability (i.e. the actual floor levels of the buildings at the Rivervue Retirement Village that were inundated in the Flood Event), and floor levels corresponding to design conditions for a 1% annual exceedance probability plus 600 mm of freeboard, are shown in Table 3.

Table 3: Occupancy Period flood risk.

	Period of occupancy (years)	10	15	20	30
		Probability of flooding			
1% AEP plus 600 mm	Flooding	4.9 %	7.2 %	9.5 %	14.0 %
	Once	4.8 %	7.0 %	9.1 %	13.0 %
	More than once	0.1 %	0.3 %	0.4 %	1.0 %
As built (2% AEP)	Flooding	18.3 %	26.1 %	33.2 %	45.5 %
	Once	16.7 %	22.6 %	27.2 %	33.4 %
	More than once	1.6 %	3.5 %	6.0 %	12.1 %

145. As can be seen from Table 3, buildings with finished floor levels corresponding to the 2% annual exceedance probability have a probability of 16.7% of being flooded once and a probability of 1.6% of being flooded more than once, over a ten year period, whereas these values are only 4.8% and 0.1%, respectively, for buildings with finished floor levels corresponding to the 1% annual exceedance probability plus 600 mm of freeboard.
146. Over a period of 30 years, the lower finished floor levels result in a 33.4% probability of being flooded once and a 12.1% probability of being flooded more than once, whereas the corresponding values for the higher floor levels are only 13% and 1.0%, respectively.
147. In the Brimbank City Council area, 10 private properties were impacted by the flood event within the geographical area of the Terms of Reference. Six of these were outside of the 1% LSIO (at 660 Flora Street, Keilor) and two were partially outside this overlay (also at 660 Flora Street, Keilor). These results are outside of expectations given the extent of the 1% LSIO is informed by the upper Maribyrnong HEC-RAS model. However, as no validation of this model has been performed yet, it is not possible to comment on any potential reasons for this, other than that, like the mid Maribyrnong model, the upper Maribyrnong model was not calibrated.
148. It is not easy to determine the differences between the impacts expected based on **modelling used to support warnings** and observed impacts. The Bureau of

Meteorology Flood Watches included wording that major flooding was likely in some catchments, including the Maribyrnong River, from 12:11 p.m. on 11 October, and the first major flood warning for the Maribyrnong River was issued by the Bureau of Meteorology at 8:24 a.m. on 13 October. That warning would have provided 17 hours before the major flood level was exceeded sometime between 2:00 a.m. and 3:00 a.m. on 14 October. However, on 13 October, the warning was downgraded to a moderate flood warning at 3:24 p.m., with the next major flood warning not issued by the Bureau of Meteorology until 2:25 a.m. on 14 October, when the river height at Keilor was above moderate flood level and rising. Consequently, there was very little warning of major a flooding from when the major flood warning was issued at 2:25 a.m. on 14 October and when major flood levels were reached at around 6:30 a.m. on that day. This, coupled with the fact that this warning was issued in the middle of the night, made it very difficult for mitigation action to be taken pre-emptively.

149. The flood warning levels were based on modelling and flood outlook scenarios provided by Melbourne Water that took account of river levels and the Bureau of Meteorology's forecast rainfall information. However, the modelling for this Flood Event was more challenging than is typically the case. This is because a flood of this magnitude would usually be preceded by extreme rainfall forecasts and warning would be issued after recorded rainfall totals start confirming or exceeding the forecasts and after river gauges start showing a significant increase in flow. However, for the Flood Event, the rainfall totals were not that alarming and the large amount of runoff resulting from a relatively small amount of rainfall was a function of the high degree of saturation of the catchment when the rain fell, resulting in the conversion of a large proportion of rainfall into runoff and a rapid increase in water levels, even though the magnitude of the rainfall event was relatively low. This meant that the lead time between rainfall and flooding was short and that many of the early indicators of a rare flood occurred much later than normal. This issue was exacerbated by the fact that the majority of the rain fell in the upper

catchment, rather than where the flooding occurred.

150. There is a trade-off in the provision of flood warnings between forecast accuracy and lead time. In this event, the rainfall forecasts were uncertain in the four days leading up to the event. This is not unusual, as forecasts are more accurate the closer they are to the rainfall occurring. Decisions must be made by the agencies responsible for managing events as to how much uncertainty is acceptable when giving warnings in its forecasts, and that may depend on the consequences of having false alarms as against a failure to provide enough lead time for meaningful action to be taken. This is particularly difficult in catchments where there is a very short lead time between rainfall and flooding.
151. In order for sufficient warning time to be available, it may be necessary to accept a less accurate prediction based on forecast rainfalls or modelled river flows although that may result in warnings of forecasts that do not eventuate as forecast. In these catchments, where rainfall can very quickly generate high flows on a wet catchment, flood warning systems need to be flexible and allow for rapid escalation when river levels are rising very quickly. In this case, there was a need to get the flood warnings quickly overnight to the residents who were likely to be impacted. In these situations, SMS alerting is one method that can be used, along with door knocking by emergency responders. However, for these approaches to be effective, the time it takes for models that support warning systems to run, and the frequency with which warnings are issued, need to be commensurate with the rate at which water levels can become dangerous. For the Flood Event, levels rose from minor to major in less than two hours, yet the time it took for Melbourne Water to run their models and to process model outputs varied between 50 and 135 minutes, and the frequency with which flood warnings were issued by the Bureau of Meteorology was six hours.
152. The Bureau of Meteorology is responsible for issuing forecasts and general warnings, but much of the responsibility of turning forecasts into local

information that can be used for planning and responding rests with water agencies like Melbourne Water, State Emergency Services (SES) and local councils. The process of providing this local level information takes some time, as agencies trigger their flood plan and activate their flood teams. On this occasion, many of the triggers to activate response teams occurred later than usual, as rainfall forecasts changed, and river levels and flows changed rapidly.

153. The effectiveness of flood warnings is generally also a function of human behaviour. The acceptance of warnings by the public is often highly dependent on their own verification process, which can involve talking to long term neighbours, looking at social media, looking at rainfall amounts, checking river levels and assessing the apparent intensity of the rainfall at their own house.
154. In this event, many people would have assumed that the rainfall was not sufficiently intense to cause serious flooding and that river levels would not rise to the levels they did. The rapid rise in river level occurred late on 13 October through to the early hours of 14 October when many residents would likely not have been monitoring conditions and may have missed the major flood warning that was issued by the Bureau of Meteorology at 2:25 a.m. on 14 October. In addition, the downgrading of the major flood warning issued by the Bureau at 8:24 a.m. on 13 October to a moderate flood warning at 3:24 p.m. on the same day, which was repeated at 8:24 p.m., may have led some of the general public to believe that the situation was deescalating rather than potentially escalating and as occurred.

5. Hydrology, topography and population matters materially contributing

155. The fifth matter for the Review Panel was to consider other matters relating to hydrology, topography, and population that may have had a material contribution. These issues are partially addressed under the other terms of reference but are also discussed below for convenience.

156. The Maribyrnong catchment lies north-west of Melbourne and covers approximately 1,408 square kilometres. The river is 160 kilometres long, beginning in the southern slopes of the Great Dividing Range, travelling south and joining the Yarra River just upstream of Port Phillip Bay. The average annual rainfall in the Maribyrnong catchment exceeds 1,000 mm in the ranges, declining to less than 500 mm on the lower plains. The catchment boundaries extend from near Rosslynne Reservoir in the west, to the Cobaw Ranges and Mount William in the north and to Pretty Sally Hill and Konagaderra in the east.
157. The catchment encompasses agricultural lands, natural grasslands and woodlands and densely populated urban areas. Most of the catchment area is in the northern part, with the narrow bottom third of the river flowing south east through Melbourne metropolitan area (see Figure 43). This lower part of the river is highly urbanised and contains most of the flood risk.

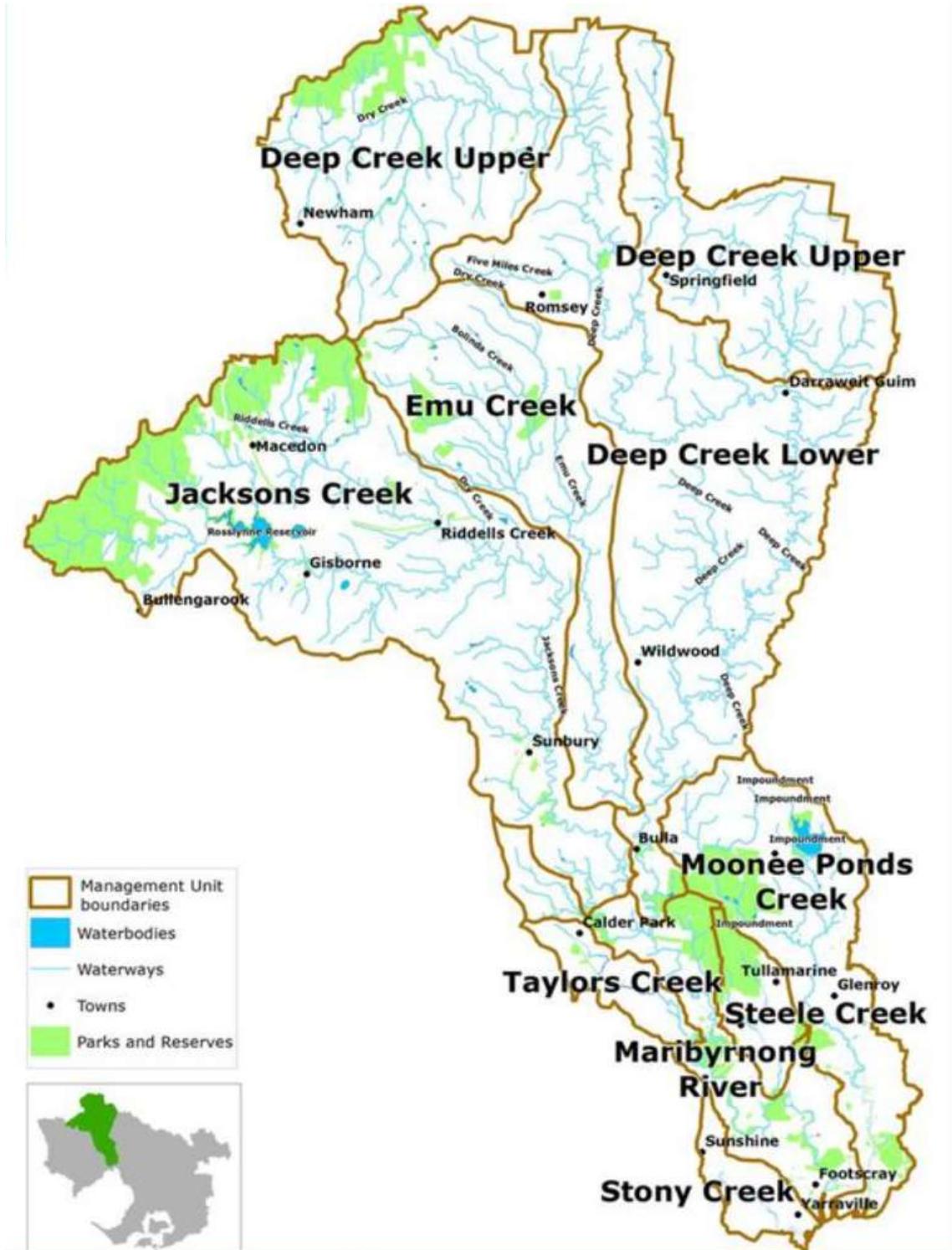


Figure 43: Location and outline of the Maribyrnong River catchment.
(Source: Victorian Healthy Waterways).

158. As mentioned previously, the main hydrological factors contributing to the impact of the Flood Event were (i) the extreme wetness of the catchment at the commencement of the rainfall leading to the Flood Event, resulting in the vast majority of rainfall being converted to runoff so that a relatively modest

rainfall event resulted in an unexpectedly large flood, and (ii) the fact that the majority of the rain fell in the upstream portions of the catchment, which, while contributing the bulk of the catchment area, and hence generating most of the runoff, does not house the majority of the risk, which meant that residents in the lower reaches were surprised by the magnitude of the flood event, as this did not align with the magnitude of the rainfall they experienced.

159. The topography of the Maribyrnong River Valley was formed over millions of years, with water eroding through the basalt plains north west of Melbourne to create a complex landscape of gorges and river flats and with a hinterland that consists of relatively flat basalt plains. It is, therefore, unlikely that the topography of the catchment resulted in any unexpected impacts during the Flood Event.
160. The lower reaches of the Maribyrnong River form part of Greater Melbourne and are urbanised areas that had been substantially developed in the 20th Century. New urban areas, specifically around Taylors Lakes, Gisborne and Sunbury, have seen substantial suburban development in the 21st Century. Similarly, significant infill development and densification has occurred in the City of Melbourne, Maribyrnong City Council and Moonee Valley City Council in the past 20 years.
161. This urbanisation has increased impervious surfaces but is only likely to have had a relatively minor impact on river flows, with the main impact of urbanisation occurring in the many urban tributaries, which have been transformed from natural conditions or farmland into Melbourne suburbs. In addition, given the high degree of saturation of the catchment during the Flood Event, any impact of urbanisation and densification had to be minimal, as even pervious areas of the catchment that would ordinarily reduce runoff via infiltration were essentially behaving the same as impervious areas.
162. Due to the topography and hydrology of the Maribyrnong catchment, the dominant cause of flooding was rainfall in the upper catchments, reducing an

awareness by the residents in the more urbanised areas downstream that a serious flood was coming down the river based on their own experience of the rainfall they could see in their part of the catchment. This meant that warning services were particularly important. The Flood Event also demonstrated that on a very wet catchment, relatively modest rainfall can cause a major flood.

FLEMINGTON RACECOURSE FLOOD WALL

6. Examine whether the Flemington Racecourse flood protection wall contributed to the extent and duration of the Flood Event.
 7. Review of efficacy of Melbourne Water’s proposed conditions of approval and mitigation measures relating to the wall and their implementation
163. We are specifically required by the Terms of Reference (i) to examine whether the Flemington Racecourse Flood Protection Wall contributed to the extent and duration of the Flood Event and (ii) to review the efficacy of Melbourne Water’s proposed conditions of approval and mitigation measures relating to the wall and their implication. The material available to us does not enable us to do either. However, for convenience we explain the issues and facts as we have explored them and do so together under the same headings.
164. Flemington Racecourse is approximately seven kilometers north west of the Melbourne Central Business District and has a direct interface with the Maribyrnong River. It occupies an area of 320 acres and is the venue for the Melbourne Cup and has been utilised for horse racing since 1840. The Victoria Racing Club Limited (VRC) was established in 1864 and since 1871 the racecourse has been managed by the VRC under a Crown land lease arrangement now under the *Victorian Racing Club Act 2006*.
165. In the early 2000s the VRC embarked upon a broader master planning process that foreshadowed the subsequent redevelopment of the Flemington Racecourse. One of the initiatives of the masterplan was the development of

a bund wall (the **Floodwall**) to provide flood protection from a one percent annual exceedance probability flood event. The VRC has indicated in its submissions that the Flemington Racecourse was historically subject to inundation by flood waters from the Maribyrnong River and that between 1974 and 2003, the river broke its banks eight times with impact on the Racecourse. The Racecourse has four grandstands, ten training tracks, 18 resident trainers, an equine swimming pool and facilities for 600 horses in training. The purpose of the Floodwall is to alleviate such an effect.

- 166. Construction of the Flemington Racecourse Floodwall commenced in 2007 abutting the southern boundary of the Flemington Racecourse and is adjacent to the Maribyrnong River, as demonstrated in Figure 43 provided by VRC.

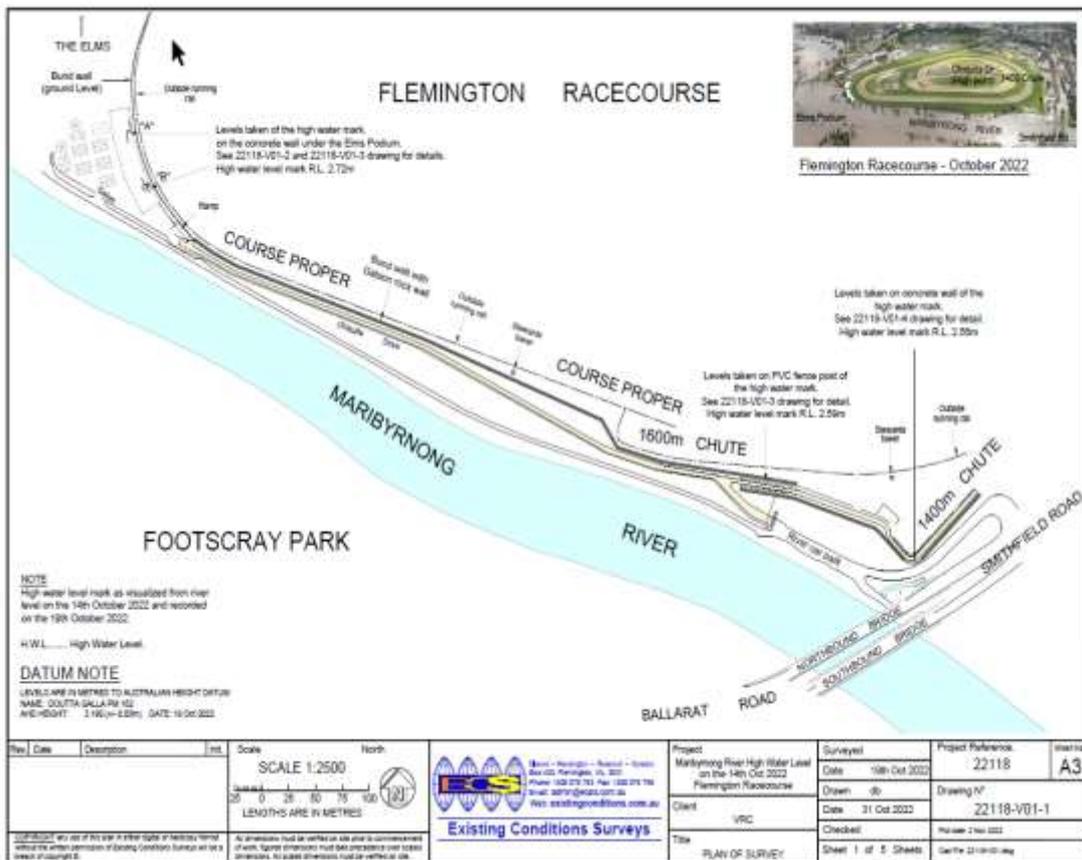


Figure 44: Location and outline of the Maribyrnong River catchment. (Source: Survey Plan as provided by VRC).

- 167. The Floodwall is approximately 900 metres in length. The material appearance of the Floodwall for the majority of its length is characterized by a gabion wall

construction with complementary landscaping (as depicted in Figure 45). The Floodwall also acts to secure the southern boundary of the Flemington Racecourse.



Figure 45: Photo of a portion of the Flemington Floodwall.
(Source: Panel supplied photo 2/5/2023).

168. The land on which the Flemington Racecourse is situated is within the City of Melbourne and is designated within the Melbourne Planning Scheme (Figure 46). The site is zoned Special Use Zone (Schedule 1) and recognizes that “Flemington Racecourse is a major recreational and entertainment resource of State and Metropolitan significance”. The Flemington Racecourse is also the subject of the LSIO (Figure 47).



Figure 46: The Flemington Racecourse is designated within the Special Use Zone – Schedule 1 (SUZ1).

Source: <https://mapshare.vic.gov.au/vicplan>.

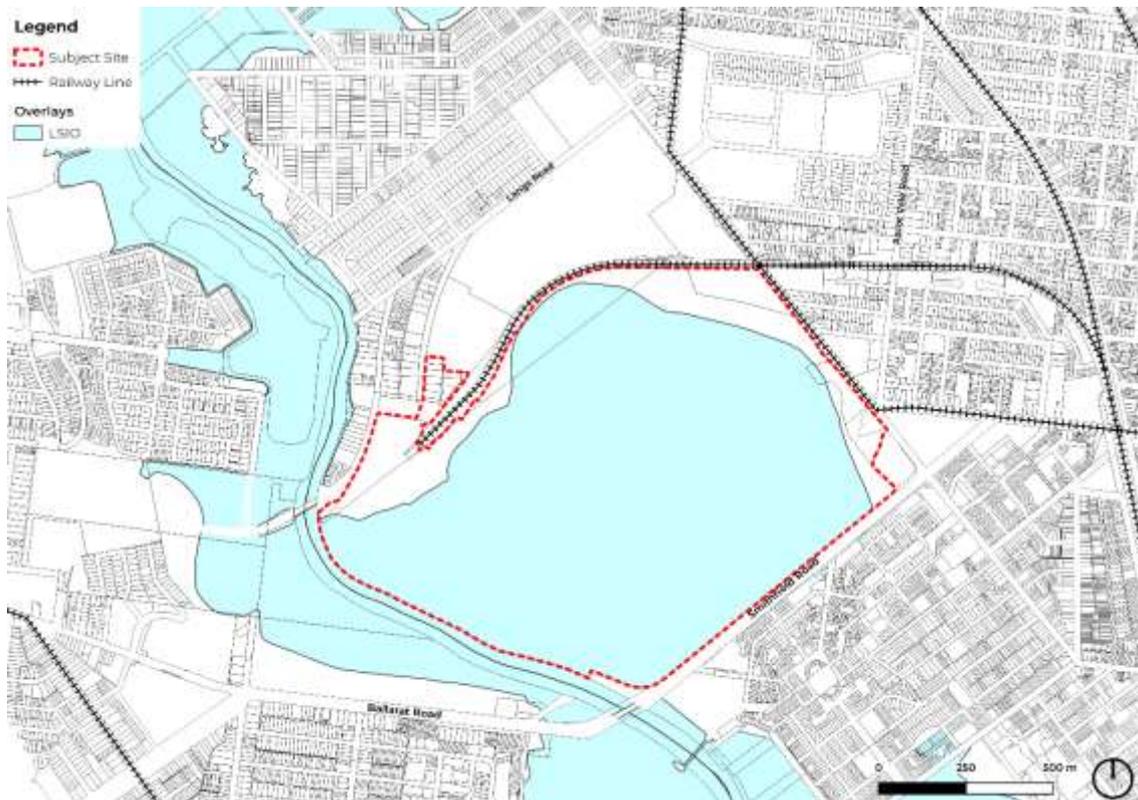


Figure 47: The Flemington Racecourse is also subject to a LSIO.

Source: <https://mapshare.vic.gov.au/vicplan>.

169. The Minister for Planning is identified at Clause 72.02-2 of the Melbourne Planning Scheme as the responsible authority for administering and enforcing a provision of the planning scheme for the Special Use Zone – Schedule 1 Flemington Racecourse including issuing any relevant planning permits. An application by the VRC to carry-out “racecourse track upgrade and flood protection works” was submitted to the Minister for Planning on 25 March 2003 (ref: Permit 2003/86).

170. The LSIO that affects the Flemington Racecourse also requires that a planning permit application must be referred to the relevant floodplain management authority under Section 55 of the *Planning and Environment Act 1987*. Melbourne Water is the flood plain management authority in this instance and was therefore a Referral Authority for the permit application. On 22 April 2003, the Department of Sustainability and Environment (DSE), on behalf of the Minister for Planning, referred the VRC planning permit application to Melbourne Water. The Minister in the role of responsible authority also notified other interested parties (under Section 52 of the *Planning and Environment Act 1987*) of the planning permit application, including the City of Melbourne, Maribyrnong City Council, Moonee Valley City Council and other affected parties.

171. Having received the referral of the planning permit application, Section 56 of the *Planning and Environment Act 1987* required Melbourne Water to consider the application and to inform the Minister of one of the following, namely that:
 - (a) it did not object to the granting of the permit; or
 - (b) it did not object if the permit was subject to the conditions specified by the referral authority; or
 - (c) it objected to the granting of the permit on any specified ground.

172. Melbourne Water, as the Referral Authority, reviewed the planning permit application and on 21 May 2003 wrote to the DSE and requested certain information with respect to Permit 2003/86. The Planning Permit application for the Floodwall was complemented by a report prepared by consultants GHD Group Pty Ltd titled the *Flemington Racecourse Flood Protection Investigation of Maribyrnong River Flood Protection*. This report was subsequently peer reviewed by an independent expert in hydraulic engineering and modelling, Dr Robert Keller. Both reports referred to the need for appropriate compensatory works to mitigate adverse impacts of the Floodwall as shown in Figure 48.



Figure 48: Location of Flemington Flood Wall and Associated Compensatory Works. (Source: Additional documents provided to IRP by Melbourne Water upon request, 5. Background Documents – Flemington Wall, File titled “Location_plan_map_opt.pdf”).

173. The proposed mitigation works associated with the construction of the Flemington Wall were (see Figure 48 - Location of Flemington Floodwall and Associated Compensatory Works):
 - a. Hydraulic improvements to Footscray Road
 - b. Hydraulic improvements to the Northern Railway.

174. Both the Moonee Valley City Council and the Maribyrnong City Council also engaged external consultants (Water Technology and WBM Oceanics) to review the GHD modelling and to provide professional advice about the impact of the proposed Flemington Floodwall. Following this advice, both Councils objected to the planning permit being issued. The issues raised by the objections included a concern that the effects of the Floodwall could be greater than predicted by GHD, and that the mitigating effects of the proposed compensatory works might be less than predicted.

175. The City of Melbourne and other independent parties also objected to the proposed Floodwall. On 3 September 2003, DSE provided Melbourne Water with the Water Technology report. Melbourne Water reviewed the report and, following a meeting with consulting firms Water Technology Pty Ltd and GHD, responded to DSE on 17 September 2003, concluding that the GHD model was technically sound, and that further hydrologic and hydraulic investigation was not warranted because:
 - GHD had comprehensively analysed and assessed the available information;
 - The model produced had been calibrated and modified for current development conditions; and
 - The model could be used to determine the behavior of flood flows in the river.

176. Thereafter, on 14 October 2003, Melbourne Water wrote to DSE confirming that it did not object to the planning permit application, subject to 39 planning permit conditions, including specific requirements for certain mitigation works being performed.
177. On 5 February 2004, the then Minister for Planning, Ms Mary Delahunty, issued a notice of decision to grant a permit in respect of Application 2003/86 under Section 64 of the *Planning and Environment Act 1987*.
178. An application to the VCAT for a review of the Minister's decision to grant a permit under Section 82 of the *Planning and Environment Act 1987* was subsequently initiated by Maribyrnong City Council, Moonee Valley City Council, the City of Melbourne, Ms Kaye Testro and the Maribyrnong Residents' Association Inc.
179. On 1 April 2004, the Minister directed the Principal Registrar of VCAT to refer the appeals to the Governor in Council for determination pursuant to Clause 58 of Schedule 1 of the *Victorian Civil and Administrative Tribunal Act 1998*.
180. On 3 August 2004, that application was determined by the Lieutenant Governor (acting in place of the Governor) under Clause 58(2)(a) and Clause 61(1)(b) of the *Victorian Civil and Administrative Tribunal Act 1998* and the Minister was directed to issue the permit subject to 49 permit conditions, including those required by Melbourne Water.
181. In December 2005, the VRC appointed Akron Roads Pty Ltd to undertake the flood mitigation works required as a condition of the planning permit. Construction of the Floodwall began in 2007 after the flood mitigation works that had been required as a condition of the planning permit had been completed in January 2006. The construction of the Floodwall was substantially completed around September 2007.

182. Compliance with each of the non-ongoing permit conditions was subsequently obtained, with DSE providing final confirmation of this in a letter to the VRC dated 17 March 2008.
183. The degree to which the Floodwall contributed to the duration and extent of the Flood Event cannot be assessed directly, as there is no modelling of the Event that includes the Floodwall. The current HEC-RAS model is out of date, and while suitable for determining design flood levels, it is not suitable for assessing the impact of specific infrastructure, such as the Floodwall and its downstream compensatory measures, on flood duration and extent. Melbourne Water have indicated that a modern hydraulic model that is capable of performing such an assessment is being developed, but this will not be available until April 2024.
184. Although the verification of the current HEC-RAS model of the lower Maribyrnong River conducted by consultants Jacobs in 2023 did not include the Floodwall (see Figure 48, right panel), a comparison of the actual extent of the Flood Event, which does include the impact of the Floodwall (Figure 49, left panel), and the modelled extent of the Flood Event, which does not include the impact of the Floodwall (Figure 49, right panel), shows that the two extents look very similar. Based on this high-level visual comparison, the impact of the Floodwall on the extent of the flooding would not appear to be significant.

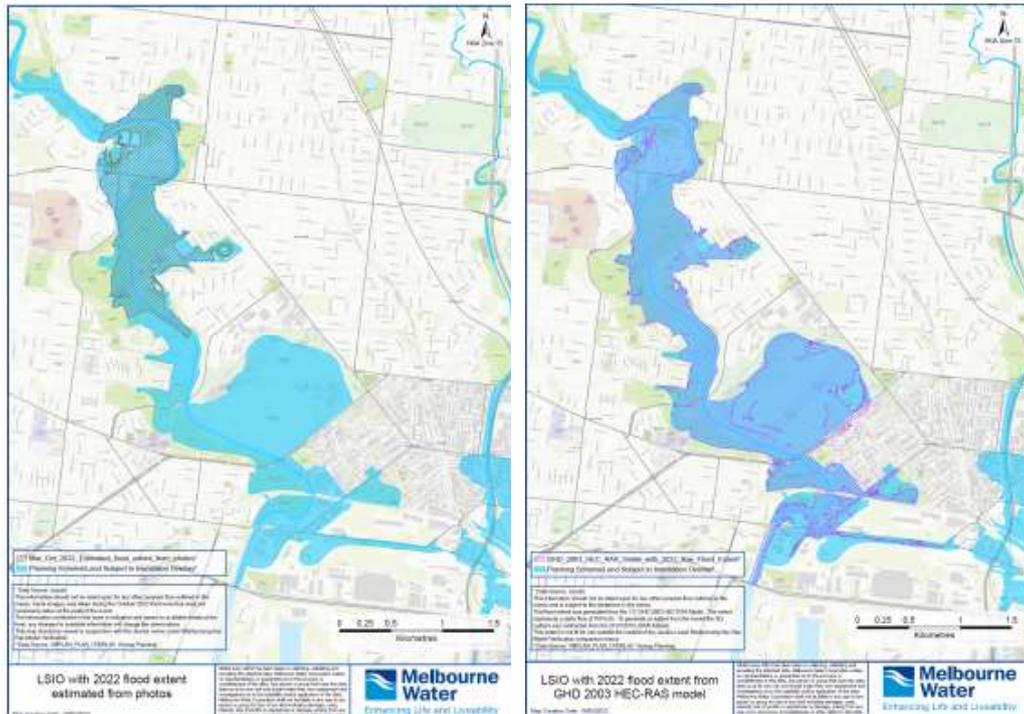


Figure 49: Comparison of the estimated extent of the Flood Event, which included the Floodwall (left panel) and the extent of the modelled extent of the Flood Event, which did not include the Floodwall (right panel).

(Source: left panel provided to IRP by Melbourne Water (“LSIO with 2022 flood extent estimated from photos”) and right panel provided to IRP by Melbourne Water (“LSIO with 2022 flood extent from GHD 2003 HEC-RAS model”).

185. The hydraulic improvements to Footscray Road (one of the mitigation works proposed by Melbourne Water; see Figure 50) consisted of the removal of the bluestone abutment from the left (eastern) bank and the construction of flow training walls upstream and downstream of this location, to improve the flow beneath the bridge, which was estimated to lower the total head loss (water level difference) across the bridge from 266 mm to 211 mm. No works were proposed for the right (western) abutment since the effect of similar changes were considered to be minimal because of the upstream jetty and the downstream wharf structures. These works led to the streamlining of the left (eastern) bridge abutment and were expected to lower the flood level by approximately 55 mm.



Figure 50: Location of hydraulic improvements to Footscray Road, including downstream end of bluestone abutment to be removed.
(Source: GHD 2003 report supplied by VRC).

186. The hydraulic improvements to the Northern Railway Culverts (the other mitigating works proposed by Melbourne Water; see Figure 51) consisted of lowering the road embankment located immediately downstream of the railway culverts in that location, thus increasing their capacity. Removing this obstruction was estimated to increase the capacity of the culverts and the waterway immediately downstream and to lower upstream flood levels by 44 mm.



Figure 51: Road embankment downstream of the Northern Railway Culverts.
(Source: GHD 2003 report supplied by VRC).

187. The efficacy of Melbourne Water’s proposed conditions of approval and mitigation measures relating to the wall and their implementation could not be assessed by the Review Panel because there is no modelling of the Flood Event that included the Floodwall and the mitigation measures relating to the wall. The VRC was asked in public consultations about any evaluation undertaken by the VRC to evaluate the efficacy of the mitigation measures but was only able to confirm that the Floodwall was able to prevent flooding of Flemington Racecourse and that they had no information on the impact of the Floodwall elsewhere, or how well the mitigation strategies performed.
188. Mr James Reid, Executive General Manager, Flemington Operations, of the VRC was asked by us at public consultations whether the VRC had undertaken any analysis of the efficacy of the Floodwall and any evaluation of whether the mitigation measures which had been required in relation to the Floodwall had been efficacious. Mr Reid informed us at the public consultations that the VRC did not have information that could assist us in relation to the impact of the Floodwall other than it having stopped water from flowing onto the Racecourse.
189. Ms Nadia Angelo, Executive General Manager – Legal, Risk and Governance, VRC, in a subsequent letter dated 14 August 2023 to the Panel Administrator confirmed that Mr Reid’s response at the public consultations had been in essence (a) that Existing Conditions Surveys surveyed the Racecourse and the impact of the Flood Event and confirmed in their report that the Floodwall continues to be suitable for its purpose. Beyond commissioning this survey, the VRC has not conducted any further evaluation of the efficacy of the Floodwall. Mr Reid also provided evidence in his statement that “*the Floodwall was effective in protecting the Racecourse from the Flood Event as no water came over the top of the Floodwall despite the significant height of the water*”; and (b) that no evaluation had been undertaken by the VRC of the impact of the Floodwall. The letter from Ms Angelo noted also on 17 July 2023 the VRC learnt that Melbourne Water was conducting analysis and modelling of efficacy impact of

the Floodwall on the Flood Event. Ms Angelo noted that the VRC was not in the position to take the kind of review or analysis which she understood was presently said to be underway by Melbourne Water and that the VRC was “not in a position to provide any useful assistance to the Review Panel in responding to the Terms of Reference (in particular, paragraphs 6 and 7).”

190. As mentioned previously, the current HEC-RAS model used by Melbourne Water is out of date and is not suitable for assessing the efficacy of a specific infrastructure such as the Floodwall and its downstream compensatory measures. Melbourne Water have indicated that a modern hydraulic model that is capable of performing such an assessment is being developed, but this will not be available until April 2024. Once this model is available, it should be used to assess the efficacy of the Floodwall and associated compensatory measures. Given the contentious nature of this issue, this assessment should be subject to independent peer review.

THE RAINFALL AND FLOOD EVENT

8. The characteristics of the rainfall event(s) across the catchment leading to the Flood Event, including consideration of how these compared to:
- i. Historical records.
 - ii. The Australian Rainfall and Runoff Guidelines (2019).
 - iii. Flood predictions or modelling that accounts for climate change.
191. Paragraph 8 of the Terms of Reference requires us to assess the characteristics of the rainfall event across the catchment leading up to the Flood Event. The characteristics of the Flood Event can be put in context by comparing its rainfall and flood levels to historical records and to flood frequency analysis of rainfall and flows. Floods typically occur when catchment conditions are average for a given season. However, flooding can occasionally occur following very dry conditions or following a prior flood or very wet period.

192. When a catchment is drier than normal, much of the rainfall infiltrates and the flood is smaller than the rainfall would suggest because a reasonable amount of the rainfall infiltrates and does not run off. In this circumstance, the flood is slow to rise and it is relatively easy to provide timely warnings and for these to be acted upon effectively.
193. In contrast, if catchments are very wet at the onset of the rainfall event resulting in flooding, floodwaters can rise much faster than usual and a modest amount of rainfall can produce a major flood. The Flood Event falls into this category, as the Maribyrnong catchment was much wetter than usual prior to the rainfall of October 13 and 14 that produced the flood.
194. More specifically, the rainfall that produced the Flood Event was preceded by a storm a week earlier during October 6 to 8 that resulted in approximately 30-40 mm of rainfall. Even before this storm the rainfall that had fallen in September had been much higher than average and a similar event to the one that occurred on October 6 to 8 had occurred on October 1 to 2. These earlier storms wet the catchment and caused much more of the rainfall of the October 13 to 14 event to turn into runoff.
195. The 24 hour rainfall totals for the October 13 to 14 event were not very remarkable, with the highest totals at Lancefield North and Romsey typically being exceeded every five years, while the total rainfalls recorded at stations at Bulla, Sunbury, Clarkefield, Rosslynne and Darraweit were unremarkable and generally less than what is experienced every other year. When the cumulative two day rainfall totals are considered, the total at the Lancefield North rain gauge corresponded to an average annual exceedance probability that is between 2% and 1%, but the equivalent values at other gauges corresponded to significantly less extreme rainfall events with annual exceedance probabilities of 10% or greater.
196. Normal practice is to look at the average catchment rainfall as rainfall values at

individual gauges can be misleading. As part of the update to *Australian Rainfall and Runoff in 2019*, the Bureau of Meteorology analysed all of the long term rainfall records in Australia to determine the probability of the occurrence of rainfalls with different depths and of different durations. This is commonly referred to as IFD data, which stands for Intensity Frequency Duration. This data set allows us to determine the probability of average rainfall on the Maribyrnong catchment.

197. The post event analysis report by Jacobs found that the catchment average rainfall on October 13 and 14 2022 would typically be exceeded every second year, while the combined rainfall would be exceeded on average every three to four years. Regardless of the exact probability, this is a relatively modest rainfall average relative to the magnitude of the resulting flood, highlighting the impact of the wet catchment. These rainfall amounts would have been exceeded many times before, but the combination of a very wet catchment and modest rainfall produced a reasonably rare flood event in this instance.
198. Even though the climate is changing and that this is likely to result in more extreme rainfall events, it is not possible to attribute the characteristics of the rainfall event on October 13 to 14 2022 to climate change. This is because of the high degree of variability in the changes in climate, as well as the complexity of the physical mechanisms that result in extreme rainfall.

PLANNING FOR THE FUTURE

9. Melbourne Water's approach to flood modelling and prediction.

199. The Review Panel was invited by paragraph 9 of the Terms of Reference to provide recommendations in relation to any matter associated with Melbourne Water's approach to flood modelling and prediction. We have provided recommendations throughout the preceding discussion in this Report but add the following observations.

200. There is a relatively standard approach to flood modelling around Australia that has developed over the last four decades. The flood study process involves collecting flood data, developing flood models and calibrating these models to observed floods and finally using these models to produce design flood levels that can be used for planning and design purposes.
201. This process has been formalised in the methodology in *Australian Rainfall and Runoff* which provides guidelines for flood estimation in Australia. The original edition was in 1958 but most of the work on this catchment was carried out under the 3rd edition published in 1987. The 4th edition was first published in draft in 2016 and was finalised in 2019. There are large differences between the 1987 and 2019 versions but the core methodology and approach remain generally the same. Under either edition the most reliable way of estimating design flows is statistical analysis of long term flow records and conversion of these flows to levels using an hydraulic model.
202. Most flood modelling today is carried out using dynamic two dimensional flood models. These can be considered third generation models and the Australian market is dominated by the locally developed but internationally used TUFLOW model. These third generation two dimensional flood models became mainstream tools around 2000, and by 2010 were the tool of choice. HEC-RAS now includes a third generation two-dimensional model but this is rarely used in Australia.
203. The Flood Event has highlighted a number of issues with Melbourne Water's flood modelling in the Maribyrnong catchment. These issues have meant that the flood levels, mapping and LSIO information have less utility than stakeholders expect. These issues also have flow on affects beyond just their direct outputs, as they are used by councils, SES and other parties as inputs to other work.

204. In order to address the shortcomings of their modelling approach, Melbourne Water have updated their flood modelling process over the last few years. This updated approach can be considered state of the art and is consistent with practice everywhere in Australia. As part of this process, Melbourne Water provides detailed practice guidelines to make modelling approaches as consistent as possible, which is a desirable attribute when managing a large number of floodplains. These guidelines were developed in October 2021 and are called “AM STA 6200 Flood Mapping Projects Specification”.
205. Melbourne Water’s updated flood modelling process requires the use of the RORB hydrologic model to convert design rainfalls to design runoffs and use of the TUFLOW hydraulic flood model to convert these design flows into corresponding flood depths and extents. The latter offers numerous ways of incorporating bridges, culverts, flow around houses and urban drainage features.
206. A real difference between the Melbourne Water process and that used in other jurisdictions is that the Melbourne Water process is more regulated, requiring the use of specific modelling platforms (i.e. RORB and TUFLOW). This results in increased modelling consistency and makes it easier for Melbourne Water to process, map and compare results, reducing some of the unnecessary differences between flood studies.
207. Melbourne Water needs to ensure, however, that all of their rainfall-runoff and flood models are calibrated. This will require an audit of existing models to identify any models that are not calibrated and prioritising the calibration of these models. In addition, Melbourne Water needs to ensure that all of their models are updated every five to ten years and in response to any significant flood events.
208. Melbourne Water should also ensure that their flood modelling accounts for the impacts of climate change. As mentioned previously, the annual

exceedance probabilities of floods of a given magnitude are either estimated based on historical flow data or historical rainfall data that are converted to corresponding flow data using rainfall runoff models. However, due to the impacts of climate change, the annual exceedance probabilities of historical flow and rainfall data are unlikely to be a good indicator of those of future values.

209. This is because climate change is affecting the global water cycle, causing significant changes to rainfall regimes in Australia. While some areas in Australia are becoming dryer and others wetter, the impact of climate change on flood producing rainfall and resulting floods is more complex. For example, even areas that are becoming dryer on average are likely to experience more extreme rainfall and flooding.
210. The reason for this is that climate change is increasing air temperatures, which also increases how much moisture a given volume of air can hold: for every 1% increase in air temperature, the same volume of air can hold an additional 7% of moisture. Consequently, even if the average annual rainfall in a region decreases due to a smaller number of rainfall events, the amount of rain that is available for release when it does rain is higher, potentially resulting in fewer, but more intense, rainfall events.
211. Detailed modelling and research has shown that increases in rainfall intensity will be larger for short duration storm bursts that last for a few hours, as well as smaller, long duration storms that last for multiple days. However, for the latter, it is the more intense periods during these longer duration storms that are likely to increase in intensity the most. In addition, climate change can also result in seasonal shifts of when extreme rainfall events are likely to occur and how dry and wet seasons are.
212. The impact of climate change on the frequency and intensity of rainfall events can be highly location dependent given the complexity of the physical mechanisms that result in extreme rainfall. In Victoria, storm intensities are

likely to increase but average rainfalls are likely to decrease and catchments will be drier, which will moderate many small floods. This will lead to smaller floods becoming smaller and larger floods becoming larger on natural and rural catchments. However, this moderating effect will be much smaller on urban catchments, as in these catchments most of the runoff is produced on hard impervious surfaces like roads and roofs.

213. National interim advice on how climate change is likely to affect flood producing rainfall is provided in *Australian Rainfall and Runoff (2019)*, which can be accessed from the Australian Rainfall and Runoff datahub (<https://data.arr-software.org>). The values provided in this datahub are based on simple scaling of rainfall volume with temperature, with a five percent increase in rainfall for every degree increase in air temperature. However, these values are currently being updated to provide more nuanced information such as how increases in rainfall intensity change with storm duration.
214. The degree to which global air temperatures will increase in the future is heavily influenced by a range of political, social, economic and technological factors that are highly uncertain (e.g. factors affecting how much carbon is emitted into the atmosphere due to global agreements, carbon pricing policies, the behaviour of individuals, advances in renewable energy technologies etc.). That means that the degree to which rainfall intensity, and hence flooding, will change in the future is also highly uncertain. For example, under a lower carbon emissions future, rainfall intensity is estimated to increase by 7.6% by 2090, while under a higher, business-as-usual carbon emissions future, this value increases to 16.3%.
215. The uncertainty associated with estimates of the impact of climate change on rainfall intensity should not provide a barrier to the incorporation of climate change impacts into planning controls, such as the one percent annual exceedance probability LSIO, given that current global average air temperatures are already approaching values that are 1.5 degrees Celsius above

pre-industrial levels. The precautionary principle should be implemented, which stipulates that consideration of the expected impact of climate change in flood planning controls is not only prudent, but necessary.

216. A failure to include consideration of the expected impact of climate change in current flood modelling is likely to have far reaching negative long term impact because the results of the flood models are used to determine a range of planning controls. Buildings potentially within flood plains are at increasing risk of (repeated) flooding into the future if, for example, required finished floor levels of new buildings, including buildings that replace existing buildings as part of urban renewal or in response to flood damage, are determined using the conclusions of flood models that do not consider climate change.
217. In contrast, considering the expected impact of climate change in flood modelling would lead to requirements for new and replacement buildings to have higher finished floor levels, enabling some of the impact of future flood events to be avoided. Without this, the chances of a repeat of the impact of the Flood Event may be significantly higher.
218. Climate change is not the only factor that can result in changes in runoff over time, as changes in land use also have an impact on how much rainfall is converted to runoff, and hence how flood depths and extents change over time. Of most concern are land use changes due to urban infill and other forms of densification, because they result in the conversion of more pervious surfaces (such as gardens and lawns) into more impervious surfaces (such as roofs, driveways and patios). Consequently, in addition to potential future impacts of climate change, potential changes in land use due to urbanisation and densification also need to be included in Melbourne Water's flood modelling.
219. A failure to take into account the change of land use is also likely to underestimate future flood water levels, resulting in increased flood impact for

rainfall events of the same annual exceedance probability. It is generally not possible to change the floor levels of buildings once they have been constructed, but it is important to include plausible future flood levels in the modelling used to support planning controls to ensure that future flood risk is not significantly greater.

220. There is also a need for Melbourne Water to change the modelling approach that is used to support the provision of flood warnings as part of their Flood Integrated Decision Support System. As mentioned previously, for fast-reacting catchments in which flood waters can rise very quickly, as was the case in the Maribyrnong River during the Flood Event, the time it takes to run current models needs to be reduced by at least 50% for the warnings to be effective.

OUT OF SCOPE

221. The Terms of Reference identify four matters as being specifically out of the Scope of the Review although it is sometimes difficult to delineate sharply between matters in and out of the Review. We have, for example, sought to avoid detailed consideration of overall emergency responses including warnings and evacuation procedures but in considering the extent and duration of the Flood Event it was inevitable that we would need to consider and reflect upon the specifics of emergency responses including the warnings (see, as an example, our analysis of the time taken for the model to be run and to enable forecasts to be updated).
222. We observe, however, that the matters which are out of the Scope of the Review are of importance and ought to be addressed. We received submissions on some of the aspects which were out of scope and, for example, were given much informal observations from [REDACTED] (when still employed by Moonee Valley City Council), [REDACTED] (whose business was adversely affected by operational decisions during the Flood Event), Ms Melan (who had specific recommendations about renewed housing stock); and by Mr Colin Waters

(a resident at Rivervue Retirement Village with a professional engineering background). It may be useful for us to make the following observations if only to make clear what some matters were which we considered out of scope and therefore which we did not specifically consider but would regard as significantly connected to what was within the scope of our review.

223. The focus of this review is on technical matters related to Melbourne Water but there is a range of broader issues that were touched upon but fell outside the terms of reference that should be considered to ensure future flood risk is managed in a holistic fashion. These include (i) how to minimise the impact of future flood events by considering plausible changes to risk due to changes in climate and land use, as well as the full suite of potential risk reduction strategies, such as structural measures, land use planning and building regulations, (ii) how flood events are managed, including how warnings are given to those potentially affected within a time frame that enables them to act, and how to manage traffic to prevent and not exacerbate damage, and (iii) how best to support those who have been affected by flooding in the short and long term, not just financially, but also psychologically and emotionally.
224. As is the case in many other domains, when dealing with flood risk prevention is better than cure. Consequently, the best way to avoid the impact of floods is to ensure that things of value (e.g. people, animals, infrastructure etc.) are not exposed to flooding in the first place. This is why current planning controls should take account of potential future changes in flood levels due to climate change and any development in the catchment to avoid creating additional future risk by decisions made today.
225. Many future planning controls, however, may only apply to future development and there is also a need to manage existing risk, such as that associated with infrastructure and other assets that are currently at risk of flood or may become so in the future because of such factors as climate change and urban development. The most effective way of achieving this, from a

purely reduction perspective, may be the removal of assets from flood prone areas using mechanisms such as buy-back schemes.

226. This may result in significant disruption to the social fabric of an area and would have to be done with great sensitivity and care. Incentivising redevelopment in these areas by considering greater densities would allow future development to replace existing housing stock that is below the 1% annual exceedance probability flood but this will also have the effect of putting more people in areas that are frequently inundated, albeit that finished floor levels were above the 1% annual exceedance probability flood height.
227. Another means for reducing existing risk is to reduce the level of flooding with the aid of either more widely applicable upstream mitigation strategies, such as dams and floodways, or more locally applicable mitigation strategies such as levees and floodwalls. Such mitigation measures are costly and can also result in a number of negative side effects, such as negative environmental impact and the transferring of flood risk from one location to another.
228. There are likely to be difficult judgments to be made and trade-offs to be considered between different objectives, requiring a holistic assessment of a wide range of mitigation strategies. For example, the number of flood damaged properties in Maribyrnong township appears to have been reduced by a previous flood prone dwelling buyback scheme, and whether a similar approach should be adopted in other areas depends on the relative costs, impact and effectiveness of other mitigation options, such as measures designed to reduce flood levels (e.g. upstream dams and levees).
229. Effective management of the flood risk at Rivervue Retirement Village will also require a holistic approach. It is clear from the Flood Event that Rivervue Retirement Village is at risk of flooding, and this risk may increase in the future as a result of climate change and with further development in the upstream catchment area. Planning controls for future construction may not be a viable

option for mitigating the flood risk because Rivervue Retirement Village is already in existence. There may therefore be a need to investigate other options, such as structural mitigation. The identification of suitable risk mitigation options is important for the residents of the Rivervue Retirement Village because of the high level and ongoing nature of the trauma experienced by residents of the Rivervue Retirement Village, as well as their high level of vulnerability.

230. Some assets are likely to be exposed to flooding both now and in the future. In such cases, the importance of having excellent warning systems to reduce the impact of flooding cannot be overstated. In addition, the co-ordination of emergency responses, is also important. For the Flood Event, it is apparent from the informal observations of council staff that improvements could have been made to the co-ordination and execution of emergency responses. Incident management during a flood requires multiple agencies across different levels of government to act quickly with little time for checking and coordination. Councils require key information (which could usefully be reviewed) from “how data from FIDSS is shared before and after flood events” to “what the responsibilities local government authorities are”.
231. The way traffic is managed is also important, as this can have a significant impact. For example, for the Flood Event, the information provided to the Panel was that allowing trucks not associated with the emergency response to access flooded roads while flood levels remained high significantly contributed to some flood damages. Traffic management during a flood event can be difficult and complex as councils, contractors, VicRoads, police and emergency services all assist with managing closed roads but protocols that restrict non-essential vehicle traffic on flooded streets could reduce damages in future floods.
232. Finally, and importantly, we have not considered appropriate responses to the huge mental and emotional toll on many people which were apparent from

submission and the public consultations. Many of the effects are ongoing. In this report we can only acknowledge the importance of these ongoing and widespread impacts and of the need to provide appropriate support for many years after the occurrence of the Flood Event.

CONCLUSIONS AND RECOMMENDATIONS

1. Melbourne Water should review their flood models every five years and update them at least every 10 years and after the occurrence of a major flood.
2. Melbourne Water needs to ensure that rainfall runoff and flood models are calibrated to observed flood information.
3. Melbourne Water should ensure that their rating curves, which represent the relationships between river levels and corresponding river flows, extend also to rare and extreme flood events and have been derived using established best-practice.
4. Melbourne Water should take account of the best estimates of the impact of climate change when setting flood levels for planning and development and the application of the Land Subject to Inundation Overlay.
5. Melbourne Water should adopt forecasting tools which enable forecasts to be made within a total of no more than 60 minutes.
6. Melbourne Water should use the hydraulic model being developed (expected to become available in April 2024) to determine (and be subjected to independent peer review) the impact of the Flemington Floodwall and the efficacy of the associated downstream compensatory works.
7. Melbourne Water should commission an independent expert review and audit of their forecasting system with the aim of identifying areas where forecast accuracy, warning times and model run times could be improved.
8. Melbourne Water should take account of the change in land use and projected changes to land use when setting flood levels for planning and development and the application of the Land Subject to Inundation Overlay.
9. Melbourne Water should immediately update the Mid Maribyrnong flood model with a modern two dimensional flood model developed in accordance

with Melbourne Water guidelines and use this model to set new design flood levels.

10. Melbourne Water should have a protocol that enables flood forecasting at intervals at less than two hours when prudent to do so by reason of the responsiveness of the catchment for significant events.
11. Melbourne Water should consult with the Bureau of Meteorology to develop rainfall forecasts more frequently than six hours.
12. Melbourne Water should seek the approval of the Minister for Planning to apply interim planning controls designating the Land Subject to Inundation Overlay in locations where flooding occurred, pending the update to the Mid Maribyrnong flood model.
13. Melbourne Water should investigate how it came to be satisfied with the reduction of the flood levels and finished floor levels at the Rivervue Retirement Village as specified in the endorsed plans dated 2 June 2009.
14. Melbourne Water should investigate the feasibility of installing one way valves on the outlets from the street and yard drainage from Evergreen Avenue (Rivervue Retirement Village).
15. Melbourne Water should investigate long term sustainable flood mitigation options for the Maribyrnong River.

ATTACHMENTS

Attachment A	Terms of Reference and Addendum
Attachment B	List of persons who made submissions
Attachment C	List of persons consulted or interviewed
Attachment D	Unredacted copies of submissions
Attachment E	Correspondence inviting submitters to participate in public consultations
Attachment F	Additional information received from submitters
Attachment G	Correspondence requesting further information
Attachment H	Responses to extra information received upon request
Attachment I	Copies of invitations to meet with the Panel
Attachment J	 letter
Attachment K	List of observers who attended public consultations
Attachment L	Public Consultation transcripts
Attachment M	Documents handed up during public consultations

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GLOSSARY AND ABBREVIATIONS

AEP	(Annual exceedance probability): The probability a specific flow or flood level is equalled or exceeded in a given year.
ARR87	(Australian Rainfall and Runoff 1987): The 1987 edition of the document that provides guidelines for flood estimation.
ARR2019	(Australian Rainfall and Runoff 2019): The 2019 and most recent edition of the document that provides guidelines for flood estimation.
Calibration	Tuning the parameters in a model to match known real world data points in order to make the model more representative of real world conditions.
Delft-FEWS	Flood Early Warning System.
DSE	Department of Sustainability and Environment.
FFA	(Flood Frequency Analysis): Statistical analysis of known historical flow in order to determine flood quantiles at a specific point, usually a streamflow gauge. When available data is reliable and abundant FFA produces the best estimate of design flood levels.
FIDSS	Flood Integrated Decision Support System.
Flood Warnings	Warnings issued by the Bureau of Meteorology for the potential for flooding at a location. Based on forecast rainfall and other data. These warnings contain a predicted flood level.

Freeboard	A factor of safety used for setting minimum floor levels. Typically, a value of 600mm is used on major river systems in Victoria.
GHD	GHD Group Pty Ltd is a multinational technical professional services firm.
HEC-2	One dimensional steady state hydraulic modelling software produced by the US Army Corps of Engineers that was the predecessor to HEC-RAS.
HEC-RAS	One dimensional hydraulic modelling software produced by the US Army Corps of Engineers.
Hydraulic Model	Software that converts flow to flood levels, extent, and depths.
IFD Data	Intense Frequency Duration.
JACOBS	Jacobs Australia Pty Limited is the Australian arm of Jacobs Solutions Inc which is an international technical professional services firm.
LSIO	Land Subject to Inundation Overlay.
Major Flood Levels	If the water level reaches the major flood level large areas are inundated. Many buildings may be affected above floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation may be required. Utility services may be affected.
Mannings 'n'	The roughness coefficient used in many different hydraulic modelling software as well as many other areas in hydrology.
MIKE 11	One dimensional hydraulic modelling software produced by the DHI group. Models the time series of a flood event.
MIKE FLOOD	A combined one and two dimensional hydraulic modelling software produced by the DHI group.

Minor Flood Levels	If the water level reaches the minor flood level, it causes inconvenience. Low-lying areas next to water courses are inundated. Minor roads may be closed, and low-level bridges submerged. In urban areas flooding may affect some backyards and buildings below floor level as well as bicycle and pedestrian paths. In rural areas removal of livestock and equipment may be required.
Moderate Flood Levels	If the water level reaches the moderate flood level, the area of inundation is larger than for minor flood levels. Main traffic routes may be affected. Some buildings may be affected above floor level. Evacuation may be required. In rural areas removal of livestock is necessary.
Rainfall Runoff Modelling	Modelling that produces runoff hydrographs for catchments based on input rainfall into the model. Sometimes referred to as hydrologic modelling.
Rainfall Gauge	A gauge, often operated by the Bureau of Meteorology, that records rainfall, either at a daily level or continuously. Continuous gauges are often called Pluviographs.
Rivervue	Rivervue Retirement Village.
RORB	A rainfall runoff modelling software suite developed at Monash University. First released in 1975.
SES	State Emergency Service.
Streamflow Gauge	A gauge that records the water level of a specific point along a waterway.
TUFLOW	A combined one and two dimensional hydraulic modelling software produced by BMT Commercial Australia Pty Ltd.

URBS	(Unified River Basin Simulator) A rainfall runoff modelling software. First introduced 1992.
Validation	Running real world events through a model not used as part of the calibration process in order to verify the results of the model in situations not used during calibration.
VRC	Victoria Racing Club Limited.