MOLINO STEWART
ENVIRONMENT & NATURAL HAZARDS

LIVERPOOL CITY COUNCIL

Georges River Evacuation Modelling

Flood Evacuation Analysis

Final

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Flood Evacuation Analysis

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Client: Liverpool City Council

Prepared by:

Molino Stewart Pty Ltd

Suite 3, Level 1, 20 Wentworth Street, Parramatta NSW 2150, Australia

PO Box 614, Parramatta CBD BC, Parramatta NSW 2124

T +61 2 9354 0300 www.molinostewart.com.au

ABN 95 571 253 092

ACN 067 774 332

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For Molino Stewart	
Name	Steven Molino
Position	Principal
For Liverpool City Council	
Name	Maruf Hossain
Position	Coordinator Floodplain and Water Management

Executive Summary

Context

Flooding has been identified as a major constraint to achieving future growth in Liverpool LGA under the Greater Sydney Commission's Liverpool Collaboration Area Place Strategy (LCA Place Strategy). Action 24 of the Strategy states that there is a need to "prepare floodplain constraint categorisation study and a flood evacuation study." However, flood evacuation of the Collaboration Area would occur at the same time as other parts of the Georges River floodplain. Molino Stewart was already investigating evacuation capacity for planning proposals in Moorebank East. Accordingly, Council commissioned Molino Stewart to investigate flood evacuation challenges across the floodplain to investigate evacuation capacity for future development in the Moorebank Peninsula and the Liverpool Collaboration Area.

The NSW SES is the lead agency for flood emergency response in NSW and it is currently updating its *Georges River and Woronora River Valley Flood Emergency Sub Plan* (NSW SES 2018). During the preparation of this study there was extensive consultation with NSW SES which made it clear that its preferred primary flood emergency response for the Georges River floodplain is evacuation. The modelling has therefore assumed that all premises threatened by flooding will need to evacuate when ordered to by NSW SES. As such, it is effectively modelling road transport capacity to see if Liverpool's entire floodplain can evacuate within the available flood warning time, given a 100% evacuation compliance rate.

Model Construction

This study uses an agent-based model (Life Safety Model) to investigate the road transport capacity of Liverpool LGA to evacuate from the Georges River Probable Maximum Flood (PMF). The model simulates warning dissemination, evacuee response, traffic flows and flood rise and spread. It can visually and dynamically show the progress of evacuation, the build-up and dissipation of traffic queues and the overtaking of vehicles by floodwaters. The model results in this report are presented as map extracts and tables but videos of each model run from start to finish are also available.

It is emphasised that the modelling is only as good as the model's inputs and assumptions. To formulate these, extensive consultation was undertaken with Liverpool Council, NSW State Emergency Service (NSW SES), Infrastructure NSW, Transport for NSW, Department of Planning and Environment (DPE) and others to provide local knowledge and ensure the modelling was in line with the most up to date information on future urban development and road upgrades, and NSW SES's approach to managing a flood emergency in the area.

Table i lists the key parameters and studies utilised in the model assumptions.

Table i. Summary of model parameters and incorporated studies

Parameter	Description	Source
Flood Study	For flood behaviour and flood impact probabilities	Georges River Flood Study 2020 2D Tuflow model
Design Flood	Georges River Probable Maximum Flood (PMF) used to set evacuation triggers and model flood impacts	Georges River Flood Study 2020 2D Tuflow model
Warning Lead Time	12 hours prior to flooding	Warning time available for floods on both the Liverpool and Milperra Bridge Gauges (NSW SES, 2019)
Road Cuts	Evacuation routes would not be cut by local creek or Georges River flooding in events more frequent than a 0.2% (1 in 500) Annual Exceedance Probability (AEP) flood	Georges River Flood Study's 2D Tuflow model (BMT, 2020) Anzac Creek Flood Study (Bewsher Consulting, 2005) Cabramatta Creek Flood Study and Basin Strategy Review (Bewsher Consulting (2011)
Time Required between Evacuation Order and Departure	• One hour Warning Acceptance Factor, plus • One hour Warning Lag Factor (see Section 4.2.1)	NSW SES Timeline Evacuation Model (TEM) (Opper et al, 2009)
Road Capacity/ Travel Time Required	• Assumed road capacity of 600 vehicles per hour per lane • This has been applied to all scenarios, except in Scenario B where the two on ramps from the Hume Highway and M5 onto the M7 will have their capacity increased to 900 vehicles per lane per hour as per TfNSW advice.	NSW SES Timeline Evacuation Model (TEM) (Opper et al, 2009)
Traffic Safety Factor (TSF)	Calculated and accounted for based on the elapsed time that vehicles are traveling on the road, as per TEM table. Subsectors were identified where accounting for the TSF meant that additional vehicles would be trapped by floodwaters or on the road.	NSW SES Timeline Evacuation Model (TEM) (Opper et al, 2009)

The study assumed that evacuation would occur by subsector as triggered by forecast flood impacts. Each subsector would evacuate either progressively from areas with a rising road access or all at once where the evacuation route would be cut before properties were flooded.

Specific assumptions regarding residential and non-residential vehicle numbers and other details for each scenario are summarised in Table ii.

Modelled Scenarios

Multiple Georges River flood evacuation scenarios were defined and modelled in this study to demonstrate how various assumptions will alter the evacuation process. The following scenarios are discussed and presented in this report:

- **Scenario 1** is the base case scenario based on 2016 Census (ABS, 2016) population and vehicle data and 2011 Journey to Work (Transport for NSW, 2011) data[1]
- **Scenario 2** is a future scenario with intensified development under existing zoning, accounting for residential and non-residential infill and planned road upgrades
- **Scenario 3** is a future scenario with rezoning and development from planning proposals currently under investigation, as advised by Council
- **Scenario A** is Scenario 2 with multiple non-residential vehicle evacuation destinations depending on the origin of the workers
- **Scenario B** is a modified Scenario 3 with updated planning proposals, adjusted vehicle yields for new development, upgrades to roads and capacities, and multiple non-residential vehicle evacuation destinations.

These are summarised in Table ii.

Key Findings

Existing and Infill Development

The modelling suggests that there are some existing flood evacuation issues which need to be addressed. In particular:

- Parts of the commercial development along Orange Grove Road and residential development in Hargrave Park may not be able to evacuate on public roads because of local creek flooding. Provision of a flood emergency evacuation route through private property would alleviate this problem.
- There are numerous low flood islands where occupants may get trapped and overwhelmed by floodwaters if they don’t leave promptly. Emergency services may need to focus resources on these areas to ensure timely evacuation.
- Nuwarra Road is an evacuation bottle neck which may prevent the timely evacuation of parts of Chipping Norton. The provision of an additional southbound lane from Brickmakers Road to Heathcote Road and the utilisation of Brickmakers Road and Anzac Road for some of the Chipping Norton evacuation traffic may alleviate this problem
- In the most extreme flood events the M5 will flood at the Moorebank Avenue underpass and, because its drainage is only designed for local rainfall, could be closed for several days due to ponded water. This could prevent some evacuees from leaving the peninsula and would disrupt through traffic for weeks. The planned additional westbound lanes crossing the Georges River at this location could be constructed in such a way to ensure access to Moorebank Peninsula in even the most extreme floods.

[1] The 2011 Journey to Work data was used since more recent 2016 Journey to Work data with the associated spatial data is not publicly available.

Table ii. Summary of modelled scenarios

	Scenario 1: Base case[1]	Scenario 2: Intensified development under existing zoning[2]	Scenario 3: Proposals currently under investigation[3]	Scenario A: Modified Scenario 2[4]	Scenario B: Modified Scenario 3[5]
Description	The "present" or current status scenario	Residential and non-residential infill development under existing zonings and currently planned road capacity upgrades	Residential and non-residential infill development under existing zonings plus development associated with planning proposals currently under investigation and currently planned road capacity upgrades	Scenario 2 but with four non-residential vehicle destinations depending on the origin of the workers	Scenario 3 with updated planning proposals, adjusted vehicle yields for new development, changes to roads and capacities, and multiple non-residential vehicle evacuation destinations as per Scenario A
Timing	2016	2036	>20 years in future	2036	>20 years in future
Destinations	M7 northbound (single destination)	M7 northbound (single destination)	M7 northbound (single destination)	M7 northbound for all residential. Four non-residential destinations depending on origin of workers: 1) M7 northbound; 2) Hume Motorway southbound; 3) Camden Valley Way westbound and 4) M5 eastbound	M7 northbound for all residential. Four non-residential destinations depending on origin of workers: 1) M7 northbound; 2) Hume Motorway southbound; 3) Camden Valley Way westbound and 4) M5 eastbound
Road Capacity	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour except for the two on ramps from the Hume Highway and M5 onto the M7 will have their capacity increased to 900 vehicles/ lane/ hour
Road Network	As current	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound, and additional third lane northbound on the M7 and improvements to M7 on ramp capacities through ramp metering
Dwelling Numbers[6]	Based on 2016 census data and Google Maps visual assessment: ~8,500 dwellings or ~27,000 people in evacuation study area	Additional dwellings based on existing zoning-dependent infill potential in Warwick Farm, Chipping Norton and Moorebank as estimated by Council (370 additional dwellings compared to Scenario 1)	Additional dwellings based on existing zoning-dependent infill potential in Warwick Farm, Chipping Norton and Moorebank as estimated by Council plus additional dwellings as per original Planning Proposal numbers from Council (21,765 additional dwellings compared to Scenario 2)	Same as Scenario 2	Modified dwelling numbers compared to Scenario 3, as per updated Planning Proposals numbers from Council
Vehicles per Dwelling	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate but with a rate of one vehicle per dwelling for new apartments
Non-Residential Vehicles	Based on 2011 Journey to Work data for vehicle drivers commuting from outside of the study area (no double counting of those both living and working in the study area)	As per Scenario 1 with additional vehicles added to Liverpool Hospital location only (discounted to include only vehicle drivers originating from outside of the study area)	As per Scenario 2 with additional vehicles associated with additional jobs from original Planning Proposals numbers from Council (discounted to include only vehicle drivers originating from outside of the study area)	Same as Scenario 2	Modified commercial development areas and associated vehicle numbers compared to Scenario 3, as per updated Planning Proposals numbers from Council
Vehicles[6]	Base case: ~27,500 total	1,541 additional evacuating vehicles compared to Scenario 1	61,671 additional evacuating vehicles compared to Scenario 2	1,541 additional evacuating vehicles compared to Scenario 1	40,097 additional evacuating vehicles compared to Scenario 2, minus existing development in the locations of new development.

1-See Section 5.5.1 for details ; 2-See Section 5.5.2 for details; 3-See Section 5.5.3 for details; 4-See Section 5.5.4 for details; 5-See Section 5.5.5 for details; 6-Excluding creek-only impacted subareas I10, R21 and R22

- It would appear that no matter how the additional lanes are provided on the M5 they would alleviate the existing evacuation risks for Chipping Norton and allow some infill development to take place on floodprone R3 and R4 zoned land in Chipping Norton and Moorebank.
- While the NSW SES evacuation planning for the Georges River relies upon motor vehicle evacuation, there are currently thousands of people within the floodplain that do not have access to a vehicle (over 30% of dwellings in some areas). It is recognised that both rail and pedestrian evacuation have their limitations and may not be able to be relied upon. Furthermore, they are generally not supported by the NSW SES.
- Failing to evacuate or deliberately Sheltering in Place in the Georges River floodplain is particularly risky considering buildings can be isolated and inaccessible to emergency services for more than 24 hours in the PMF.

Planning Proposals

The capacity for the expected augmented road network to accommodate development associated with future planning proposals is mixed.

Table iii summarises the key challenges for future development in the study area.

Table iii. Constraints on Future Development

Development	Challenge
The Grove	Requires a flood free evacuation route connection between Homepride Avenue and Orange Grove Road
Shepherd Street	May require an emergency level crossing of the railway line at Atkinson Street
Warwick Farm Structure Plan	Insufficient road capacity to cater for the evacuation of the planning proposals
Moore Point	Insufficient road capacity to cater for the evacuation of the planning proposals
Moorebank East	Approved and proposed development in Moorebank East would be able to evacuate in time but proposed development blocks the evacuation of Chipping Norton

“Spare” evacuation capacity has been investigated at a high level for some of the large planning proposals included in Scenario B. However, it is stressed that this is only a high-level calculation, and the capacity would have to be modelled in order to test the impact of a reduction in vehicles from certain developments. Also note that the vehicles which escape the floodwaters but are trapped on the Moorebank Peninsula have not been accounted for in those calculations.

The Grove

The Grove development should be able to evacuate if an emergency evacuation route through private property is provided to deal with existing evacuation problems.

33 Shepherd Street

The capacity to evacuate 33 Shepherd St by vehicle will depend on how much of the evacuation capacity has been taken up by approved neighbouring developments. Shepherd Street gets cut by frequent floods at the railway underpass which is a threat to both existing development and that being considered in the planning proposal. An emergency level crossing at Atkinson Street would significantly reduce risks to existing and proposed development. It might be possible for 33 Shepherd St to shelter in place because it is generally above the PMF level or subject to shorter duration flooding in the PMF. The provision of the emergency level crossing would make this more viable.

Warwick Farm Structure Plan

Development proposed for the Warwick Farm structure plan would appear to exceed the evacuation capacity of the area because many surrounding areas need to share the same evacuation routes at the same time. Scenario B suggests that the road network could have capacity for 850 evacuating vehicles from Warwick Farm in Scenario B, accounting for the road upgrades included in Scenario B.

Other than reducing the scale of the proposed development, there is not a lot which can be done to mitigate the above challenges. Providing two exit lanes on Warwick Street might assist if it does not create capacity issues on the Hume Highway. Sheltering within buildings is not advisable as the area is surrounded by hazardous floodwaters in the PMF for more than 24 hours and for up to 8 hours in a 0.2% AEP flood.

The precinct is not a flood island and rises gently towards the Hume Highway which then rises rapidly as it crosses the rail line to higher ground west of the railway. Therefore, walking out ahead of rising flood waters should vehicular evacuation fail would be an option.

Moore Point

The planning proposals for Moore Point far exceed the capacity of the road network to cater for their evacuation during a flood. Together they would result in nearly 32,000 vehicles having to evacuate in advance of a flood under the current settings and the modelling suggests that more than 26,000 of them would not be able to evacuate by vehicle in time. The problem is caused because there are only two lanes of Newbridge Road on which it can evacuate and the road gets cut in a 2% (1 in 50) AEP flood. Scenario B suggests that the road network may have capacity for approximately 5,500 evacuating vehicles from Moore Point, accounting for the road upgrades included in Scenario B.

Alternatives to vehicular evacuation such as pedestrian evacuation or sheltering in place present their own challenges because tens of thousands of people are involved and the development can be surrounded by high hazard floodwaters for more than 24 hours in the most extreme floods.

Moorebank East

The modelling suggests that while planning proposals for Moorebank East would have sufficient time to evacuate, they would take up road capacity currently used by Chipping Norton evacuees and thousands would be caught by floodwaters who would otherwise have time to escape. Modelling suggests that that the road network could have capacity for approximately 700 evacuating vehicles from Moorebank East, accounting for the road upgrades included in Scenario B. It is noted that the model included over 360 vehicles for Site C, which is already approved and under construction. This only leaves capacity for 340 additional vehicles. The suggested widening of Nuwarra Road and use of additional roads for evacuation may facilitate some further modest development at Moorebank East without compromising the safety of those already living and working in Chipping Norton.

Recommendations

A. Current Flood Evacuation Challenges

- Ensure that the proposed additional lanes on the M5 across the Georges River are configured to reduce the probability of flooding isolating the Moorebank Peninsula

- Investigate the provision of an additional southbound lane on Nuwarra Road between Brickmakers Drive and Heathcote Road to reduce the queuing that severely limits the evacuation of Chipping Norton onto the M5
- Investigate an emergency level crossing at Atkinson Street to improve the evacuation capability of current developments on Shepherd Street and Riverpark Drive
- Investigate an emergency flood evacuation route through private property between Homepride Avenue and Orange Grove Road (Figure 25 is one possibility) to ensure a flood-free evacuation route for the existing commercial, industrial and residential developments in the areas
- Investigate development of a comprehensive flood forecasting and warning system in the Georges River Catchment to increase the warning time for evacuation
- Investigate the benefits of an intelligent traffic system (ITS) to see whether this could increase evacuation route capacities at route bottlenecks
- Investigate whether contraflow arrangements are likely to increase flood evacuation capacity
- Use data and consider outcomes from this study to inform preparation of Volume 2 and 3 of the Georges River and Woronora River Valley Flood Emergency Sub Plan
- Identify means of safely managing the thousands of people on the floodplain who do not have access to private motor vehicles, many of whom may have mobility challenges. This might include pedestrian evacuation, mass transport or sheltering in place.

B. Planning Proposals

- Many of the above listed recommendations to deal with “current” challenges may also facilitate evacuation capacity improvements for future planning proposals
- Development at Moorebank East should be restricted, considering it is estimated that half of the potential evacuation capacity is taken up by the already-approved Site C development. An additional lane on Nuwarra Road should be investigated to see whether it would provide sufficient additional evacuation capacity to enable further development at Moorebank East without compromising the safe evacuation of existing development in Chipping Norton
- Development at Shepherd Street has a relatively low flood evacuation risk and is unlikely to compromise the evacuation of nearby developments. Emergency access in the area could be improved through the provision of an emergency level crossing at Atkinson Street
- The Grove in Warwick Farm should only be approved if a flood free emergency evacuation route can be created between Homepride Avenue and Orange Grove Road
- The planning proposals for Moore Point and the Warwick Farm Structure Plan either need to be substantially scaled back or:
    - more time to evacuate is provided through an improved warning system
    - improved evacuation route capacity is provided through road upgrades, contraflow traffic arrangement and/or an ITS
    - alternatives to private motor vehicle evacuation is catered for through mass transport, pedestrian evacuation or sheltering in place.

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1.1 Background

In October 2019, Molino Stewart prepared a report for Liverpool City Council (Council) on flood evacuation potential in the Moorebank Peninsula in Liverpool LGA. This was specifically for the potential development of five sites in the Moorebank East precinct (Figure 1) which was previously used for extractive industry and commercial purposes. The whole precinct is at risk of flooding from the Georges River and, to a lesser extent, from local creek flooding.

The highest part of the area was rezoned for residential development in 2008 (Site C) and a development application was submitted in 2017 for low density residential development on that site. A condition of the planning approval for Site C was that a road bridge be constructed to connect the development to Brickmakers Drive to facilitate evacuation in advance of an extreme flood in the Georges River. More recently, development approval was granted for a marina at Site D with approval conditional on the availability of Site C's road infrastructure. It is noted that a separate planning proposal is also being pursued by the landowner of Site D for additional residential development, this planning proposal has yet to receive a Gateway determination.

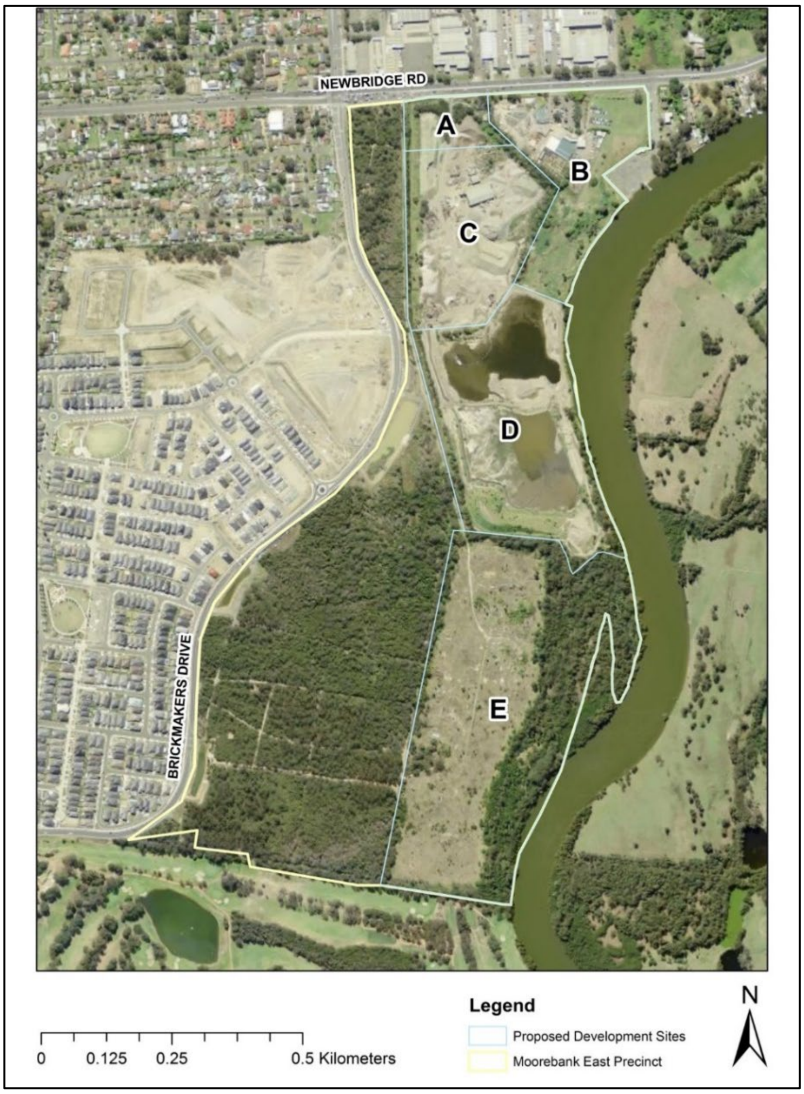


Figure 1. Moorebank East Development Precinct, the scope for the 2019 Molino Stewart report

Since then, additional planning proposals for residential and commercial development on the floodplain have been submitted to Council. While sheltering in place (SIP) above the reach of the Probable Maximum Flood (PMF) level may be physically possible on some of these sites if evacuation from these properties is not achievable, the NSW State Emergency Service (SES) has advised that SIP is not an appropriate primary flood emergency response for new developments. An important consideration in this advice from the NSW SES is that in the most extreme floods most sites on the floodplain can be isolated by hazardous flood waters for nearly two days. This means the developments must allow for vehicular evacuation ahead of flooding, with pedestrian evacuation being an essential secondary response should vehicular evacuation fail for any reason.

Application of the NSW SES Timeline Evacuation Model in the Molino Stewart 2019 study showed that there is sufficient time to evacuate all of the proposed residential and non-residential vehicles in the Moorebank East precinct onto Brickmakers Drive. However, where traffic converges onto a single lane at the intersection of Brickmakers Drive and Nuwarra Road, there is insufficient road capacity for timely evacuation. Therefore, for evacuation to be possible, either Nuwarra Road would need to be widened or the number of evacuating vehicles would need to be reduced. The study also recognised that accounting for the evacuation of existing development in Moorebank and Chipping Norton along with the proposed developments would further constrain the development capacity of the Moorebank East Precinct.

However, it was beyond the scope of that report to assess the constraints which may be imposed by the evacuation of existing development in Moorebank and Chipping Norton, which may take up some, or all, of the local road capacity. Additionally, Liverpool has been flagged as a centre for future growth under the Greater Sydney Commission's Collaboration Area Place Strategy, which aims to find opportunities for growth including housing developments within the collaboration area.

According to the Greater Sydney Commission (2018), the population of the Western Sydney Region is set to grow from 740,000 in 2016 to 1.1 M by 2036, and to over 1.5 M by 2056. The majority of this growth is projected to occur around the existing hub of Liverpool, which has established transportation, residential areas, employment opportunities and educational centres. While significant growth is anticipated for the area, flooding has been identified as a major constraint to achieving the vision of the Strategy, which has identified the need to "prepare floodplain constraint categorisation study and a flood evacuation study" as per action no. 24 of the Strategy.

Accordingly, Council commissioned Molino Stewart to investigate flood evacuation challenges for both the Moorebank Peninsula and the Liverpool Collaboration Area.

1.2 Study Area

1.2.1 Moorebank Peninsula

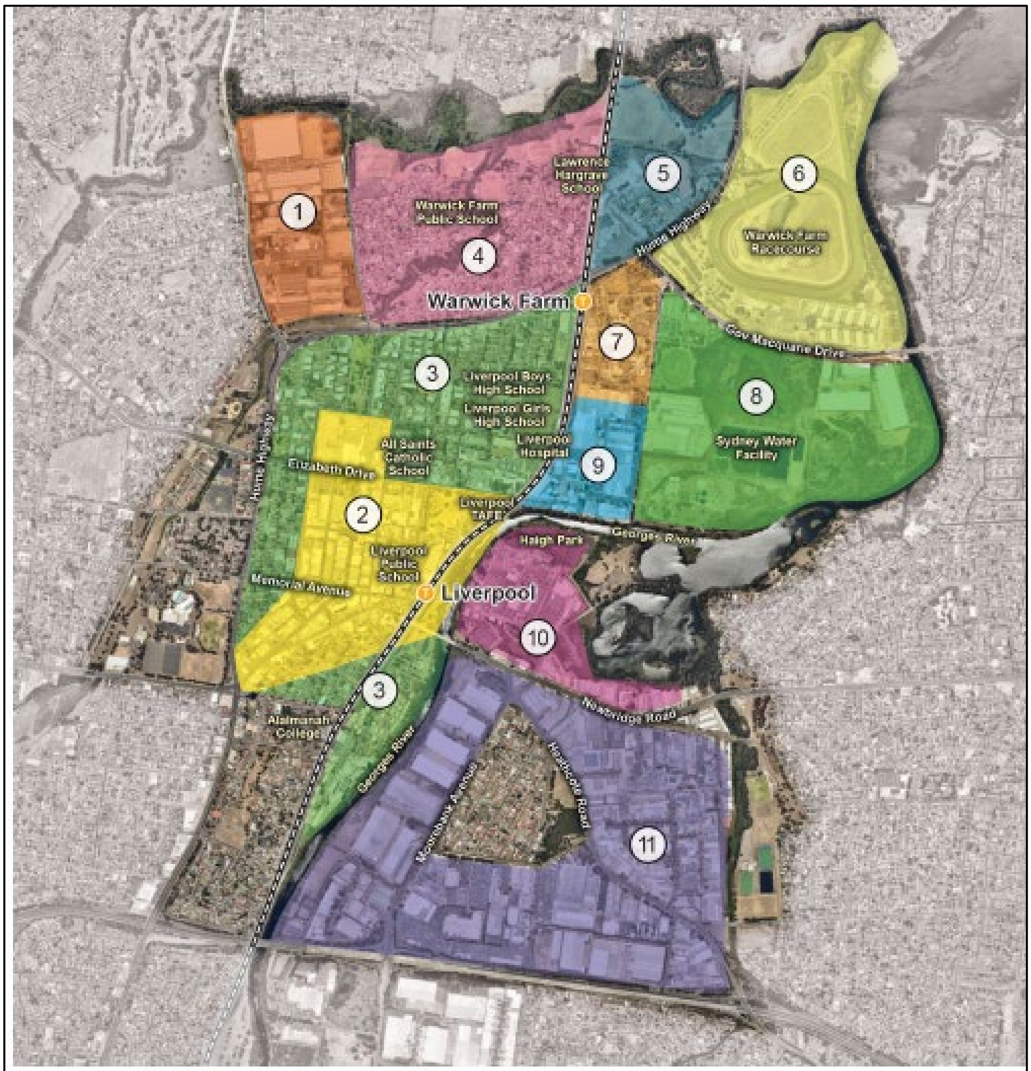
The Moorebank Peninsula encompasses the suburbs of Chipping Norton and Moorebank. The Georges River bounds the peninsula from the west to the east, and Anzac Creek flows into the Georges River through the southwest of this area. This area includes the Moorebank East Precinct (Figure 1), which sits south of Newbridge Road between Brickmakers Drive and the Georges River. The Precinct is flagged for potential development and divided up into five sites, which are referred to as:

- Site A – Benedict Sands
- Site B – Flower Power
- Site C – Moorebank Cove
- Site D –Georges Cove Marina
- Site E – EQ Riverside

1.2.2 Liverpool Collaboration Area

The Liverpool Collaboration Area was co-designed by the Greater Sydney Commission and the Liverpool Collaboration Area Stakeholder Group and was approved in 2018. The extent of the Liverpool Collaboration Area is shown in Figure 2 and encompasses the area between Cabramatta Creek and the Georges River, as well as a section of the Moorebank Peninsula between the Georges River and Anzac Creek. It includes the Liverpool CBD, the health and education precinct, the Warwick Farm precinct, and nearby residential and industrial lands. It therefore partially overlaps with the above study area for the Moorebank Peninsula.

As the Moorebank Peninsula will be evacuating at the same time as the Liverpool Collaboration Area, it is necessary to cover the extents of both areas within a single evacuation model. The combined area is shown in Figure 3 along with the PMF extent of the Georges River, Cabramatta Creek and Anzac Creek which must all be taken into consideration in the evacuation modelling.



1	Orange Grove Road	5	Sapho Road	9	Scrivener Street
2	Liverpool City Centre – Core	6	Equine Precinct	10	Georges River North
3	Liverpool City Centre – Frame	7	Munday Street	11	Georges River South
4	Hargrave Park	8	Eco/ Utility		

Figure 2. Extent of the Liverpool Collaboration Area

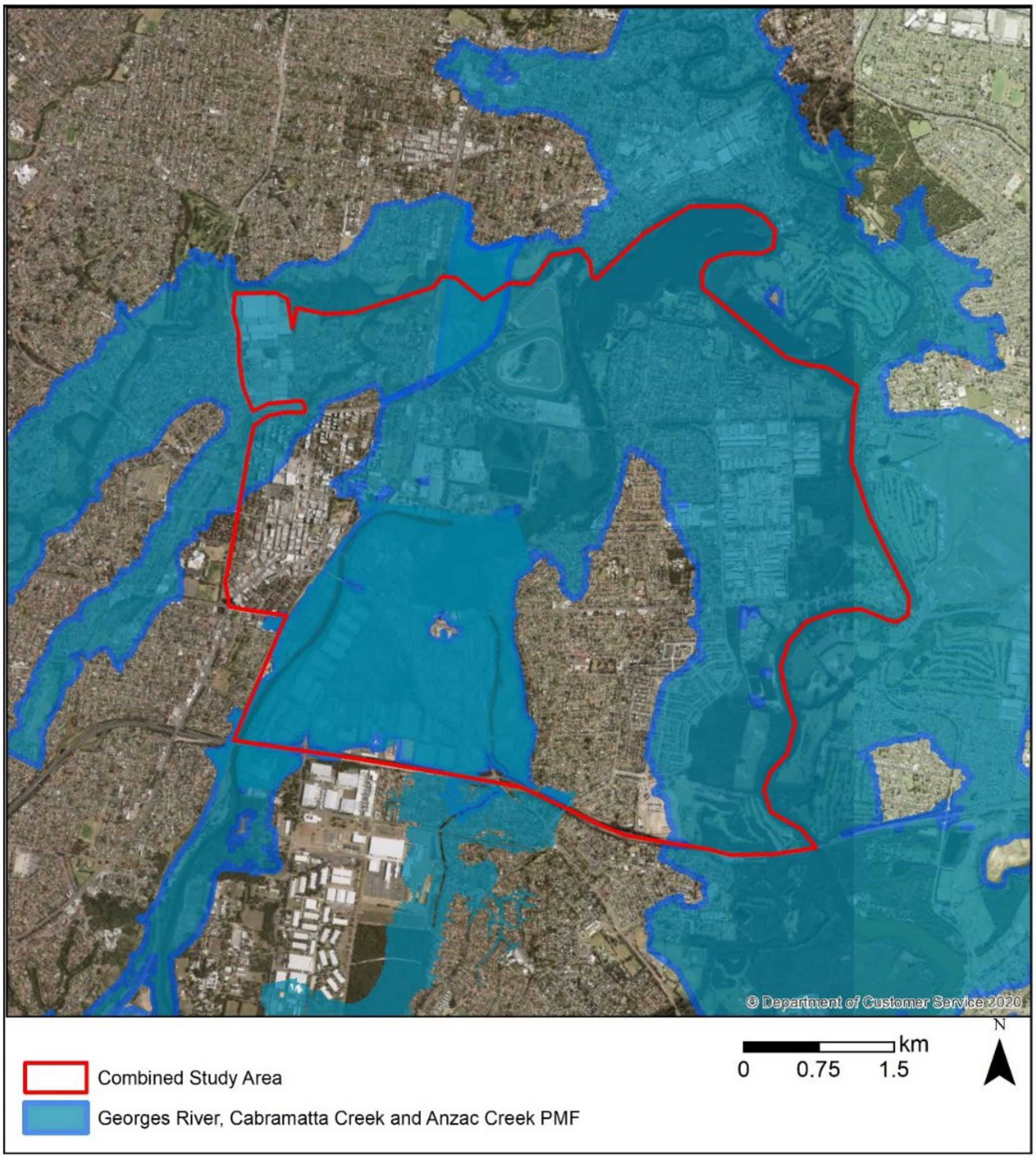


Figure 3. Extent of the combined study area

1.2.3 Extended Study Area

While Figure 3 shows the extent of the primary study area for evacuation modelling, an extended study area was also identified which takes into account additional areas which may need to evacuate at the same time. The extended area includes:

- Areas affected by the modelled Probable Maximum Flood (PMF) from the Georges River which are outside of the primary study area but which will share evacuation routes with the primary study area and contribute to traffic congestion.
- Areas flooded by nearby creeks which are likely to be experiencing some degree of flooding when the Georges River is flooding but are unlikely to receive flood warnings or evacuation orders. While not the focus of this study, these additional areas may place additional loads on the road network if people undertake self-directed evacuation to escape rising flood waters and were included for potential sensitivity analysis to

understand the possible impact of simultaneous flooding of the Georges River and the local creeks.

Figure 4 shows the extent of the extended study area that is affected by the PMFs from the Georges River, Cabramatta Creek Brickmakers Creek, or Anzac Creek and that will need to utilise the same regional evacuation routes when flooding. Therefore, some of the areas are affected only by creek flooding, some only by the Georges River and some by the creeks and the Georges River.

The suburbs within the entire modelled area include Liverpool, Chipping Norton, Moorebank, Hammondville, Voyager Point, Casula, Prestons, Lurnea, Cartwright, Wattle Grove, and Holsworthy.

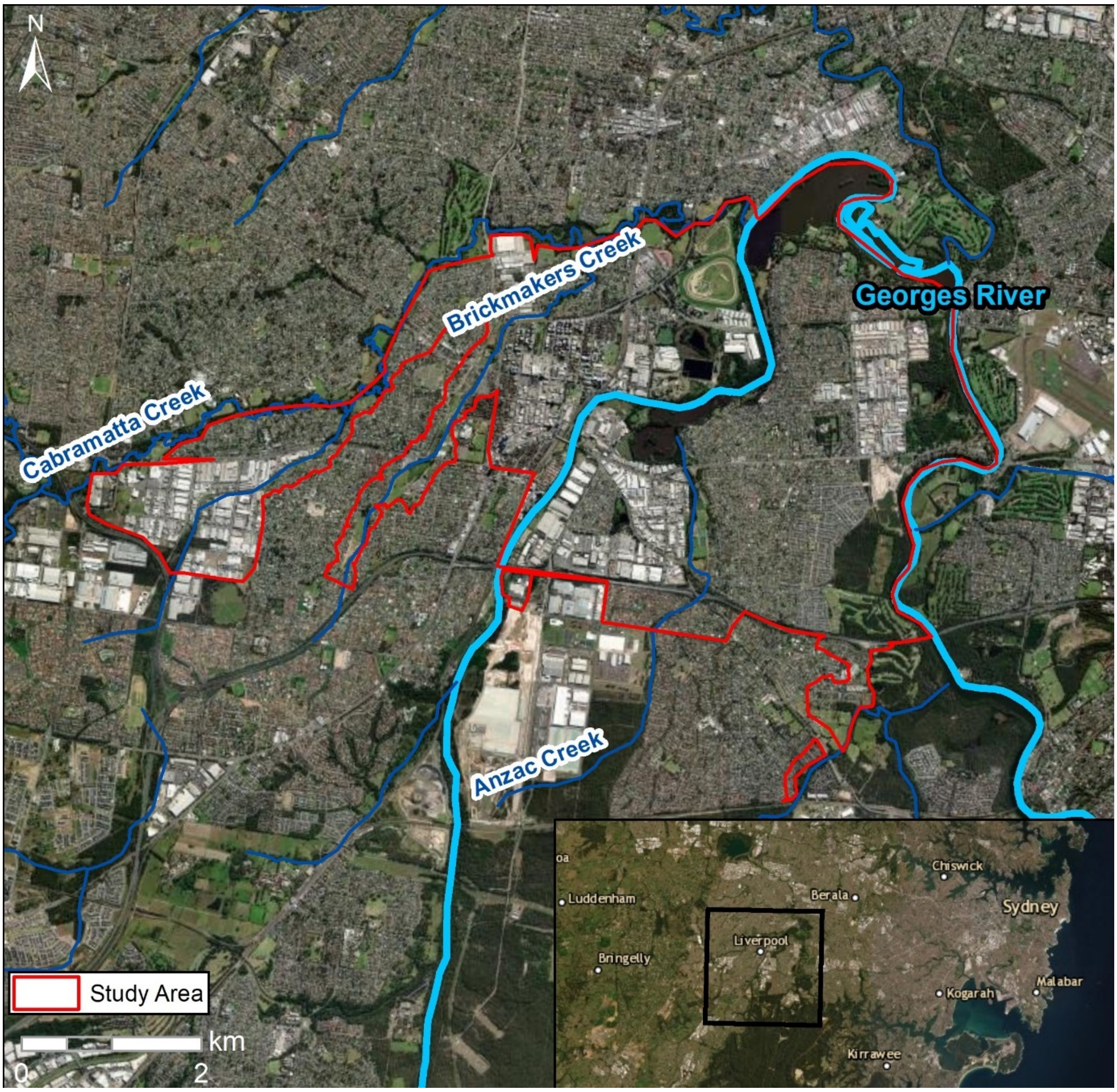


Figure 4. Study area

1.3 Scope of Work

This report is a single comprehensive document describing the study context, the model construction, assumptions, inputs and outputs and a discussion of the results. The primary components covered in this report are:

- Urban Development Context
- Local Flooding Context
- Emergency Planning Context
- Life Safety Model Inputs and Outputs
- Implications for Evacuation Planning
- Conclusions and Recommendations

1.4 Modelled Scenarios

Over the course of this study, multiple Georges River flood evacuation scenarios were defined and modelled to demonstrate how various assumptions will alter the evacuation process. The following scenarios are discussed and presented in this report:

- **Scenario 1** is the base case scenario based on 2016 Census (ABS, 2016) population and vehicle data and 2011 Journey to Work (Transport for NSW, 2011) data[2]
- **Scenario 2** is a future scenario with intensified development under existing zoning, accounting for residential and non-residential infill and planned road upgrades
- **Scenario 3** is a future scenario with rezoning and development from planning proposals currently under investigation, as advised by Council
- **Scenario A** is Scenario 2 with multiple non-residential vehicle evacuation destinations depending on the origin of the workers
- **Scenario B** is a modified Scenario 3 with updated planning proposals, adjusted vehicle yields for new development, changes to roads and capacities, and multiple non-residential vehicle evacuation destinations.

These are summarised in Table 1.

[2] The 2011 Journey to Work data was used since more recent 2016 Journey to Work data with the associated spatial data is not publicly available.

Table 1. Summary of modelled scenarios

	Scenario 1: Base case[1]	Scenario 2: Intensified development under existing zoning[2]	Scenario 3: Proposals currently under investigation[3]	Scenario A: Modified Scenario 2[4]	Scenario B: Modified Scenario 3[5]
Description	The "present" or current status scenario	Residential and non-residential infill development under existing zonings and currently planned road capacity upgrades	Residential and non-residential infill development under existing zonings plus development associated with planning proposals currently under investigation and currently planned road capacity upgrades	Scenario 2 but with four non-residential vehicle destinations depending on the origin of the workers	Scenario 3 with updated planning proposals, adjusted vehicle yields for new development, changes to roads and capacities, and multiple non-residential vehicle evacuation destinations as per Scenario A
Timing	2016	2036	>20 years in future	2036	>20 years in future
Destinations	M7 northbound (single destination)	M7 northbound (single destination)	M7 northbound (single destination)	M7 northbound for all residential. Four non-residential destinations depending on origin of workers: 1) M7 northbound; 2) Hume Motorway southbound; 3) Camden Valley Way westbound and 4) M5 eastbound	M7 northbound for all residential. Four non-residential destinations depending on origin of workers: 1) M7 northbound; 2) Hume Motorway southbound; 3) Camden Valley Way westbound and 4) M5 eastbound
Road Capacity	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour	600 vehicles/ lane/ hour except for the two on ramps from the Hume Highway and M5 onto the M7 will have their capacity increased to 900 vehicles/ lane/ hour
Road Network	As current	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound	Additional planned road upgrades to Governor Macquarie Drive and M5 westbound, and additional third lane northbound on the M7 and improvements to M7 on ramp capacities through ramp metering
Dwelling Numbers[6]	Based on 2016 census data and Google Maps visual assessment: ~8,500 dwellings or ~27,000 people in evacuation study area	Additional dwellings based on existing zoning-dependent infill potential in Warwick Farm, Chipping Norton and Moorebank as estimated by Council (370 additional dwellings compared to Scenario 1)	Additional dwellings based on existing zoning-dependent infill potential in Warwick Farm, Chipping Norton and Moorebank as estimated by Council plus additional dwellings as per original Planning Proposal numbers from Council (21,765 additional dwellings compared to Scenario 2)	Same as Scenario 2	Modified dwelling numbers compared to Scenario 3, as per updated Planning Proposals numbers from Council
Vehicles per Dwelling	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate	Based on 2016 census vehicle ownership rate but with a rate of one vehicle per dwelling for new apartments
Non-Residential Vehicles	Based on 2011 Journey to Work data for vehicle drivers commuting from outside of the study area (no double counting of those both living and working in the study area)	As per Scenario 1 with additional vehicles added to Liverpool Hospital location only (discounted to include only vehicle drivers originating from outside of the study area)	As per Scenario 2 with additional vehicles associated with additional jobs from original Planning Proposals numbers from Council (discounted to include only vehicle drivers originating from outside of the study area)	Same as Scenario 2	Modified commercial development areas and associated vehicle numbers compared to Scenario 3, as per updated Planning Proposals numbers from Council
Vehicles[6]	Base case: ~27,500 total	1,541 additional evacuating vehicles compared to Scenario 1	61,671 additional evacuating vehicles compared to Scenario 2	1,541 additional evacuating vehicles compared to Scenario 1	40,097 additional evacuating vehicles compared to Scenario 2, minus existing development in the locations of new development.

1-See Section 5.5.1 for details ; 2-See Section 5.5.2 for details; 3-See Section 5.5.3 for details; 4-See Section 5.5.4 for details; 5-See Section 5.5.5 for details; 6-Excluding creek-only impacted subareas I10, R21 and R22

2 | Urban Development Context

2.1 Existing Land Uses

2.1.1 Existing Development

The study area currently encompasses a range of land use zonings according to the Liverpool Local Environmental Plan (LEP) 2008 (Figure 5). The lands directly adjacent to the Georges River and creeks in the study area are generally zoned as open space for private or public recreation, as these flood prone lands are unsuitable for habitable buildings. The majority of the study area is zoned as either residential or industrial. The equestrian precinct of Warwick Farm is also included in this study area. These three generalised zones are shown in Figure 6.

There are 15 major industrial subareas, including in the east of Chipping Norton, west Moorebank, Liverpool CBD, Warwick Farm, and Prestons. There are 27 residential subareas, which are located along the Georges River in Chipping Norton, Moorebank, and Hammondville; along the Anzac Creek in Moorebank and Wattle Grove; and along Cabramatta Creek and Brickmakers Creek in Casula, Lurnea, Cartwright, and Liverpool. There are scattered business zonings such as local shops across these generalised zones.

There is a strip of properties along Newbridge Road in the east of Moorebank along the Georges River which have long had houses on them but due to their flood risk are subject to a voluntary purchase scheme by Council (the Moorebank Voluntary Acquisition Scheme), which is currently operational. As houses are acquired by Council in this area the land is rezoned from residential to recreational.

Under the LEP, residential lots are zoned as either R1 General Residential, R2 Low Density Residential, R3 Medium Density Residential, or R4 High Density Residential. Based on these current categories, different numbers of residential dwellings are allowed on each lot without any change to zoning. This means that there is potential for densification of residential dwellings within the study area without any amendments to the LEP and current zoning. A summary of the zones is as follows:

- **R1 General Residential:** There is only one area with this zoning in the study area, which is in Moorebank and is filled with recently constructed dwellings.
- **R2 Low Density Residential:** Over half of the residential lots in the study area, or approximately 4,500 lots, fall under R2 zoning. There is currently an average of 1.11 dwellings per lot as of the 2016 census.
- **R3 Medium Density Residential:** There are 17 R3 zones within the study area, which contain over 2,300 lots with a current average density of 1.29 dwellings per lot as of the 2016 census.
- **R4 High Density Residential:** There are 12 R4 zones within the study area, within which almost one third of the dwellings in the study area are located. There is currently an average density of 4.65 dwellings per lot as of the 2016 census. There is currently a maximum of 144 dwellings on a single lot, as well as a large number with only one dwelling per lot.

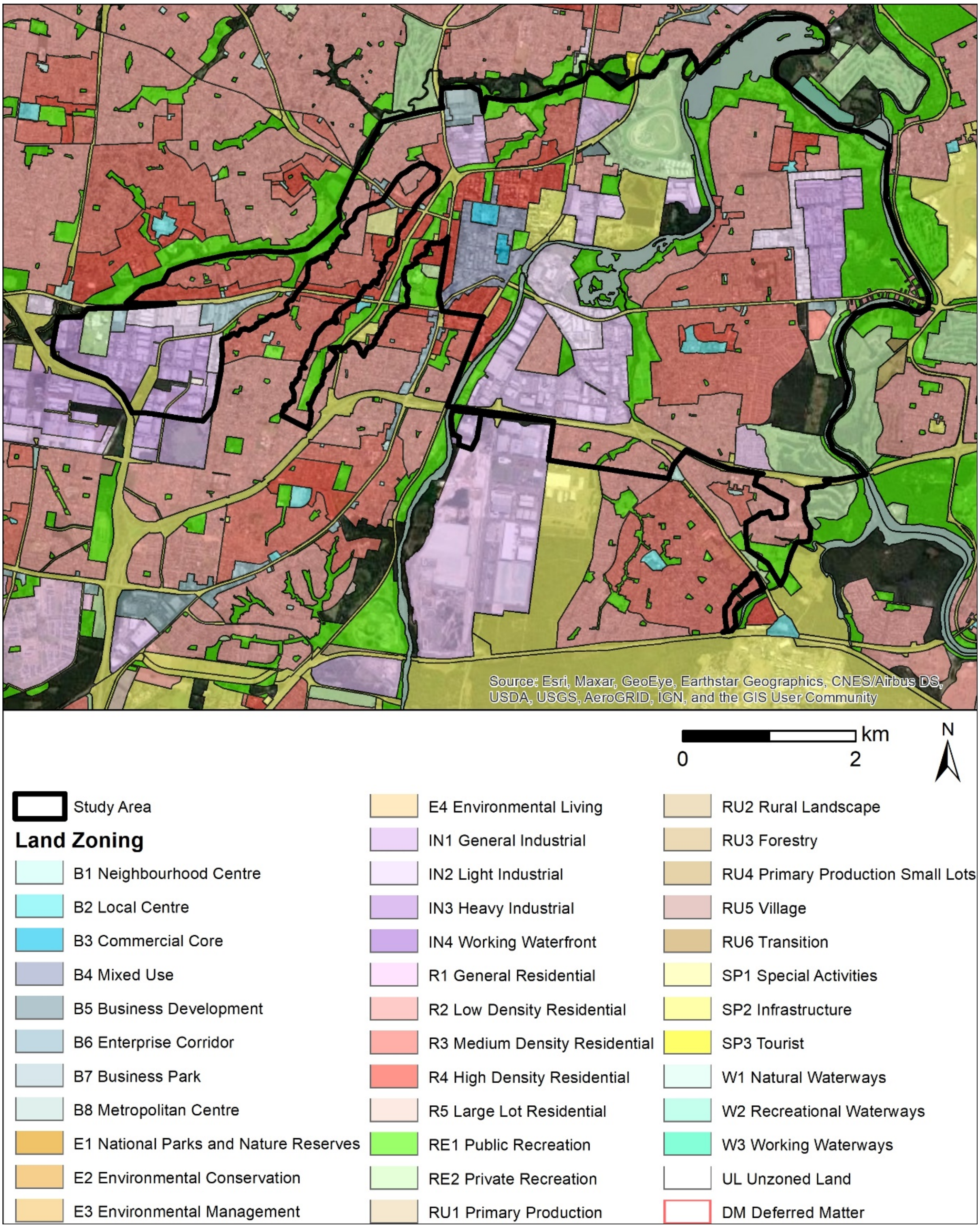


Figure 5. Liverpool City Council land use planning in the extended study area

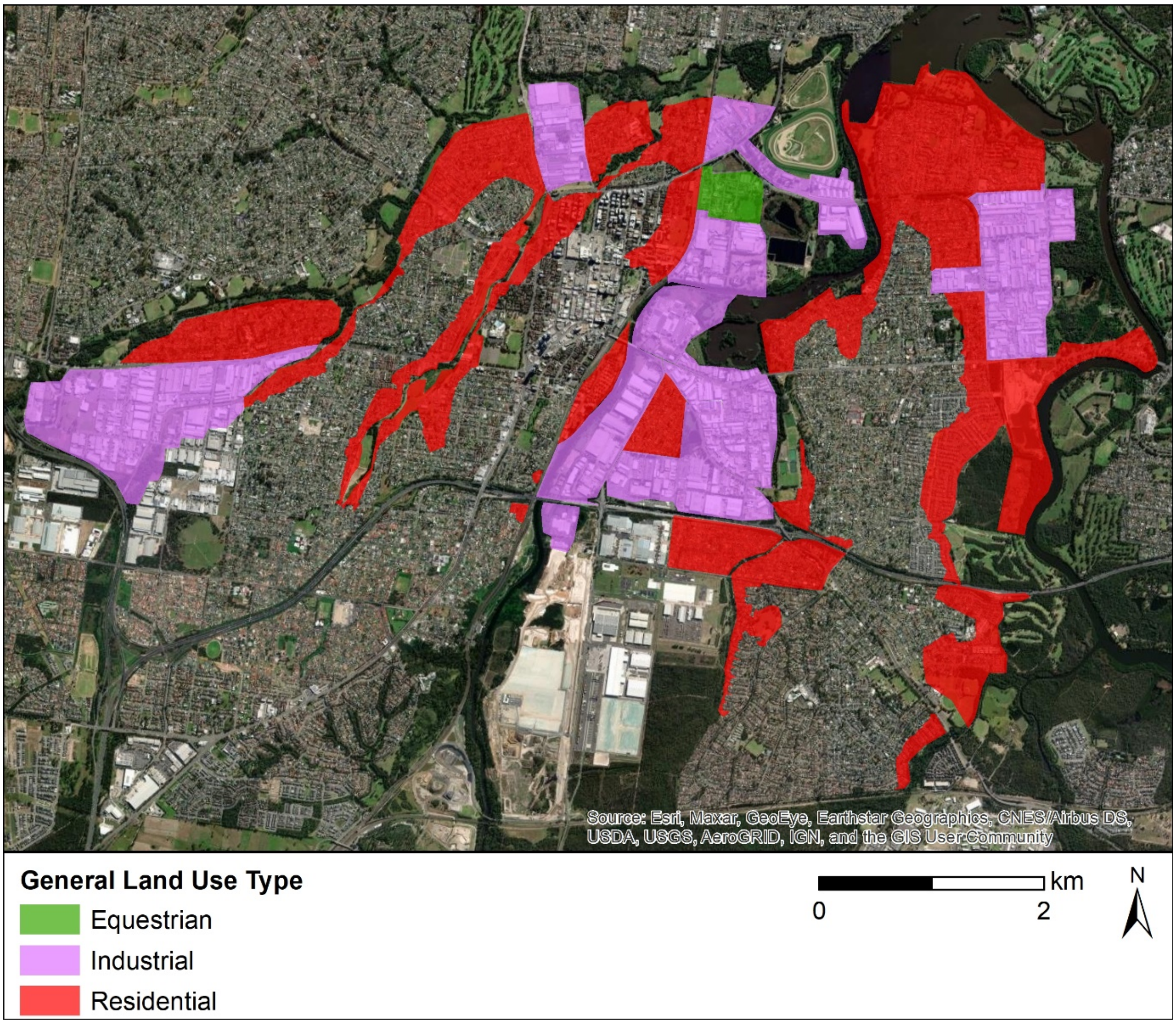


Figure 6. General land use type by evacuation subareas in the extended study area

2.1.2 Residential Infill Development Potential

Without any rezoning, there is the potential for the residential density to increase within the study area. There may be potential for infill, redevelopment and intensification to take place within R2, R3 and R4 residential zones. This can range from replacing small houses with larger houses with more people and more cars, adding granny flats to existing dwellings, replacing single dwellings with duplexes, building townhouse developments and erecting residential apartment buildings. The potential for lots to increase their number of dwellings depends on their zoning and size, as well as a number of other factors specified in Liverpool's Development Control Plans. Therefore, not every lot meeting the zoning and size requirement would be able to increase its number of dwellings, but there is potential for more dwellings than currently present in these areas.

Evacuation modelling scenarios have accounted for assumptions regarding future infill under existing zoning, as explained in Section 5.5.2. This includes assumptions regarding how much infill development and intensification is likely to take place in R1, R2, R3 and R4 zoned areas over the next 20 years.

2.2 Planning and Development Proposals

Liverpool is a rapidly growing local government area (LGA), experiencing substantial growth through both urban release areas and redevelopment of existing areas. Both Liverpool City Council and the NSW Government are involved in the planning of several major land release areas in the LGA, including the South West Priority Growth Area, the Western Sydney Employment Area, and the Western Sydney Aerotropolis. While not all impacting the specific study area of this assessment, it is evident that Liverpool LGA is rapidly growing as a southwest Greater Sydney Central Business District. Development proposals relevant to the study area are discussed below, and specific assumptions integrated into evacuation modelling are discussed in Section 5.5.3.

2.2.1 Moorebank East

As discussed in Section 1.1, the Moorebank East Precinct is flagged for potential development within the five sites shown in Figure 1. Table 2 summarises the current data for each development or planning proposal, as provided by Council in 2021.

Table 2. Proposed Moorebank East Developments

Site	Development Type	Commercial Space (ha)	Employees	Dwellings	
				Houses	Apartments
Site A: Benedict Sands	Mixed use	0.89	857	0	126
Site B: Flower Power	Mixed use and commercial strip	2.32	361	0	602
Site C: Moorebank Cove	Low density residential	0	N/A	179	0
Site D: Georges Cove Marina	Apartments	0	N/A*	21	374
Site E: EQ Riverside	Apartments and commercial/ retail	0.18	207	0	1,500

**there are an estimated 45 employees under Site D's existing deferred commencement consent for a Marina, however the modelling considered the residential planning proposal for the site.*

2.2.2 Liverpool Collaboration Area

The Liverpool Collaboration Area is an action in the Greater Sydney Regional Plan and is one of the locations identified as a place of metropolitan significance with potential to grow into a larger centre. The Liverpool Collaboration Area Place Strategy was developed between 2017 and 2018 by the Greater Sydney Commission and the Liverpool Collaboration Stakeholder Group. The vision of the strategy is that, by 2036, Liverpool is a rejuvenated city with diverse and growing residential and employment opportunities. It aims to have major health, education and retail precincts along with open spaces and parklands along the Georges River bringing employees, residents and recreational users to Liverpool.

Part of its mission will be to service the new Western Sydney International Airport through upgraded public transport. A key goal for the area is to improve public spaces, including connections to the Georges River. The four immediate imperatives from the Liverpool Place Strategy (Greater Sydney Commission, 2018) are to:

1. *Develop an integrated transport strategy that applies movement and place and addresses the transport challenges associated with delivering the vision, shared objectives and growth profile (led by Transport for NSW/Roads and Maritime Services).*
2. *Update and complete the Georges River, Brickmakers Creek and Liverpool CBD Overland Flood Studies and prepare floodplain risk management plans.*
3. *Prepare a floodplain constraints categorisation study (led by Liverpool City Council) and a flood evacuation study (led by State Emergency Service).*
4. *Establish an enduring Collaboration Area Partnership that facilitates the implementation of stakeholder actions and builds on existing governance structures (led by Liverpool City Council and the Greater Sydney Commission).*

With flooding recognised as a major factor that could potentially limit growth in the area, the flood studies and floodplain risk management plan have already been completed by Liverpool City Council. The Floodplain Constraints Categorisation Study has also been completed (FloodMit, 2020) but due to resource constraints the NSW SES was not able to commence the flood evacuation study. To expedite this aspect Liverpool City Council commissioned Molino Stewart to undertake the flood evacuation study.

The Liverpool Place Strategy states that one challenge is that market interest in new residential development significantly exceeds the NSW Government forecasts. Planning proposals have been assessed by Liverpool City Council that equate to more than 30,000 dwellings, compared to the 2036 Government forecast of 7,800 dwellings. The Collaboration Area aims to provide a mix of housing densities, including affordable housing and high-density housing close to public transport.

As shown in Figure 2, there are 11 places that make up the Liverpool Collaboration Areas, which are:

- **Orange Grove Road:** an employment precinct outside Liverpool City Centre;
- **Liverpool City Centre – Core:** Liverpool's primary commercial centre for Liverpool, including a mixed use central business district with commercial offices, retail, government services, educational services, and residential apartments;
- **Liverpool City Centre – Frame:** a mixed-use area including the Liverpool Hospital, educational centres, and high-density residential dwellings;
- **Hargrave Park:** a low-density residential area with a large proportion of Land and Housing Corporation dwellings and some educational services;
- **Sappho Road:** an urban employment precinct;
- **Equine Precinct:** the Australian Turf Club racecourse and the Inglis Hotel;
- **Munday Street:** predominantly low-density residential development with horse stables;
- **Eco/Utility:** the Sydney Water Liverpool Water Recycling Facility;
- **Scrivener Street**: industrial precinct with some hospital facilities and offices;
- **Georges River North:** industrial precinct;
- **Georges River South:** predominantly industrial precinct surrounding a low-density residential neighbourhood.

Stakeholders have assessed potential growth profiles prepared by Liverpool City Council meant to guide a coordinated response to development. The preferred "Metropolitan City" growth profile anticipates that the Collaboration Area could potentially host up to 16,200 new jobs, have capacity for up to 18,800 new dwellings by 2036, and host up to 15,000 tertiary students.

As discussed in the FloodMit (2020) study, recent planning proposals assessed by council equate to more than 30,000 new dwellings, including high density residential development proposed within:

- Liverpool City Centre Frame;
- Hargrave Park Area;
- Munday Street Area;

- Georges River North Area; and
- Georges River South Area.

This includes the area covered by the Warwick Farm Structure Plan and Moore Point Planning Proposal, which both aim to contribute significant residential and non-residential precincts to the area. Table 3 shows the proposed development yields for significant developments planned in the Collaboration Area.

Table 3. Liverpool Collaboration Area development yields

Site	Additional Dwellings	Additional Jobs
Moore Point (JLG) in Moorebank	12,200	16,648
Moore Point (Rose Group) in Moorebank	1,854	6,352
The Grove in Warwick Farm	--	600
Warwick Farm Structure Plan including 240 Gov Macquarie Drive	3,224	925
33 Shepherd Street, Liverpool*	1,200	--

**This Planning Proposal is already gazetted with some developments approved and constructed and others pending approval.*

2.2.3 Liverpool Hospital

Liverpool Hospital is undergoing a planned expansion which is due for completion by 2026. This includes the construction of the Liverpool Health and Academic Precinct with a new education and research hub. The redevelopment will include additional clinical services and public spaces. The recently approved concept plan included provision for an additional approximately 900 car parking spaces across the hospital campus, including a multi-storey car park, amounting to a total of 2,400 spaces.

2.2.4 Floodplain Constraints

While there is significant growth projected for the study area, flooding has been identified as a constraint on the development potential for the area. Liverpool City Council commissioned FloodMit (2020) to prepare a study considering the flood constraints that apply to the Liverpool Collaboration Area Place Strategy. This study looks at how the following legislative and flood policy requirements may have an impact on planning proposals and future development in the area:

- Directions by the Minister (formerly Section 117 Directions);
- NSW Floodplain Development Manual;
- Floodplain Management Studies and Plans;
- Liverpool LEP 2008;
- Liverpool DCP 2008.

A summary of the regional flood constraints that apply to the study area are outlined in Table 4 as set out in the FloodMit report.

Table 4. Regional Flood Constraints for the Liverpool Collaboration Area (based on FloodMit, 2020)

Constraints	Details
Flood Planning Area (FPA)	This is the area within which developments may be subject to flood related development controls. Approximately 56% of the Liverpool Collaboration Area is included in the Flood Planning Area.
Flood Planning Level (FPL)	This is a level used to set flood planning controls. It is calculated from a designated flood event plus an allowance for freeboard. It is the height used to set floor levels for property development in flood prone areas. In Liverpool LGA the FPL for habitable floor levels in residential, commercial and industrial properties affected by riverine flooding is the 1% AEP flood level plus 0.5m freeboard.
Flood Risk Management Areas	Approximately 20% of the Liverpool Collaboration Area is within High Flood Risk areas, which are subject to significant development restrictions.
Floodway Area	There are floodways in the Georges River and Cabramatta Creek that need to be kept clear of all development.
Riparian Corridors	A riparian corridor is required to act as a buffer between the area's waterway banks and future development.
Vulnerable Development	Vulnerable existing development has been identified throughout the study area, and future development must not exacerbate the existing flood problems.
Potential Climate Change Impacts	The climate change impacts of sea-level rise and increased rainfall intensities need to be considered, although not expected to have a large impact compared to the presently adopted models.
Emergency Management and Evacuation Considerations	The availability of suitable evacuation routes must be assessed considering both the existing and future population of the area.
Controls on Future Development	Future development in land below the flood planning area will be restricted by controls such as those relating to minimum floor levels, building components, structural stability, car parking, driveway access, evacuation and others.
On-Site Detention (OSD) and Water Harvesting	OSD in the Liverpool Collaboration Area is not likely to be effective, and runoff retention for all new development is likely to be a more appropriate response.

Some specific flood risks for the following areas were examined in the report (Figure 7):

- **Orange Grove Road Place Area** which is affected by both Cabramatta Creek and Brickmakers Creek;
- **Shepherd Street/Riverpark Drive** in Liverpool City Centre, where the only site access is via a railway underpass at Shepherd Street that is inundated in a 20 year flood, prior to flooding of the homes in this area;
- **Hargrave Park Place Area**, where 56% of the area is below the residential flood planning level;
- **Sappho Road Place Area**, which is approximately 82% below the residential flood planning level, and consideration of flood free access is needed for future development;
- **Equine Precinct Place Area**, which is approximately 78% below the residential flood planning level, with considerable high flood risk areas in the north of the site and potential issues surrounding flood free site access;
- **Munday Street Place Area**, which is entirely below the residential flood planning level, is within a flood storage area, and has low spots on local road restricting flood free access;
- **Scrivener Street Place Area**, which has a limited evacuation route across the railway bridge towards the Liverpool CBD;

- **Georges River North Place Area**, which is 92% below the residential flood planning level, has areas of vulnerable development including along Newbridge Road, and requires considerations of flood free site access;
- **Georges River South Place Area**, which is 70% below the flood planning level, at risk in flood greater than a 1% AEP flood, and contains industrial and residential areas vulnerable to flooding.

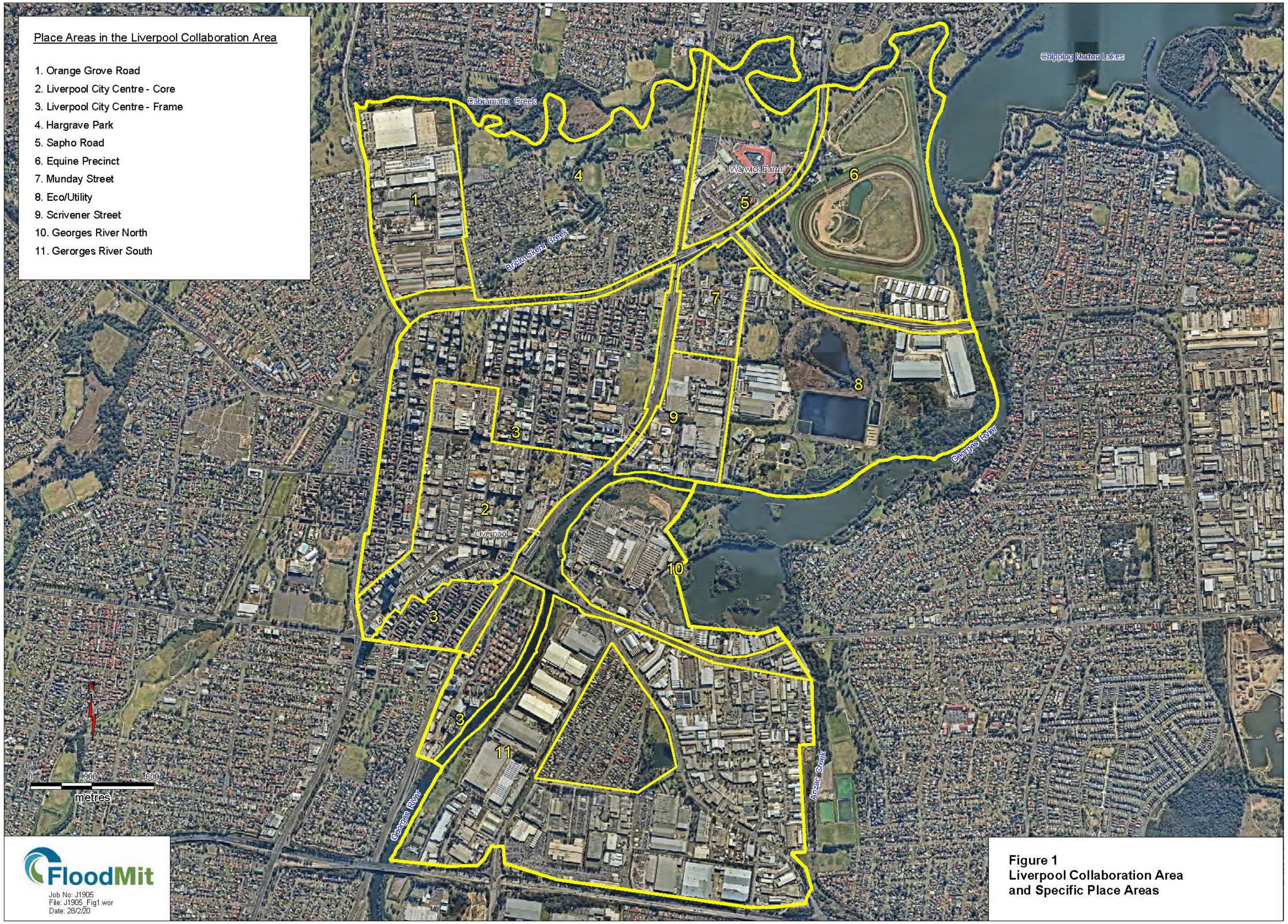


Figure 7. Liverpool Collaboration Place Areas from the Floodplain Constraints Study (FloodMit, 2020)

3 | Local Flooding Context

3.1 Topography and Drainage

The Georges River has a catchment area of 960 km^2 and is heavily urbanised in its northern half and in a natural state in its southern half with some rural residential areas in its western parts which are gradually being urbanised as Sydney expands. The major tributaries for the middle reaches of the Georges River, relevant to the study area, include:

- Anzac Creek – which flows from the site of the Moorebank Intermodal Terminal south west of Wattle Grove and runs under the M5 and flows north through the western part of the study area before joining the river at Lake Moore;
- Cabramatta Creek – which drains western parts of the catchment and flows into the upstream end of the Chipping Norton Lake on the Georges River to the north of the study area;
- Brickmakers Creek – which is a major tributary of Cabramatta Creek and runs roughly parallel to Cabramatta Creek and the Georges River flowing north east between the two before joining Cabramatta Creek upstream of its confluence with the Georges River
- Prospect Creek – which drains the north western parts of the catchment and has several tributaries before entering the downstream end of Chipping Norton Lake on the Georges River north of the study area;
- Harris Creek – which flows north towards the south western part of the site in Holsworthy, where it meets with Williams Creek and joins the Georges River.

The Georges River wraps through the study area around the Moorebank Peninsula to the east, north and western boundaries. There are low lying floodplains all along most of this reach of the Georges River on both sides of the river. Within Moorebank, there is a ridge that runs north to south roughly along Nuwarra Road. On either side of this there is land which is above the reach of any flooding.

Part of the study area, mostly west of Stockton Avenue in Moorebank, generally flows into Anzac Creek via the local piped drainage network and overland flow paths. Between Stockton Avenue and Nuwarra Road the drainage and overland flow paths generally lead to a major trunk drain and an overland drainage pathway heading north roughly along what would have been the original route of Cunningham Creek, the northern most section of which leads into the Georges River. East of Nuwarra Road and north of Alfred Road there are pipes and some open canals which direct rainfall into the Georges River as well as there being overland flow paths leading directly to the river.

South of Alfred Road in Chipping Norton there is a drainage pathway running south just to the east Governor Macquarie Drive which intercepts piped and overland flows east of Nuwarra Road and directs them into the north-western corner of the Moorebank East Development Precinct. From here stormwater runoff flows south along the eastern side of Brickmakers Drive. Pipes through the developments between Nuwarra Road and Brickmakers Drive also discharge into this drainage swale which then drains east into the Georges River along a drainage pathway in Moorebank East.

In addition to the Georges River, Cabramatta and Brickmakers Creeks influence drainage in the western section of the study area, in the Liverpool Collaboration Area. Cabramatta Creek is a major tributary of the Georges River, with a 74 km^2 catchment (Bewsher, 2004) from the suburb of Denham Court to Liverpool. Brickmakers Creek flows from Casula to meet Cabramatta Creek approximately 1.7 km upstream of where it flows into the Georges River.

3.2 Flood History

There are several river height gauges within the catchment and along the Georges River for which the Bureau of Meteorology reports river levels. Before the establishment of the current gauging system flood levels were recorded at various locations along the river during significant floods. Three points have long records, with one going back to early colonial history. These points correspond to the current gauges operating at:

- Liverpool Weir, south of Newbridge Road between Liverpool and Moorebank;
- Lansdowne Bridge, which sits north of the study area where the Hume Highway crosses Prospect Creek;
- Milperra Bridge which sits where Newbridge Road becomes Milperra Road to the east of the study area.

These give some insight into the history of flooding on the Georges River as seen in Table 5.

Table 5. Historic Flooding Events

Date	Level (m AHD)		
	Liverpool Weir	Lansdowne Bridge	Milperra Bridge
May 1809		8.2	
Apr 1860		7.5	
Feb 1873	10.5	8.0	
Apr 1887	9.2		
May 1889	9.7	7.2	
1892	6.3		
Jan 1895	7.1		
Feb 1898	9.0	5.5	
July 1900	7.3		
Mar 1914	7.4		
1927	6.7		
1943	7.0		
Jun 1949	7.6		
Jun 1950	7.4	5.3	3.5
Feb 1956	8.3	5.7	4.8
Nov 1961	7.1	4.6	3.8
Dec 1962	5.6		
Aug 1963	6.7		3.3
Jun 1964	7.1		3.6
Apr 1967	5.9		
Mar 1978	5.8	3.7	2.9
April 1981	3.8		
Apr 1982			3.0
Aug 1986	7.2	5.1	4.4
Oct 1987	6.0		2.4
Apr 1988	7.4	5.8	4.9
Jul 1988			2.9
Feb 1990	5.1	3.1	2.9
Aug 1990			2.4
Jun 1991	6.6	4.7	3.8
Aug 1996	5.8	2.4	2.0
Feb 2008			2.1
Mar 2012			2.2
Apr 2015			2.8
Feb 2020	5.4	3.6	4.6

Source: George River Floodplain Risk Management Study and Plan (Bewsher, 2004), MHL Historical Gauge Data (1982-2019) and correspondence from the Bureau of Meteorology (2020)

The largest recorded flood occurred in February 1873 and is estimated to be well above the 1% annual exceedance probability (AEP) event (Maruf Hossain pers. comm.). The April 1860, April 1887 and the May 1889 floods were estimated to be similar in magnitude to a 1% (1 in 100) AEP flood (Bewsher Consulting, 2004).

It is noted that there is now a new Milperra gauge just downstream of the bridge which has replaced the gauge located on the bridge. It has a gauge zero of zero metres AHD.

3.3 Flood Behaviour

3.3.1 Georges River

a) Flood Model

Although the NSW Government's guidance is that planning controls for residential development should be based on the 1% AEP flood level plus 0.5 m of freeboard, the NSW Floodplain Development Manual (DIPNR, 2005) requires consideration of the consequences of the full range of floods up to the Probable Maximum Flood (PMF) when assessing the merits of planning and development proposals.

For this work, Liverpool City Council provided outputs of the 2020 Georges River Flood Study 2D TUFLOW hydraulic model (BMT, 2020) which covered the entire study area and some of the Georges River upstream and downstream floodplains. This is the latest flood model available for the Georges River and was jointly developed by Canterbury-Bankstown and Liverpool City Council under the State Floodplain Management Program funded by OEH and councils.

The primary objective of the 2020 Georges River Flood Study was to develop a 2D model and assess flooding behaviour in the local catchment and to identify significant inundation patterns, flow paths and flooding locations within the study area for a range of design flood events up to the Probable Maximum Flood (PMF). Council's objectives are to evaluate the impact of flooding on existing and future developments within the study area and assess floodplain management options in subsequent floodplain management and planning studies. The flood model went through extensive calibration and validation against all historical floods including August 1986, April 1988, April 2015 and June 2016 events.

Output files were provided for the following events:

- 20% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- 0.5% AEP
- 0.2% AEP
- Probable Maximum Flood (PMF)

This model uses LiDAR data to define the existing ground levels throughout the study area. Because it is looking at a large section of the Georges River, a 10 m grid size was used for the flood modelling to make computing run times manageable. The model runs for 50 hours after the commencement of rainfall.

Note that there is an older Georges River Flood Study (Bewsher, 2004) which is a 1D Mike 11 flood model that is adopted by Council. Council uses the adopted flood levels of the MIKE 11 flood model for development controls.

b) Spatial Extension of Georges River Flood Model

The 2020 Georges River 2D TUFLOW hydraulic model (BMT, 2020) extent is truncated where Cabramatta Creek and Harris Creek enter the river. Cabramatta Creek has its own separate TUFLOW model, which is discussed below. However, if these tributaries are not flooding, but the Georges River is, the riverine flooding would extend up these creeks and affect residential areas that would also be required to evacuate. This is important because even though the same rainfall event would cause flooding in all watercourses, the specific spatial and temporal distribution of the rainfall will mean that the timeline of flooding of the tributaries are independent of the flooding of the river.

In order to account for Georges River flooding in the northwest of the study area, the additional area that would be flooded was mapped by extrapolating the flood levels at the Georges River model extent along the contours using the digital elevation model (DEM). This allowed for the identification of additional areas around Cabramatta Creek and Harris Creek that are lower than the Georges River flood levels, and therefore would be inundated during river flooding. This flood extent is shown in Figure 8 for the PMF.

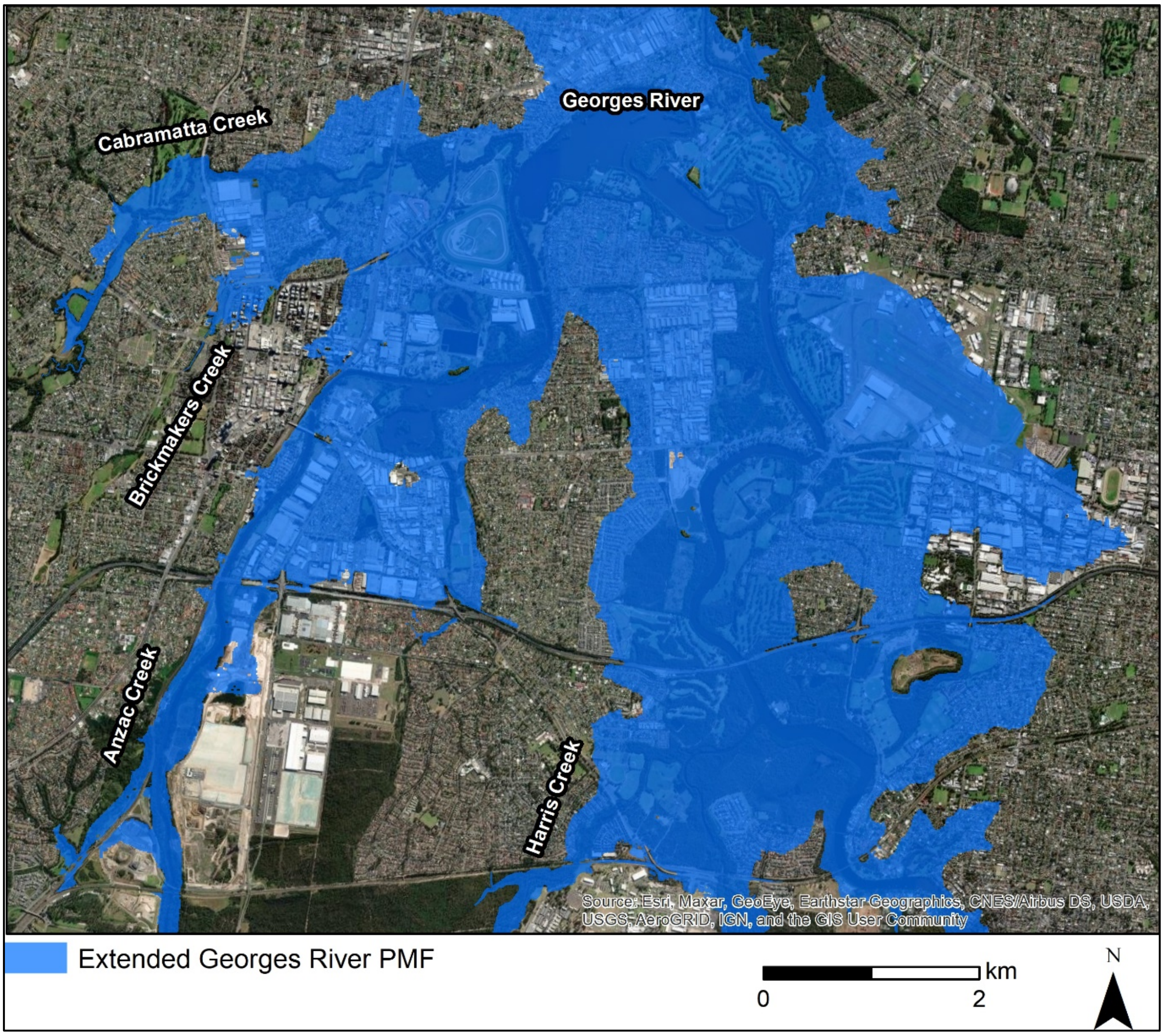


Figure 8. Extent of the Georges River modelled PMF extended up Cabramatta and Harris Creeks

c) Georges River Modelled Flood Levels

Figure 9 shows the modelled Georges River PMF levels across the study area. There is a considerable change in water level across the study area, as the river goes from the Liverpool side of the peninsula to the Milperra side. Flood levels are 12.4 m AHD where the M5 crosses the Georges River to the west of Moorebank. Levels decrease to 11.7 m AHD where the M5 cross the eastern reach of the Georges River by Milperra.

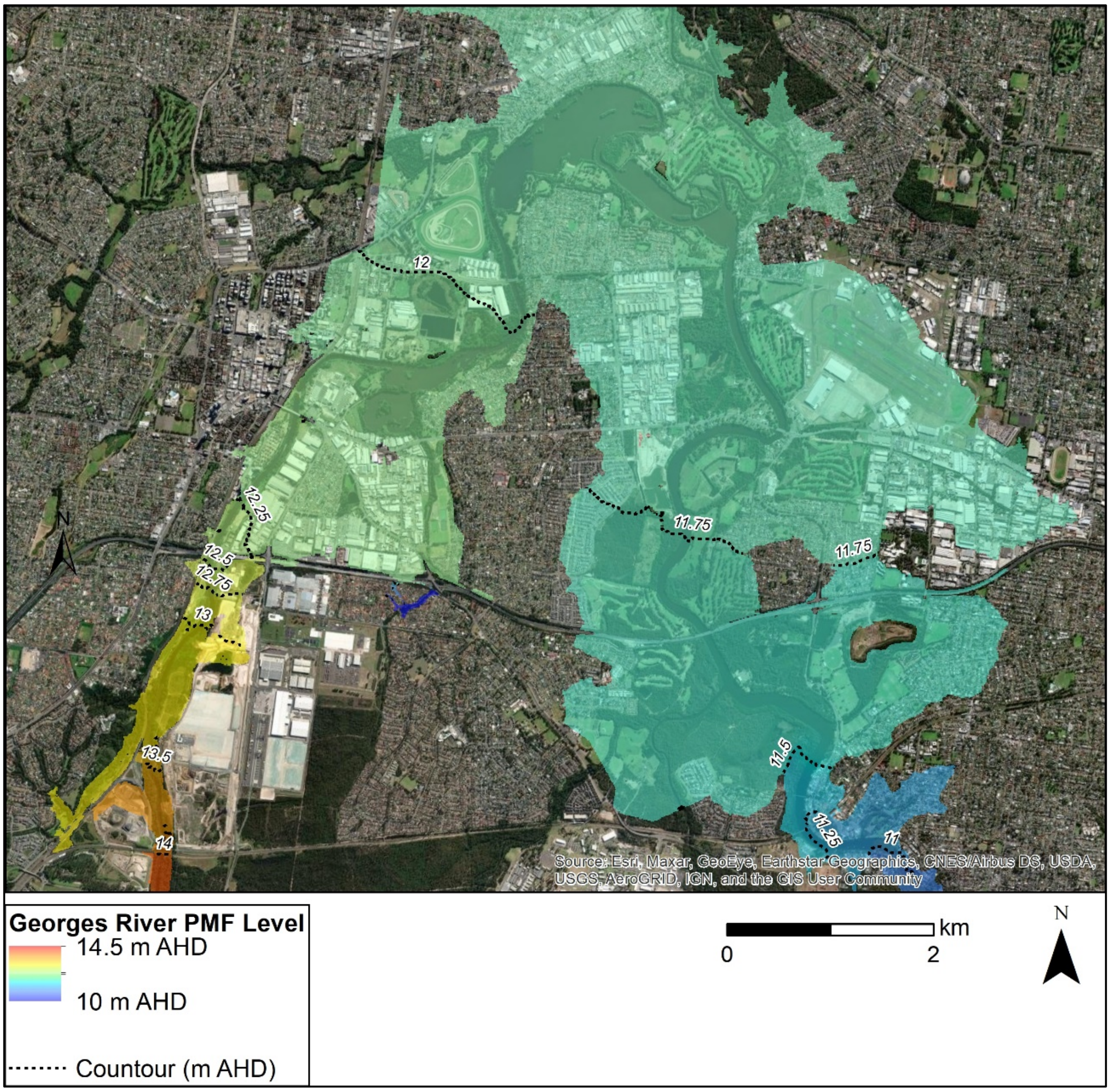


Figure 9. Georges River modelled PMF levels (BMT, 2020)

d) Impacts on road network

Floodwaters from the Georges River can inundate and cut roads within the study area, including:

- The Hume Highway to the north, where it crosses Cabramatta Creek, can flood by backwater from the Georges River up the creek in the Georges River 5% AEP flood.
- Backwater flooding from the Georges River PMF up Cabramatta Creek can also flood the Cumberland Highway/ Orange Grove Road and Elizabeth Drive.
- Governor Macquarie Drive can flood in the vicinity of Warwick Farm Race Course in the 2% AEP flood.
- The western end of Newbridge Road does not flood where it crosses the Georges River to the west, even in the PMF. However, Newbridge Road does flood between the Georges River and Anzac Creek (i.e. by the intersection with Heathcote Road) in events as frequent as the 2% AEP flood making the bridge over the river inaccessible.

- The eastern end of Newbridge Road is cut at multiple points between Governor Macquarie Drive and the Georges River in events as frequent as the 20% AEP flood.
- Junction Road can be cut near its intersection with Heathcote Road in a 5% AEP flood on the Georges River, where backwater flows up Anzac Creek. Flooding can also cut the intersection of Junction Road and Heathcote Road in the Georges River 2% AEP flood.
- East of the bridge over the Georges River the M5 can be cut by flooding in the 0.2% AEP flood in the vicinity of the UWS Campus.
- The M5 can flood in the Georges River PMF west of Heathcote Road as well as where it goes under Moorebank Avenue.

These critical locations are shown in Figure 10.

3.3.2 Anzac Creek

It is important to understand flooding in the study area's creeks as well as the Georges River, as the same rainfall event is likely to cause flooding in both at the same time, impacting evacuation routes and required evacuation areas. Anzac Creek has been modelled separately by Council and the TUFLOW model results were provided for this investigation.

Anzac Creek can flood independently of the Georges River with floodwaters coming from the upper reaches of its catchment and flowing under the M5 Motorway towards the River. Figure 11 shows the extent of the 1% AEP and PMF floods on Anzac Creek, along with the other creeks and the Georges River. The 1% AEP cuts Junction Road but not Heathcote Road, Nuwarra Road or the M5 Motorway on ramps. The PMF overtops Heathcote Road just southeast of the M5 Motorway on ramps but a bridge on Anzac Road appears to be above the PMF flood level and this provides and alternative route to the M5 Motorway via Anzac Road and Moorebank Avenue. These are shown in Figure 10.

3.3.3 Cabramatta Creek

Cabramatta Creek is a major tributary of the Georges River, with a catchment area of 74 km^2. It has five major subcatchments, including the Upper Cabramatta Creek, Hinchinbrook Creek, Lower Cabramatta Creek, Maxwells Creek and Brickmakers Creek.

The majority of the catchment is located within the Liverpool LGA, and it is bound by the Hume Highway in the east, where it flows into the Georges River. Brickmakers Creek joins Cabramatta Creek near the downstream end of the catchment. Compared to the Georges River, Cabramatta Creek generally experiences rapidly rising waters and short-duration flooding, and also a history of flooding. It has been modelled separately to the Georges River (Bewsher, 2011) for the 1%, 0.5% and 0.2% AEP events as well as the PMF. Figure 11 shows the extent of the 1% AEP and PMF floods along with the other creeks and the Georges River.

Cabramatta Creek flooding can cut several roads in the study area. The 1% AEP Cabramatta Creek flood cuts many local roads in Prestons and Jedda Road is cut by Maxwell Creek. This event also cuts Camden Valley Way. It is possible that these roads are cut in more frequent events. In the PMF, it cuts Hoxton Park Road and Camden Valley Way by the M7 entrance. Cabramatta Creek and its tributaries do not cut the M7 and its on ramps from the Hume Highway and the M5. These are shown in Figure 10.

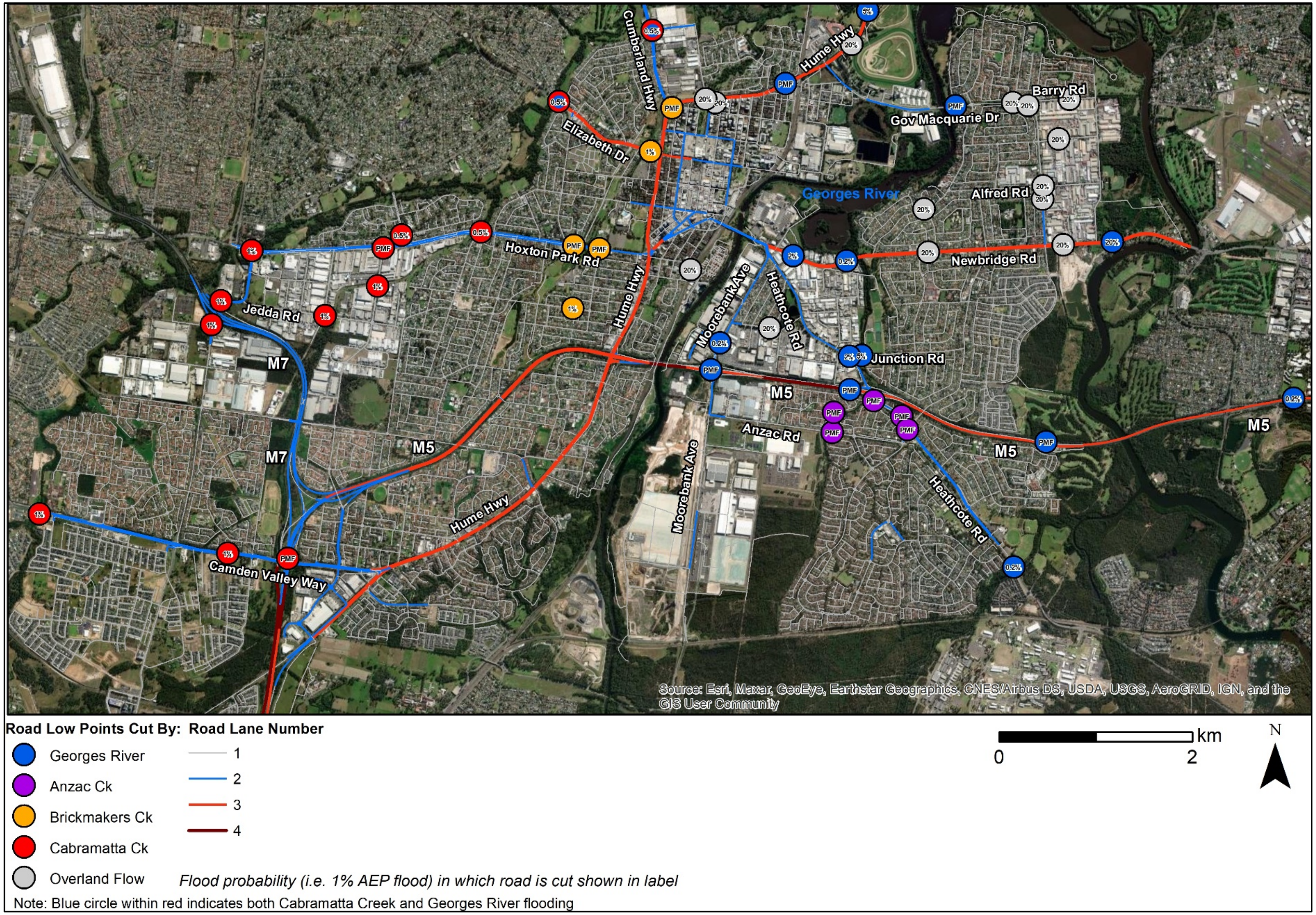


Figure 10. Location of road low points inundated by the Georges River, creek and overland flow flooding

3.3.4 Brickmakers Creek

Although it is a subcatchment of Cabramatta Creek, Council has had Brickmakers Creek modelled separately for the 1% AEP flood and the PMF. The creek starts in Casula and flows north to the west of the Liverpool CBD and flows into Cabramatta Creek. Figure 11 shows the extent of the 1% AEP and PMF floods along with the other creeks and the Georges River.

Brickmakers Creek 1% AEP flooding can cut many local roads in Liverpool and Lurnea as well as Elizabeth Drive. Orange Grove Road, the Hume Highway and Hoxton Park Road are inundated in the PMF. These are shown in Figure 10.

3.3.5 Harris Creek

Flood modelling was not available for Harris Creek, however, backwater flooding from the Georges River cuts Heathcote Road where it crosses Harris Creek in the 1% AEP event. It was therefore assumed that no evacuation traffic from the study area would head south along Heathcote Road.

3.3.6 Local Overland Flows

Modelling of the Liverpool City Centre Overland flow has also been completed, which defines local flood behaviour throughout the heavily urbanised city centre catchment. This includes the analysis of flows within the underground pipe drainage network and surface runoff across the catchment. The catchment drains into the Georges River to the east and Brickmakers Creek to the west. There is no flood warning for local overlands flows, but they have the potential to inundated local roads with relatively short duration flooding.

Overland flows can cut roads throughout Liverpool and Moorebank in floods as frequent as the 20% AEP. This includes inundation of Governor Macquarie Drive, Newbridge Road, Alfred Road, and Barry Road in Chipping Norton, the Hume Highway by the Warwick Farm race course and by Brickmakers Creek, and Shepherd Street and Macquarie Street in Liverpool. These are shown in Figure 10.

Figure 11 shows the combined peak 1% AEP and PMF extents of the creeks and Georges River. The critical duration of the 1% AEP and the PMF in the Georges River would be different from the 1% AEP and PMF events in the creeks and the probability of a PMF occurring at the same time on the river and all major creeks would be extremely low. The figure is included to show the potential extent of impacts from flooding from any of these watercourses.

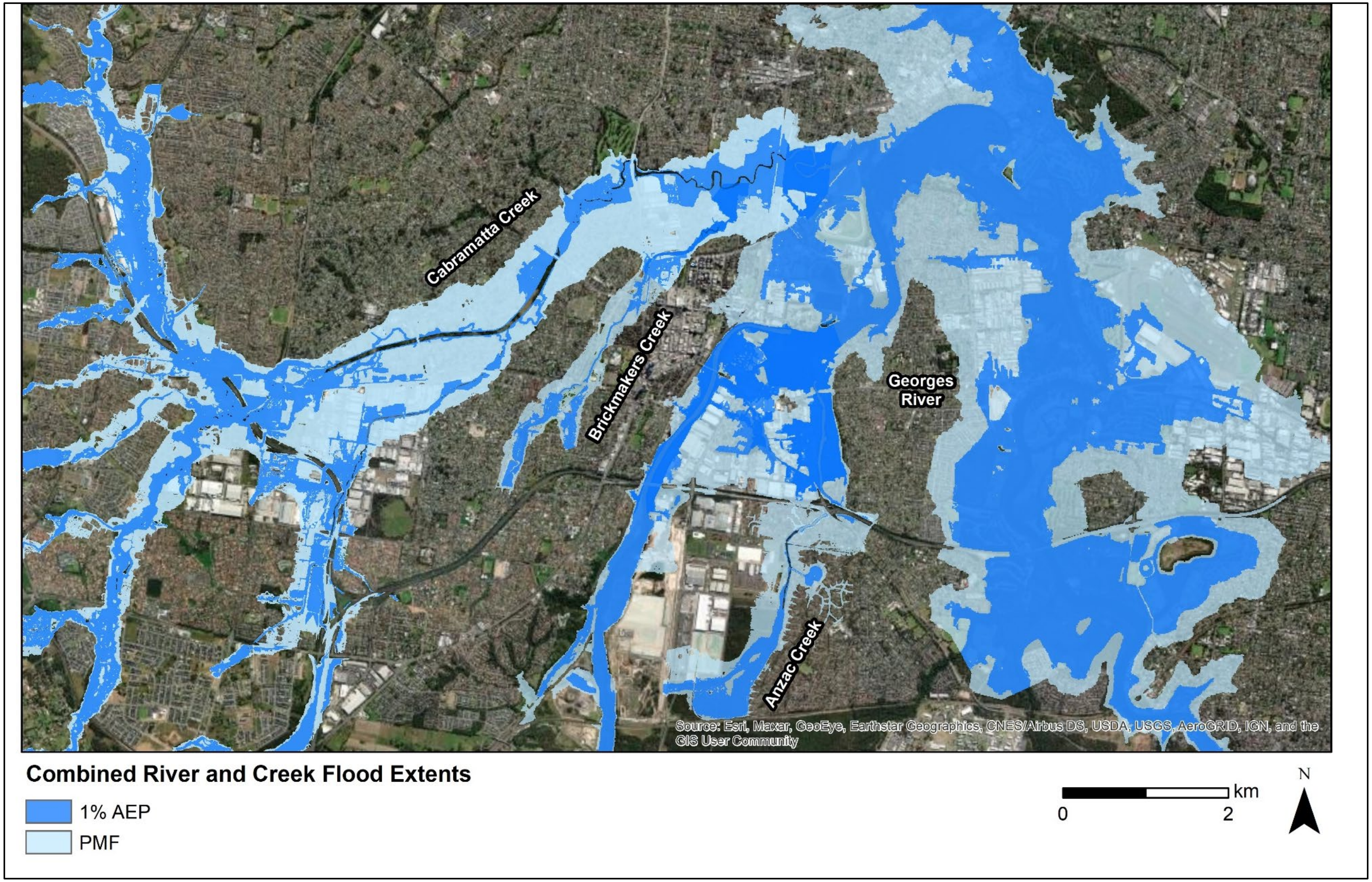


Figure 11. Combined 1% AEP and PMF extents for Georges River, Anzac Creek, Cabramatta Creek and Brickmakers Creek

4| Emergency Planning Context

4.1 Georges River Flood Plan

The NSW SES is the designated combat agency for floods, and has roles in prevention, preparedness, response and recovery. This includes protecting dangers to people, protecting property from destruction or damage, and preparing for the eventuality of severe to extreme floods in the Georges River. The NSW SES Metro Zone is the unit dealing with Georges River flooding.

The NSW SES has developed the *Georges River and Woronora River Valley Flood Emergency Sub Plan* (NSW SES 2018) which is a Sub Plan of the *Sydney Metropolitan* and *South West Metropolitan Regional Emergency Management Plans* (EMPLAN) and a sub plan to the *NSW SES State Flood Plan*. This is the most up-to-date document relevant to Georges River flooding. This sets out the responsibilities for all organisations involved in flood planning, as well as preparation, response and recovery measures in place. The purpose of this document is to outline roles and responsibilities of support agencies specific to cross boundary arrangements during the Prevention, Preparedness, Response and Recovery (PPRR) phases.

Volume 1 of the *Georges River and Woronora River Valley Flood Emergency Sub Plan* (NSW SES 2018) is currently available, which maps out the emergency management arrangements. The NSW SES advises that Volume 2 is in preparation, which will detail hazards and risks. It will describe flood behaviour and consequences across the river system using current flood studies and reports, and will include information generated from the Floodplain Risk Management review and Liverpool evacuation modelling. Volume 3 is in the preliminary stages of drafting. This volume articulates the triggers and emergency response arrangements based on Volume 2 and other data and analysis. Volume 2 and 3 are prepared by the NSW SES for informing the relevant Emergency Management Committees, rather than for endorsement. Note that Volume 1 will be revised when Volumes 2 and 3 are developed, to align with the HN Flood Plan which uses the SEMC recommended format for State level plans.

The following are relevant excerpts from Volume 1:

> ***1.4 Out of Scope***
>
> > *1.4.1 This plan is based on existing information publicly available at the time of writing. Planned and future development beyond current levels are not covered by this plan. Consultation with the NSW SES and modification to this plan will be required to account for future population increases and development within the area.*
>
> ***2.9 Community Members Within the Georges River Valley***
>
> > *2.9.1 Prepare now, know how to respond appropriately and recover effectively to help your community become more resilient, including:*
> >
> > ***Preparedness***
> >
> > *2.9.2 Know your risk: Understand the potential risks and impact of flooding at home, work and places you visit. The flood risk is so severe in parts of the Georges River that in a major flood, evacuation will be the only safe option for people in these areas.*
> >
> > *2.9.3 Know where to go: Including which evacuation route you will take and where you will stay in case you are flood affected.*
> >
> > *2.9.4 Get your home ready: Prepare homes and property to reduce the impact of flooding. Have an emergency kit and essential supplies.*

2.9.5 Plan for what you will do: Develop home emergency plans to identify who to contact, what to do, where to go and when. Share plans and practice them with family, friends, pets and neighbours.

2.9.6 Businesses develop continuity plans to prepare, minimise losses and reinstate essential services as soon as possible after a flood.

2.9.7 Be informed: Know where to find risk information, understand warnings, triggers and the safest actions to take in a flood.

2.9.8 Be involved: Work with local Emergency Services, local leaders, councils and other stakeholders to anticipate and manage the flood emergencies that could affect your community.

Response

2.9.9 Be aware: Monitor emergency warnings and broadcasts, and follow the advice of emergency services.

2.9.10 Never drive, ride or walk through floodwater: The major cause of death during floods is due to people entering floodwater.

2.9.11 Look out for each other: Share information with family, friends and neighbours and help those that may need assistance.

2.9.12 Leave flood affected areas early: If you are at risk of flooding or are advised by emergency services to evacuate.

Recovery

2.9.13 Stay clear of flood affected areas: Until you are advised by emergency services that it is safe to enter.

2.9.14 Ensure your home is safe before entering: Check for structural damage and potential risk of electrocution.

2.9.15 Manage ongoing health, safety and hygiene: Ensure personal items, food and water in contact with floodwater are not consumed and protective clothing is worn while cleaning.

2.9.16 Understand where and how to get support and assistance with your recovery.

2.9.17 Check the NSW SES website for further information on what to do before, during and after a flood.

5.3 Operational Strategies

5.3.1 The main response strategies for NSW SES flood operations are:

a. Provision of timely, relevant, accurate and tailored information to the community regarding the potential impacts of a flood and what actions to undertake to support and encourage proactive measures to be taken.

b. Evacuate people pre-emptively from dangerous or potentially dangerous places created by the flood hazard to safe locations away from the hazard.

c. Rescue people and domestic animals from floods in accordance with the NSW Flood Rescue Policy including where evacuation operations have not been successfully completed.

d. Coordinate the protection of property of residents, businesses and essential infrastructure at risk of flood damage where feasible.

e. Resupply properties, towns and villages which have become isolated as a consequence of flooding to minimise disruption of the community.

f. Manage the transition from response operations to recovery.

5.3.3 The NSW SES Incident Controller will select the appropriate mix of response strategies to deal with the expected impact of floods and set operational objectives.

5.11 Warnings and Information

5.11.13 NSW SES Evacuation Warnings and Evacuation Orders. These are usually issued to the media by the NSW SES Operations Controller on behalf of the NSW SES Incident Controller. Evacuation warnings are a message advising the community to prepare for likely evacuation. The warning advises people what to do and what to take with them. Evacuation orders communicate the need for a community (or parts of a community) to evacuate within a specified time frame in response to an imminent threat. It also advises where people should go and may advise which evacuation route to take.

5.29 DECISION TO EVACUATE

5.29.1 The decision to evacuate rests with the NSW SES Incident Controller who exercises his/her authority as an emergency officer in accordance with Section 22(1) of The State Emergency Service Act 1989. The decision to evacuate will usually be made after consultation with the NSW SES Operations Controller and the Local Emergency Operations Controller.

5.29.2 In events that require large scale evacuations, the decision to evacuate will remain with the Incident Controller with the approval of evacuation warnings and orders required from State Duty Operations Controller/NSW SES Commissioner.

5.29.3 Some people will make their own decision to evacuate earlier and move to alternate accommodation, using their own transport. This is referred to as self-managed evacuation (5).

5.29.4 Evacuations will take place when there is a risk to public safety. Circumstances may include:

a. Evacuation of people when their homes or businesses are likely to flood.

b. Evacuation of people who are unsuited to living in isolated circumstances, due to flood water closing access.

c. Evacuation of people where essential energy and utility services have failed or are likely to fail where buildings have been or may be made uninhabitable. Evacuation is the primary response strategy as isolated properties can lose power, water, phone lines, sewerage services, become a refuge for spiders, snakes and other animals and are at risk of the consequences secondary emergencies without assistance.

5.31 Evacuation Warning and Order Delivery

5.31.12 Refusal to evacuate. Field teams should not waste time dealing with people who are reluctant or refuse to comply with any Evacuation Order. These cases are to be referred to the NSW Police Force.

5.32 Withdrawal

5.32.3 The most effective means of evacuation is via road, using private vehicles and public buses for those who do not have or unable to use their own vehicles. This allows residents more control over their own evacuation. However, other means of evacuation may also be used if available and as necessary (e.g. by foot, rail, air).

5.32.4 Evacuees who require emergency accommodation or disaster welfare assistance will be directed to designated evacuation centres. Evacuees who have made their own accommodation arrangements will not be directed to evacuation centres. It is not possible to determine in advance how many will fall into this category.

5.32.5 Evacuees will:

a. Move under local traffic arrangements from the relevant sectors to the evacuation route entry point.

b. Move under traffic management arrangements to the evacuation route exit points.

c. Continue along the road network to allocated evacuation centres.

5.32.6 On major evacuation routes there may be one lane set aside for emergency vehicle traffic into and out of the Sectors. These include:

a. Utility service provider vehicles to disconnect services and make safe utility assets.

b. Waste service vehicles to make final collections and make safe waste assets.

c. Vehicle breakdown repair and towing vehicles.

d. Road maintenance repair crews.

e. Road barricade and traffic signage crews.

5.33 All Clear and Return

5.33.1 Evacuation Centres: Evacuees will be advised to go to friends or relatives, or else be taken to the nearest accessible evacuation centre, which may initially be established at the direction of the NSW SES Incident Controller, but managed as soon as possible by Welfare Services.

The currently available Volume 1 of the plan does not include information regarding the evacuation triggers, proposed evacuation routes, local evacuation centres or the scale of evacuation operations required for the existing population. This information is expected to be included in Volume 3.

Accordingly, the NSW SES has been closely liaised with over the course of this project. This has included multiple meetings during 2020 and 2021 to ensure that the approaches and assumptions are applicable to the study area and in line with NSW SES methodologies. This includes:

- The NSW SES requires modelling of the "worst case scenario" evacuation, which includes all residential and non-residential premises evacuating at the same time although only the non-residential vehicles which originate from outside of the floodplain are counted in the evacuating traffic.
- Determining the methodology for estimating non-residential vehicles based on Infrastructure NSW's approach in the Hawkesbury-Nepean Valley;
- Vehicles in the study area would primarily be evacuating south on the Hume Highway or west on the M5 and then northwest onto the M7 out of the floodplain in advance of a flood which would trigger evacuation of the precinct, as per the NSW SES provision;
- There would be 12 hours warning time of flooding reaching the level which would trigger evacuation as per the Provision of and Requirements for Flood Warning (NSW SES, 2019);
- The NSW SES would have mobilised in advance of it being necessary to issue an evacuation order and the whole of the warning time would be available for occupants of the precinct to respond to the evacuation order;
- Evacuation would occur on a subsector by subsector basis, and the subsectors used in the modelling are modifications of original subsector boundaries provided by NSW SES by adjusted to account to roads being cut by flooding. The adjusted boundaries were sent to the NSW SES in order to be transparent in the methodology and to seek any feedback, although none was received at time of writing.

The above list is not exhaustive, and the NSW SES has confirmed in meetings that all assumptions adopted in the various model runs are in line with its approach for flood evacuation in the Georges River.

It is reiterated that the preferred primary response of the NSW SES to a flood emergency in the Georges River is evacuation, rather than Shelter in Place. The NSW SES does not support Shelter in Place for any new development where that is relied upon as the primary means of flood emergency response.

4.2 NSW SES Flood Evacuation Planning

4.2.1 SES Timeline Evacuation Model

The NSW SES has developed the Timeline Evacuation Model (TEM) as an empirical tool for consistently estimating the ability of people to safely evacuate by motor vehicle from floodplains (Opper et al, 2009). It takes into account the time people take to accept a warning, act upon the warning and travel along an evacuation route which may face delays due to incidents along the route. It then compares this estimated “Time Required” with the estimated “Time Available”. The Time Available is derived from information about warning times, flood travel times and flood rates of rise.

The TEM was born out of the 1997 Hawkesbury-Nepean Floodplain Management Strategy, where the NSW SES applied conventional timeline project management to the flood evacuation problem. It became apparent that this approach provided a clear and concise method for examining the evacuation process. Since that time, the approach has been refined into a model that can be easily applied to different developments. The TEM has been used widely within NSW by both the NSW SES and consultants in evacuation planning, with the scale of the model ranging from small subdivisions to towns of tens of thousands of people.

The primary goal of the TEM is to compare the time required for evacuation with the time available for evacuation. This can be represented by the equation:

Surplus Time (ST) = Time Available (TA) – Time Required (TR)

Where the Time Available exceeds the Time Required there can be greater confidence that a community can evacuate safely by motor vehicle. Where the Time Required exceeds the Time Available it is unlikely that everyone will be able to evacuate safely by motor vehicle in all floods.

The Time Required (TR) is the sum of the following four components:

- **Warning Acceptance Factor (WAF)** accounts for the delay between receiving an evacuation order and acting upon it. The NSW SES recommends a value of one hour.
- **Warning Lag Factor (WLF)** is an allowance for the time taken by occupants to prepare for evacuation. The NSW SES recommends a value of one hour.
- **Travel Time (TT)** is defined as the number of hours taken for all of the evacuating vehicles to pass a point given the road capacity. The NSW SES recommends an assumed road capacity of 600 vehicles per hour per lane. Therefore, if an evacuation generates 1,200 vehicles and the evacuation route has one lane, then the travel time is two hours. If there are two lanes the travel time is reduced to one hour.
- **Traffic Safety Factor (TSF)** is added to the travel time to account for any delays that occur along the evacuation route. This includes potential for incidents such as vehicle accidents or breakdowns, fallen trees or power lines or water across the road. The NSW SES has developed a table of traffic safety factors, where the safety factor is proportional to the travel time, ranging from one hour to three and a half hours (Table 6).

This is summarised in Figure 12.

The time needed to disseminate an evacuation order also needs to be considered. Generally, the NSW SES will broadcast the order by several means but will also initiate doorknocking of the target premises. The model assumes that the evacuation order is not received at a property until it is doorknocked and that at any one time there will be properties at different stages of the evacuation sequence.

However, this is only true if the number of door-knocking teams available is equal to the number that would produce enough traffic to keep the evacuation route at full capacity. Should the number of door knocking teams available be less than this optimal number, then the travel time must be modified to account for this. If more door knockers are provided than the optimal number, then the rate of traffic generation will exceed the road capacity and traffic queues will form until no more premises evacuate.

Table 6. Traffic Safety Factors

Travel Time (TT) (hrs)	Traffic Safety Factor (TSF) (hrs)
0 to 3	1.0
>3 to 6	1.5
>6 to 9	2.0
>9 to 12	2.5
>12 to 15	3.0
>15	3.5

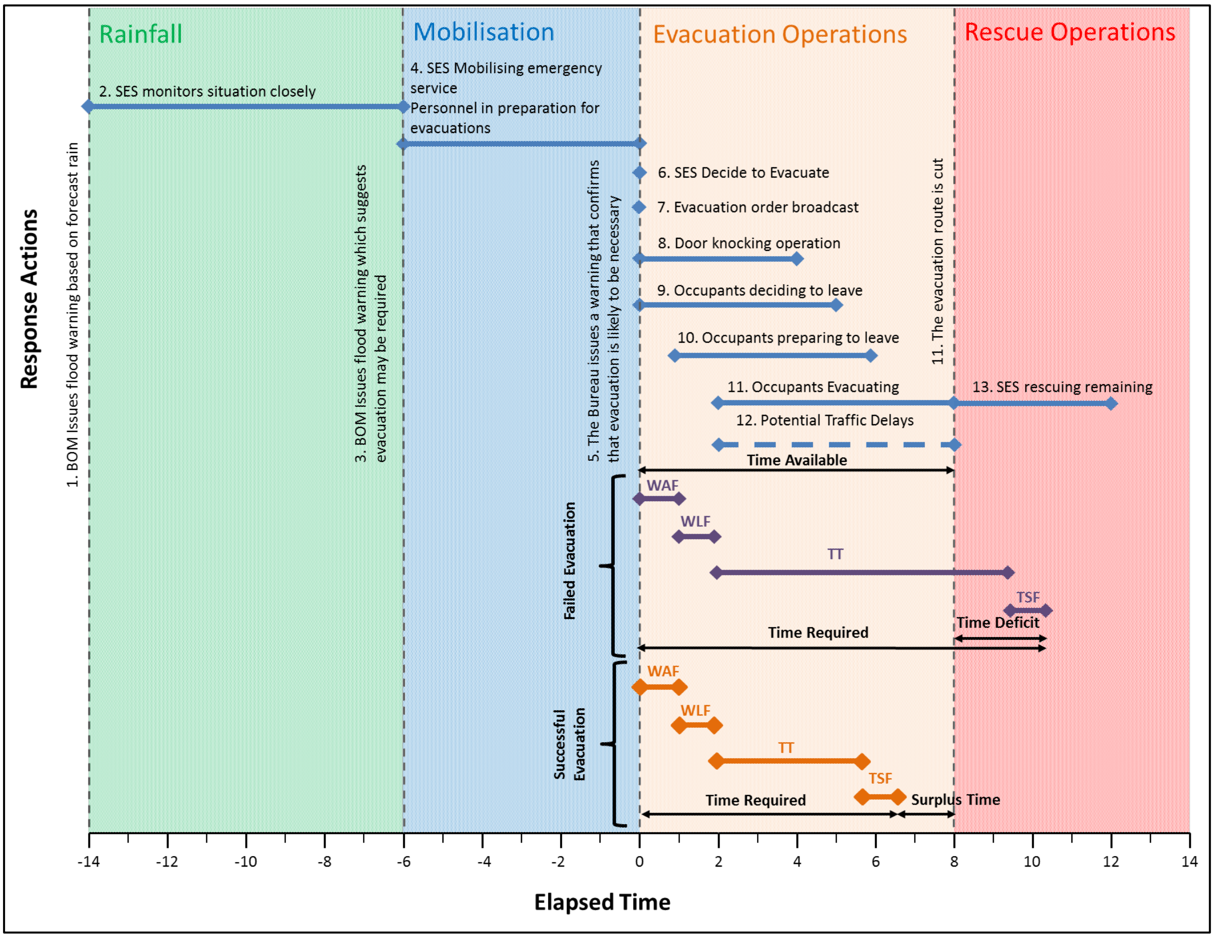


Figure 12. Timeline Evacuation Model summary

The Time Available (TA) is usually the time from when an Evacuation Order is issued by the NSW SES to when the lowest point on the evacuation route is cut by floodwaters. The ability to estimate this time for use in the TEM will be very dependent on the quality of available flood data and the type of warning products which the Bureau of Meteorology (BoM) is able to provide.

When determining the Time Available, consideration also needs to be given to the relative position of where the warning is provided for, compared to the location where the road will be cut. This requires accounting for the flood travel time from the gauge to the road cut location in estimating the available warning time.

4.2.2 NSW SES Evacuation Subsectors

The NSW SES manages flood response on a sector by sector basis, and has divided the Georges River floodplain into 46 draft subsectors. They have provided their draft Georges River evacuation subsectors for this study, which have informed the identification of evacuation subsectors for this study. It is noted that the NSW SES subsectors extend beyond the scope of this study (i.e. into Fairfield City Council). Many of the NSW SES evacuation subsectors were further subdivided in this study in order to assess evacuation in the study area at a higher resolution, particularly where it became clear from a detailed analysis of flood modelling results that flooding would sever key road connections within a subsector.

4.3 Other Flood Evacuation Considerations

4.3.1 Availability of Safe Refuge

While vehicular evacuation is the preferred primary response to a major flood on the Georges River and pedestrian evacuation a critical secondary response should vehicular evacuation fail, it is also important to consider where safe refuges are available to building occupants in the full range of flood events should evacuation fail. For such refuge to be considered suitable there must be sufficient, accessible and appropriate shelter above the peak PMF level, including for those with limited mobility, those on lower levels of multi-floor buildings or people in buildings which do not have their own refuge above the PMF level. The building in which shelter is to take place must be able to remain structurally sound during a PMF and withstand the hydrostatic, hydrodynamic, buoyancy and debris loads of the flood. It must be of suitable size and have adequate amenities for the number of people likely to use it.

Taking refuge as a final response should both vehicular and pedestrian evacuation fail is quite different from planned Sheltering in Place as a primary flood emergency response. Where evacuation is planned and there is sufficient time and road capacity for it to occur, there should be a low probability of people needing to take refuge and only a small proportion of the population which needs to do so. The space and facilities provided can arguably be minimal.

On the other hand, where Sheltering in Place is the proposed primary response, adequate provisions need to be made for the entire population for the full range of events in which sheltering is to take place. The potential for secondary emergencies or inappropriate behaviour by individuals which can place lives at risk needs to be considered. The longer the duration of isolation by flooding the higher the likelihood of such things occurring.

The NSW SES does not support shelter in place for future development. It considers that such an approach is only suitable to allow existing dwellings that are currently at risk to reduce their risk, without increasing the number of people subject to the flood risk.

4.3.2 Human Behaviour

According to Haynes et al. (2009), most of flood-related death and injuries in Australia have occurred to people voluntarily entering floodwaters, usually trying to walk or drive through them. For this reason, avoiding direct contact with floodwaters is the main aim of every flood emergency policy in Australia and overseas.

All the NSW Councils that have a risk to life policy in place recommend evacuation as the preferred emergency response for new development only if enough time is available to safely reach a flood free area. If this is not possible, avoiding the risk of direct contact with floodwaters by sheltering in place becomes the preferred emergency response strategy.

Whether the preferred flood emergency response is evacuation or sheltering in place, the success of the response is highly dependent on people responding appropriately. It requires those that need to evacuate evacuating in a timely manner and those that need to shelter, doing so until the flood hazard has gone.

In recent years there have been floods in Australia where evacuation orders have been given with sufficient time to evacuate but many residents have failed to do so. Some research shows that less than 25% of people evacuate when told to do so (Opper et al., 2006; Strahan Research, 2011). However, in the June 2007 Hunter Valley floods, 76% of people in Maitland said they evacuated when ordered to do so (Molino Stewart, 2008). Yeo et al. (2018) found that compliance with Evacuation Orders in the Murrumbidgee region in March 2012 was frequently greater than 80%, although rates were as low as less than 5% in other areas. About 10-20% of people say they will not evacuate under any circumstances. On 27th January 2013 a voluntary mass evacuation of north and east Bundaberg was called in advance of forecast flooding. On 28th January this was escalated to a mandatory evacuation. Although 7,000 people were provided with sufficient advanced warning to leave, 850 people had to be rescued by 24 Blackhawk helicopters in the largest air evacuation in Australia's history (Honor and Regan, 2014).

The safety of sheltering in place is also highly dependent on appropriate human behaviour. This can be illustrated by two examples.

The June 2007 Hunter Valley floods resulted in flash flooding in the Newcastle CBD at about 5pm on the Friday of the June long weekend. Office workers who saw the flooding in the streets contacted the NSW SES who told them to stay within their buildings until the flooding had subsided which would occur within a couple of hours. Within an hour, the NSW SES was rescuing those same people as they had tried to drive out through the floodwaters (Greg Perry, NSW SES, pers. comm.).

During the 2017 Lismore floods, many residents of North Lismore elected not to evacuate when ordered to do so because their homes were elevated on piers and they believed they could sit out the flood with stocks of food and drinking water. Many of those people regretted that decision when they lost power and the flooding continued for more than 24 hours. They were left in the dark with no communication to the outside world and refrigerated food was spoiling. Some had medical emergencies. Some traversed hazardous floodwaters to escape their homes or to get help (BNHCRC, 2017).

These examples illustrate that when people are sheltering in a building that is isolated by floodwaters, they might decide to take actions which increase the risks to their lives and the lives of others. The longer they are isolated the more likely they are to want to leave the premises and the more time they have available to make poor decisions.

The viability of evacuation plans or plans to shelter in place will be very dependent on the relationship people have with the buildings. Typically, workers will want to leave the flood threatened building to be able to get home even if the flood duration is only a couple of hours. On the other hand, residents will tend to remain in their dwellings for several hours or more even if they are without services such as electricity but will then want to leave if they are isolated for longer durations. Residents who are outside of the floodplain when the building isolation occurs are very likely to try to reach their homes, risking travelling through hazardous floodwaters in the process.

4.3.3 Secondary Emergencies

A secondary emergency is where a non-flood related emergency, such as a building fire or medical emergency, occurs during a flood. In many cases the flood and secondary emergency will be two unrelated events, however there is potential for floodwaters to damage the electrical system and cause fires or for occupants to use improvised lighting (candles), cooking and heating with naked flames that may also cause fires. The flood could also cause elevated stress levels in occupants that could aggravate pre-existing medical conditions leading to more medical emergencies.

While the probability of a fire in a building during a flood is likely to be small, the consequences, should a fire occur, could be significant if people are unable to evacuate the building because they are surrounded by hazardous floodwaters and firefighters are not able to reach the building to undertake rescues and extinguish the fire. Ambulance emergencies are more likely to occur than a fire while areas are isolated by flooding, particularly if the stress of flooding aggravates pre-existing medical conditions.

While a secondary emergency has a relatively low chance of occurring during a flood, it is important to recognise the potential and understand the potential consequences. Buildings can be designed to be accessed by boat or helicopter for rescue during floods but there are practical difficulties due to the river and weather conditions which prevail during a flood that may prevent emergency access.

4.3.4 Flood Duration

An important consideration in assessing the risks associated with isolation from floodwaters is the duration of the isolation. There are several aspects of risk associated with isolation. Firstly, the shorter the duration of the isolation, the lower the probability that a secondary incident such as a fire or a medical episode is likely to occur. Secondly, the shorter the duration of the isolation, the less likely that building occupants will be frustrated by being isolated and therefore they are less likely to be motivated to traverse floodwaters to leave the building. Finally, the shorter the isolation duration the less opportunity people will have to traverse the floodwaters.

For example, the NSW SES Timeline Evacuation Model suggest that on average it takes about two hours people to make an evacuation decision and get ready to evacuate (Opper et al, 2009). The probability of people traversing floodwaters when isolated for two hours or less is therefore expected to be quite low. An isolation of up to eight hours might be considered to be another key threshold as it is about the average time that people sleep or are in a workplace and isolation up to this duration might not be considered particularly inconvenient. Research has also shown that even people who have decided not to evacuate and to shelter within a building they know will be surrounded by floodwaters can change their minds after 24 hours (Tofa et al., 2018). This therefore would appear to be another key threshold for isolation risk analysis.

Based on an analysis by Molino Stewart for this study of the 2020 Georges River 2D TUFLOW hydraulic model data (BMT, 2020), the vast majority of the area inundated by the Georges River PMF experiences high hazard flooding (i.e. Hazard level 3 (H3) according to the Australian Rainfall and Runoff 2019 hazard classification which is described as, "unsafe for vehicles, children and the elderly") for over 24 hours, in many places for in excess of 40 hours (Figure 13). Therefore, failing to evacuate or deliberately sheltering in place in the Georges River floodplain is particularly risky considering buildings can be isolated and inaccessible to emergency services for more than 24 hours.

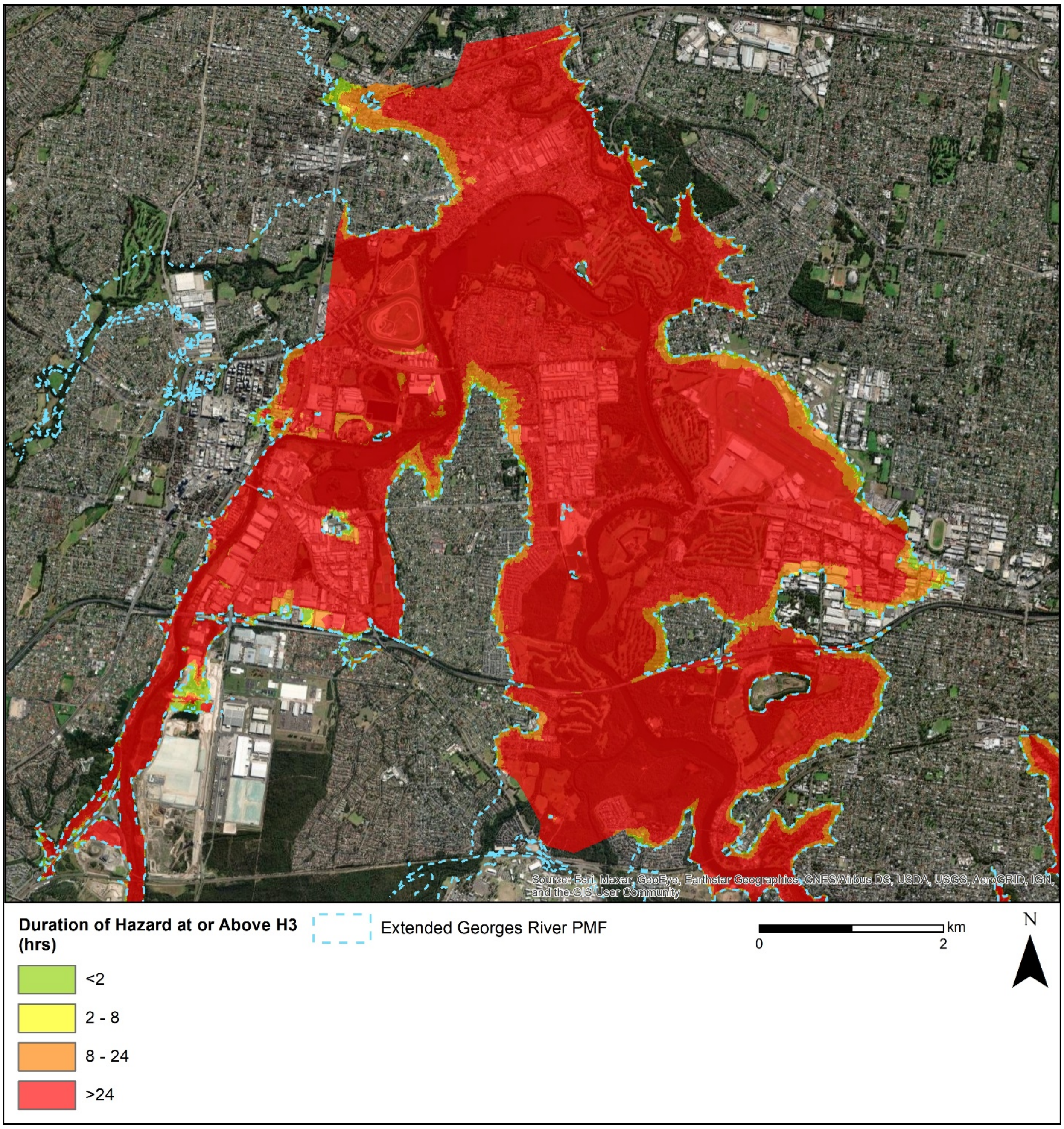


Figure 13. Duration of high flood hazard during the PMF for the modelled extent of Georges River flooding

4.3.5 Warning Systems

There are two gauges on the Georges River within the study area that have quantitative flood warnings provided by the Bureau of Meteorology. The key gauges, defined as "key location for downstream predictions, critical for the provision of a quantitative flood forecasting service" in the study area are the Liverpool Gauge and the Milperra Gauge. Table 7 shows the information for these gauges, as per *The Provision and Requirements for Flood Warning in New South Wales* (NSWSES, 2019) and the Bureau of Meteorology *Service Level Specification for Flood Forecasting and Warning Services for New South Wales and the Australian Capital Territory* (BoM, 2013).

Table 7. Service Level Specification for Flood Forecasting and Warning Services for New South Wales (BoM, 2013)

Bureau number	AWRC number	Forecast location	Station owner	Gauge type	Gauge datum	Flood classification (m)			Prediction type	Target warning lead time		70% of peak forecasts within	Priority
						Minor	Moder-ate	Major		Time (hrs)	Trigger height (m)		
213 – Georges River and Sydney Coast													
566054	213400	Liverpool	Sutherland Shire Council NSW OEH	Auto-matic	Local	2.0	3.0	4.5	Quantitative	6 hrs 12hrs	>2.0 m >4.0 m	+/- 0.3 m	High
66168	213405	Milperra	MHL*	Auto-matic	AHD	2.0	3.3	4.2	Quantitative	6 hrs 12hrs	>2.0 m >4.0 m	+/- 0.3 m	High

** Updated from the referenced document which has the station owner as Sutherland Shire Council and NSW OEH.*

It is noted that a reading of 0 m on the gauges does not necessarily equal 0 m AHD. The Milperra Gauge has a gauge zero of 0 AHD but the Liverpool gauge has a gauge zero of 2.8 m AHD.

Table 8 shows the impacts of various flood and gauge levels in the study area.

Table 8. Georges River flood levels and impacts

Georges River Flood Classification	Liverpool Weir Gauge Level (m)	Liverpool Weir Flood Level (m AHD)	Milperra Gauge and Flood Level (m AHD)	Impacts for the Study Area
Minor[1]	2	4.8	2.0	No significant impacts
Moderate[1]	3	5.8	3.3	Flooding of low-lying areas in Moorebank East, along eastern Newbridge Road, and along Cabramatta Creek in Warwick Farm.
Major (about a 1 in 15)[1]	4.5	7.3	4.2	Flooding along eastern Newbridge Road, Barry Road in Chipping Norton, the Hume Highway by Cabramatta Creek, and Junction Road by Anzac Creek.
2% AEP[2]	6.5	9.3 (8.7)	5.6 (5.5)	Flooding throughout western and eastern Moorebank, eastern Chipping Norton, and Warwick Farm, cutting many roads and inundating properties.
1% AEP[2]	6.8	9.6 (9.0)	5.8 (5.9)	High flood islands form in east Moorebank, extensive flooding through Liverpool, Warwick Farm and western Moorebank, cutting many roads and inundating properties.
0.5% AEP[3]	6.9	9.7	5.9	As above, with additional flooding throughout and in Chipping Norton.
0.2% AEP[3]	7.2	10	6.2	As above, with additional flooding throughout entire study area.
PMF[2]	9.4	12.2 (11.6)	11.8 (10.4)	Study area inundated except for the high ridge in the Moorebank peninsula and higher terrain in western Liverpool.

1. Levels from Bureau of Meteorology flood gauge information
2. Levels from Georges River Flood Study Report (BMT, 2020)
3. Levels extracted from Georges River Flood Study model results
( ) bracketed values are corresponding levels currently adopted by Council

Based on the above information, there should also be at least 12 hours warning that a precinct's evacuation route will be cut or that the precinct will start flooding.

While the time for floodwaters to travel from the gauges to the evacuation subsectors can theoretically be accounted for as additional effective warning time, the distances between the gauges and the subsectors in the study area are such that such travel times are short and can be discounted for practical purposes.

It is noted that flood warning systems are not failsafe. During the floods in Victoria between September 2010 and February 2011, about 50% of the warning systems experienced some type of failure (Molino Stewart, 2011). This included mechanical and electrical failures in gauges, gauges being damaged by flood debris or erosion, communication failures between the gauges and the receivers or human error in the interpretation of the data. The more extreme the flood event, the more likely it is that the gauging hardware will be damaged by the flooding.

Forecasts made for future flood levels at the Liverpool and Milperra gauges are based on rainfall gauge readings in the catchment and stream gauges readings upstream on the Georges River and its tributaries as well as current water levels at Liverpool and Milperra. Damage to the Liverpool or Milperra gauges could compromise the ability to gain accurate information on current flood levels at those locations. Damage to upstream gauges could compromise the ability to accurately forecast future flood levels at Liverpool and Milperra.

4.4 Emergency Response Classification

In this study, areas have been spatially defined according to emergency response classification of communities in accordance with Handbook 7, Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIRD, 2017). This is a classification in regard to isolation and access considerations. The four classes of land that are flooded in the PMF include:

- **Flooded Isolated and Submerged** (FIS), also known as low flood islands, where the area is first isolated from flood-free land and then completely inundated as flood waters continue to rise. This is the most dangerous scenario.
- **Flooded Isolated Elevated** (FIE), also known as high flood islands, which are similar to FIS areas but a portion of the site remains flood free in the PMF, providing a refuge for those who do not evacuate before the loss of access.
- **Flooded with an Exit Route via Rising Road** (FER), where the area is flooded but there is a continuously rising flood evacuation exit route by road out of the floodplain.
- **Flooded Overland Escape** (FOE) where the area is flooded but there is a continuously rising overland exit route out the floodplain rather than by road.

In addition, there are two classes of not flood affected areas outside of the PMF, including:

- Indirect Consequence (NIC), which are areas not flooded but may lose access to services such as electricity, gas, water, and telecommunication.
- Flood free areas that do not experience any indirect consequences of flooding.

The above emergency response classification thus differentiates between buildings where occupants can evacuate by driving (FER) or walking (FOE) from rising floodwaters, and buildings where occupants would get trapped by floodwaters before they are affected themselves (FIS and FIE). This provides the framework for gauging the nature, severity and scale of inundation and isolation risk across the floodplain.

5| Georges River Flood Evacuation Model

5.1 Limitations of Timeline Evacuation Model

In the earlier Moorebank East evacuation analysis, the NSW SES Timeline Evacuation Model (TEM) was used to estimate the time needed to evacuate each sector in the Moorebank Peninsula, which was compared to the time available based on expected warning times published by the NSW SES. Based on this, sectors were identified where there was insufficient time or road capacity to evacuate.

Traffic was then converged from each sector according to their relative evacuation trigger timings based on a flood rising as fast as the modelled PMF. It was then assessed whether the converged traffic would have sufficient time to evacuate in the time available using TEM. This was based on the assumption that all sectors would evacuate onto the M5 Motorway, but once on the Motorway, would have free flow to evacuate east or west to an area outside of the Peninsula which is above the PMF extent. As there were only two roads leading onto the Motorway in this study, and each sector fed onto one of these two roads, the modelling was sufficiently straightforward that the Timeline Evacuation Model could be used in this instance.

The NSW SES recognises that evacuation of a development may not necessarily occur in isolation as other nearby developments may also have to evacuate at the same time. The TEM makes provision for estimating how converging evacuation traffic may impact on the ability of developments to evacuate simultaneously. However, the TEM is not set up to consider more than two converging traffic streams such as when there are multiple subsectors evacuating onto shared evacuation routes. This means that more sophisticated modelling that accounts for traffic convergence in more detail is required for larger scale studies. This would allow consideration on what impact other existing evacuating traffic from Moorebank and Liverpool would have on the safe evacuation of new development.

Furthermore, the TEM is coarse in that it analyses towns, precincts, subsectors or sectors as a single block and provides no sense of what is happening to evacuation traffic on the roads within the spatial unit which is evacuating.

Nevertheless, the fundamental principles and assumptions of the TEM including warning lead times, delays in evacuation response, evacuation route capacities and potential for traffic delays need to be incorporated in any flood evacuation model.

5.2 Life Safety Model

In recent years more sophisticated models for the estimation of loss of life in any flood event have been created. One of the most advanced of these was developed by British Columbia Hydro in Canada and commercialised as the Life Safety Model (LSM) by HR Wallingford in the UK.

HR Wallingford, under licence from British Columbia Hydro, has developed the LSM into a dynamic model that represents the:

- Rise and spread of floodwaters;
- Receipt of warning messages;
- Response of occupants to the warning;
- Evacuation traffic flow;
- Fate of those who fail to evacuate before the arrival of floodwaters.

It models the evacuation and fate of each individual household based on their exact spatial location and the available road network over time. Time series output from the model can be viewed as animations as well as in tables.

In the LSM, each individual and vehicle is represented as an autonomous entity within the model. The behaviour of each entity is individually governed by a set of rules that control its interactions with other entities and with the flood hazard. The traffic model is a simplified traffic model that is appropriate for traffic that is constrained by flow rate limits and congestion (the high vehicle density associated with mass evacuation). The traffic model uses the Greenshields relationship between traffic density and speed to control the movement rate of vehicles, with additional rules to:

- Account for the movement across junctions;
- The interaction with other vehicles (it is assumed that vehicles can't pass one another on a single lane);
- Once a queue is formed, the length of each vehicle is used to determine the position of the next vehicle back of the queue.

The LSM has previously been compared with a full traffic model (Omnitrans) and produced similar results for large scale evacuation (Tagg et al., 2012; 2016).

The inputs required for the LSM are:

- **Buildings:** The physical location of occupied buildings to provide a start location for the population groups and vehicles.
- **Population Data:** Census or other data to define household groups and distribute them to a physical building location.
- **Number of Vehicles:** The number of vehicles evacuating from each property. These are distributed to the building locations.
- **Road network:** A simplified, digitised road network containing the evacuation routes and minor roads leading to it. The number of lanes and free flow speed limits are required.
- **Hydrodynamic data:** A two-dimensional flood modelling of depths, water levels, velocity for a number of time intervals covering the flood event. The time interval depends on the duration and rate of rise of the flood event.

The advantages that the LSM has over the TEM are that it:

- fully integrates with two-dimensional flood models;
- can model different warning dissemination mechanisms;
- can model vehicular and pedestrian evacuation;
- models individual buildings and vehicles with spatial accuracy;
- can replicate NSW SES TEM warning, departure and travel assumptions;
- models the entire road network including networks internal to evacuation nodes;
- models traffic convergence within and outside of evacuation nodes;
- shows results dynamically and visually in a way which helps communicate convergence, queuing and evacuation failure;
- can undertake sensitivity analysis quickly.

LSM is also able to estimate the movement of pedestrians leaving buildings or leaving vehicles which are no longer able to travel on the traffic network. In addition, it can estimate the fate of people who are caught by floodwaters by using information about their situation (in a building, in a vehicle or on foot), the water conditions (depth, velocity, temperature) and their exposure (duration).

The fully featured model has been calibrated/verified against the Malpasset dam failure in Italy (Johnstone et al., 2003; 2005) and the storm surge on Canvey Island (Di Mauro et al., 2008; Lumbroso et al., 2011).

5.3 Applying the Life Safety Model to the Georges River

In this project, the Life Safety Model (LSM) was used to model vehicular evacuation from the study area. The pedestrian evacuation and the fate features of the model were not used but they can be switched on in the model if these issues are to be explored in the future.

Council's 2020 Georges River 2D TUFLOW hydraulic Probable Maximum Flood (PMF) model (BMT, 2020) was used in the model to represent the maximum flood extent and fastest rising flood which evacuees would need to respond to. While it is recognised that this is an extremely rare event, more frequent events could rise this quickly and if vehicular evacuation can be achieved in this event then it should be possible to achieve it in events which rise more slowly or which have a lower peak.

The NSW cadastral lot layer, together with satellite imagery, was used to identify each individual premises from which evacuating vehicles would originate. The number of vehicles at each premises was assigned using census data for existing residential premises and journey to work data for existing non-residential premises. Vehicles numbers for potential future development were informed by the census data and journey to work data as well as other considerations about the nature of the development.

The floodplain was divided into subsectors based on preliminary subsector boundaries provided by NSW SES. The boundaries were refined through detailed analysis of the TUFLOW model times series outputs and where and when roads would be cut. It was assumed that each subsector would receive an evacuation order 12 hours in advance or either its evacuation route being cut or premises being flooded by the PMF. It was assumed that the evacuation order would be disseminated at a rate which would generate a maximum of 600 vehicles per hour from each subsector with each premises receiving their evacuation order in order of the ground elevation from lowest to highest.

In the LSM it was assumed that those receiving the evacuation order would take one hour to accept the order and a further hour to be ready to leave. Therefore, there was a two hour delay between order delivery and evacuation commencement which is the same as the TEM.

The NSW road network GIS layer was used to represent the road network with some modifications where roads are gated at railway crossings or where local flood modelling suggested that roads may be closed by local flooding during and evacuation. Generally, it was assumed that each evacuating lane would have a capacity of 600 vehicles per hour per lane as recommended by the NSW SES in its TEM and there would be no contraflow lanes available for evacuation.

To account for the traffic safety factors (TSF) recommended by NSW SES, the LSM model outputs were interrogated to determine the duration of evacuation from a particular subsector or along a particular length of road. The NSW SES TSF was then applied to that location and the number of vehicles remaining in the subsector or still on a section of road at the earlier time was extract from the model.

The details of how these model assumptions and inputs were derived and applied is elaborated upon in Section 5.4.

Over the course of this study, multiple different Georges River flood evacuation scenarios were defined and modelled to demonstrate how various assumptions will alter the evacuation process. The following scenarios are discussed and presented in this report:

- **Scenario 1** is the base case scenario based on 2016 Census (ABS, 2016) population and vehicle data and 2011 Journey to Work (Transport for NSW, 2011) data
- **Scenario 2** is a future scenario with intensified development under existing zoning, accounting for residential and non-residential infill and planned road upgrades
- **Scenario 3** is a future scenario with rezoning and development from planning proposals currently under investigation, as advised by Council

Subsequently, two of the above scenarios were run with modified assumptions. These are:

- **Scenario A** is Scenario 2 with multiple non-residential vehicle evacuation destinations depending on the origin of the workers being:
  - M7 north (i.e., the single destination of all vehicles in Scenarios 1, 2 and 3),
  - Hume Motorway south,
  - Camden Valley Way west, or
  - M5 east
- **Scenario B** is a modified Scenario 3 with the following modifications:
  - updated numbers of vehicles from proposed residential and non-residential areas for all developments, including a decrease in the number of vehicles per dwelling for new planning proposal apartments,
  - non-residential vehicle traffic will evacuate to multiple destinations depending on the origin of the workers as per Scenario A (i.e. M7 north, Hume Motorway south, Camden Valley Way west or M5 east),
  - the two on ramps from the Hume Highway and M5 will have their capacity increased to 900v/h/lane,
  - there will be a third lane heading north on the M7

The above scenarios are referred to in the discussion and presentation of results.

5.4 Model Inputs and Assumptions

5.4.1 Warning Times

According to the *Provision and Requirements for Flood Warning in New South Wales* (NSWSES, 2019), the Bureau of Meteorology has a target minimum warning lead time of 12 hours for floods greater than 4.0 m, and 6 hours for floods greater than 2.0 m for both the Liverpool and Milperra Bridge Gauges.

As evacuation from the Georges River floodplain is only necessary in floods exceeding 4.0 m at these gauges, there will be at least 12 hours warning available. Therefore, in all five of the modelled scenarios, a warning time of 12 hours was utilised.

5.4.2 Time Required to Evacuate

All modelled scenarios utilised the assumptions from the NSW Timeline Evacuation Model (TEM) as explained in Section 4.2.1. This included:

- Vehicles leave two hours after being notified of evacuation order (one hour Warning Acceptance Factor plus one hour Warning Lag Factor).
- The travel time is based on an assumed road capacity of 600 vehicles per hour per lane. This has been applied to all scenarios, except in Scenario B where the two on ramps from the Hume Highway and M5 onto the M7 will have their capacity increased to 900 vehicles per lane per hour.
- Traffic Safety Factors (TSF) were calculated and accounted for based on the elapsed time that vehicles are traveling on the road. Subsectors were identified where accounting for the TSF meant that additional vehicles would be trapped by floodwaters or on the road.

5.4.3 Evacuation Subsectors and Trigger Levels

As shown in Figure 14, there are 43 evacuation subsectors in the study area that are impacted by the PMF from the Georges River and the study area's creeks. These have been identified based on an analysis of the flood model time series and the NSWSES published warning times for the Georges River. The evacuation subsectors have been informed by the draft NSW SES subsectors that were provided, but are not identical. The NSW SES was provided with the subsectors identified in this study for its approval.

The subsectors used in all modelled scenarios were refined by selecting areas with shared evacuation routes and flood risks, and thus would need to respond to specific trigger level(s). They were classified based on the emergency response classification of communities in accordance with DPIE guidelines to identify the flood islands within the study area and those which have rising road access and overland escape routes. Of these subsectors, 15 are primarily industrial, 26 are primarily residential, one is both industrial and residential, and one was classed as an equestrian area.

Subsectors R13, R14, R20, R22, I10 and I11 are only affected by local creek flooding and their evacuation was not included in the modelled scenarios.

The trigger levels at the Liverpool and Milperra gauges which would cut off the flood islands or start to flood areas with rising road access were identified. The timing of these trigger levels were identified by timestep on the PMF design flood hydrograph in Liverpool Council's TUFLOW model of the Georges River. The standard warning dissemination, warning acceptance, evacuee response and road capacity assumptions as per the NSW Timeline Evacuation Model were utilised.

A database of both initial and progressive evacuation triggers for each subsector was developed. The staging of evacuation of each subsector was based on the following three possible scenarios:

- Areas where everyone is told to evacuate based on a single trigger level ("all"). This was generally where the subsector is a flood island and the trigger for evacuation is the level at which the evacuation route is cut although it also applied to subsectors where there is little change in level across the subsector. The model assumed that evacuees would be warned at a rate which would generate a maximum of 600 vehicles per hour evacuating from the subsector and that the evacuation order would be issued to the premises in order of ascending ground level;
- Areas where they will progressively evacuate by ground level based on revised flood forecasts, as per SES staging of subsector evacuations ("by level"). These are subsectors with rising road access or overland escape routes and a significant change in level across the subsector. Only those parts of the subsector which are expected to flood would be evacuated based on current forecasts. As forecasts are revised upwards more elevated parts of the subsector would be ordered to evacuate;
- Areas where there will initially be a staged evacuation, until the evacuation route gets cut, at which point everyone will need to evacuate ("by level until..."). This used a combination of the above two approaches.

Appendix A shows the triggers that have been identified for each subsector.

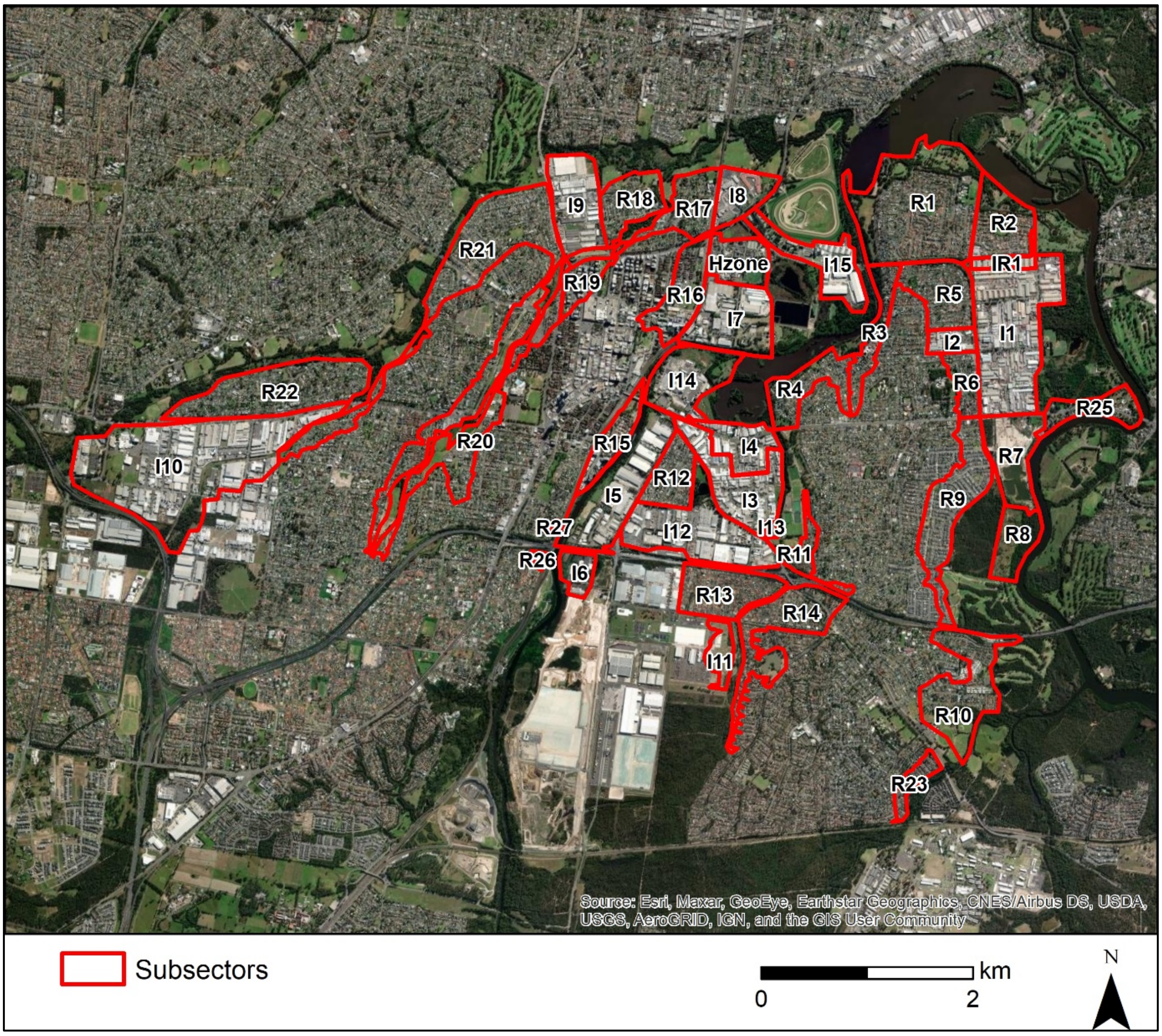


Figure 14. Subsectors identified and used in this study

5.4.4 Existing and Future Road Network

The existing road network was input into the modelled base case (Scenario 1), with modifications made in the future scenarios (Scenarios 2, 3, A and B) based on advice from Council.

As advised by the NSW SES, all traffic is expected to be directed to evacuate west to the M7 and north from there. Therefore, to force traffic in this direction in the model, Newbridge Road and the M5 were cut at the eastern extent of the study area where they cross the Georges River in scenarios 1, 2, and 3. In Scenarios A and B where some vehicles need to evacuate to the east, the M5 crossing of the Georges River was opened.

To account for the very real possibility of local creek flooding during an evacuation from the Georges River flooding, every road that crosses Anzac Creek, Brickmakers Creek, Cabramatta Creek and Maxwell's Creek was cut in the model if it was flooded by a 1 in 500 annual exceedance probability (AEP) flood or more frequent events (Figure 15) according to the local flood modelling. It was assumed that wherever overland flooding would cross roads it would be of a short enough duration and low enough hazard that it would be accounted for in the delays allowed for the in the TSF within the modelling.

There were three locations where the road network layer suggested roads cross the railway line but investigation showed that these crossings are all gated, so they were closed in the model. These locations are also shown in Figure 15.

In the model each road was assigned a number of evacuation lanes based on the number of lanes available in the direction of evacuation. This was groundtruthed using GoogleMaps aerial imagery and is also shown in Figure 15.

For scenarios 2, 3, A and B, committed road upgrades in Moorebank, Chipping Norton and Warwick Farm, as advised by Council, were incorporated into the evacuation models. These are shown in Figure 16 and include:

- Governor Macquarie Drive widening to two lanes in each direction between Newbridge Rd and Alfred Rd, between Alfred Rd and Childs Rd, and between Munday St to the racecourse access.
- an upgrade to the M5 Motorway westbound that will add two additional lanes connecting between east of the Moorebank Avenue and the intersection with the Hume Highway.

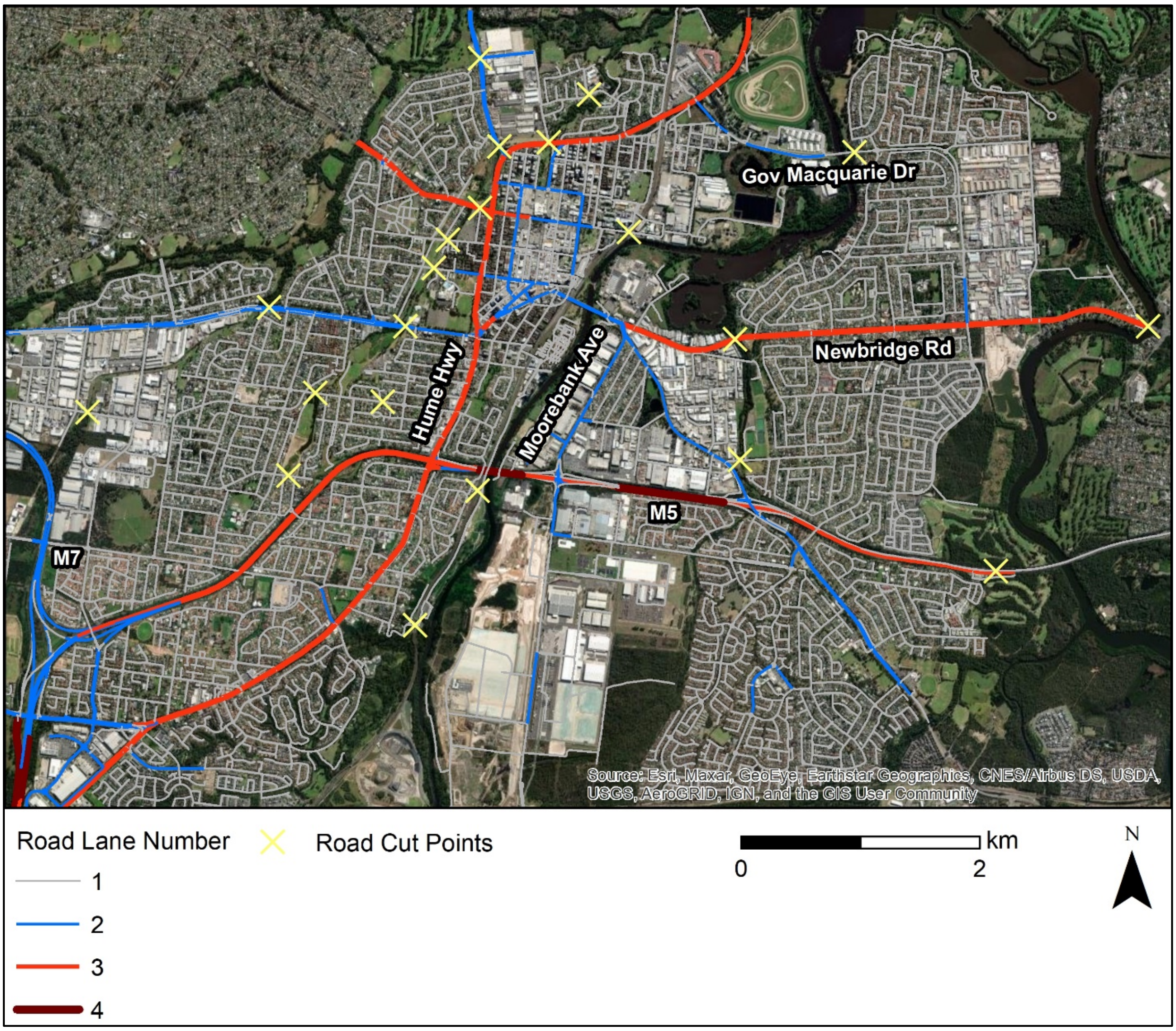


Figure 15. Road cut locations

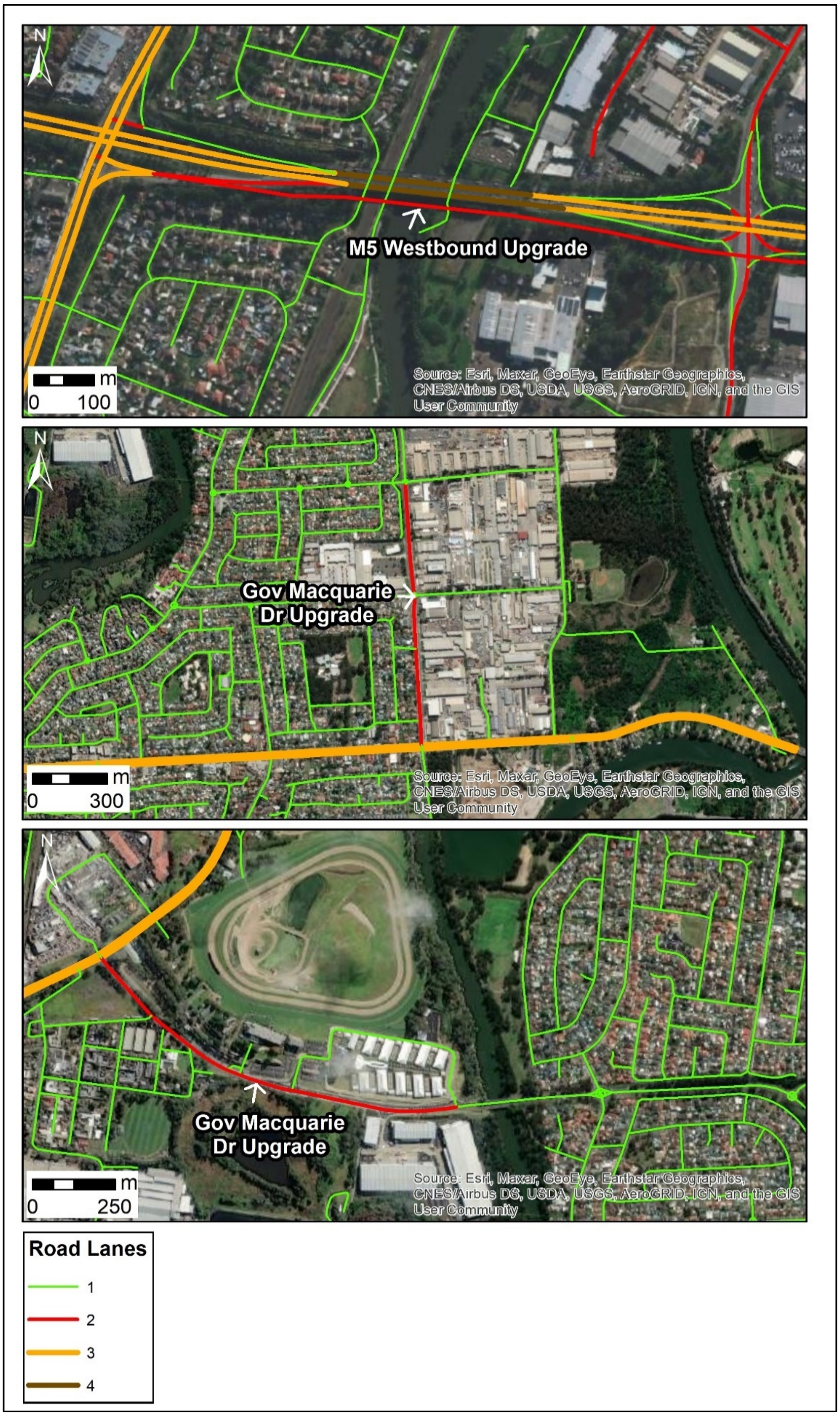


Figure 16. Road upgrades for the future scenarios including additional two lanes of M5 westbound traffic (top), and widening of Governor Macquarie Drive to two lanes in Chipping Norton (middle) and Warwick Farm (bottom)

5.4.5 Evacuating Vehicles

As advised by NSW SES, all of the modelled scenarios assume that all of the residential and non-residential premises in the lots that fall under the extent of the Georges River design PMF will need to be evacuated in the same event. The methodology ensured that those who both live and work within the study area were not double counted (i.e. only non-residential traffic originating from outside of the area was counted as the non-residential traffic originating within the floodplain was assumed to be counted in the residential traffic).

Each of the five modelled scenarios used different assumptions and inputs for the numbers of residential and non-residential vehicles distributed across the subsectors that require evacuation from the Georges River PMF. This is summarised in Table 1. Section 5.5 details the five modelled scenarios and the current and future residential and non-residential vehicle model inputs.

It was assumed that each evacuating vehicle would occupy 6 m of road for the purposes of representing traffic queueing in the model. The exception is that vehicles originating from the equestrian area in Warwick Farm were assigned a 15 m vehicle length to account for trailers being towed.

5.5 Modelled Scenarios

5.5.1 Scenario 1: Base Case

Existing building and vehicle numbers were used to develop the scenario 1 Base Case.

a) Residential

Molino Stewart developed a methodology using an integration of the flood model data, 2016 Australian Bureau of Statistics Census data, cadastre data, and Google Maps imagery to estimate the number of vehicles that would need to evacuate from existing residential developments in the study area.

The total number of dwellings based on the 2016 Census at the Mesh Block spatial scale (the smallest geographical area available) was distributed as whole integer numbers among the cadastre lots containing residential buildings that were affected by the Georges River PMF. Where the value of dwellings was higher than the number of lots within the Mesh Block, visual assessment using Google Maps Street View was used to determine which lots contained multi-dwelling residences (i.e. apartment blocks, or houses with granny flats) and the number of dwellings on the lots (i.e. using number of post boxes). Where the number of dwellings was slightly fewer than the number of lots, visual assessment in Google Maps was used to determine if any lots did not contain a unique dwelling (i.e. if there were single dwelling houses occupying two lots). Where the number of dwellings based on the 2016 census was clearly less than observed visual assessment in Google Maps, it was assumed that development had happened since 2016 resulting in additional dwellings. For example, there had been recent development in southwestern Moorebank (south of Brickmakers Drive) and Hammondville (i.e. the HammondCare development that is partially affected by the Georges River PMF). The majority of the newer development is relatively dense and on smaller lots, so typically only has one dwelling per lot. These lots were thus assigned a number of dwellings based on the Google Maps and Google Street View assessment (i.e. counting the number of mailboxes in a new subdivision).[3]

[3] Note that it has been determined that the number of vehicles requiring evacuation from Shepherd Street has likely been underestimated due to recent apartment developments (i.e., post-2016 census) that were not accounted for in the base case nor picked up as infill development but are included in the planning proposal.

Data on average residential vehicle ownership for each suburb (the lowest spatial resolution this data was available in) was calculated based on 2016 census data. This is shown in Table 9. Each residential lot containing at least one dwelling was assigned the average value of vehicles for its suburb, which was multiplied by the number of dwellings to result in a whole integer number of vehicles per lot. The remainder or excess of vehicles per suburb that resulted from whole-integer rounding was calculated. The remaining number of unassigned or excess vehicles were added or removed from lots to achieve the more accurate total number within the suburbs by either: 1) subtracting where necessary from multi-dwelling lots (i.e. apartment buildings) particularly close to public transport, or 2) adding to single-dwelling lots in suburban areas further from public transport.

Table 9. Current vehicle ownership rate (based on 2016 census)

Areas	Vehicles per Dwelling
Liverpool	1.31
Chipping Norton and Moorebank	2.03
Holsworthy, Wattle Grove, Hammondville,	2.00
Lurnea and Cartwright	1.63
Warwick Farm	1.14
Casula	1.95
Prestons – Edmondson Park	2.19

b) Non-Residential

Molino Stewart consulted with NSW SES and Infrastructure NSW (INSW) regarding a method for estimating the number of cars which might evacuate from the industrial and commercial areas, and the proportion of these which might need to evacuate at the same time as the residential areas. INSW provided guidance based on its government-endorsed methodology established as a part of the Hawkesbury-Nepean Valley Flood Risk Management Strategy (2016-2021) to inform evacuation modelling.

The base data used is Journey to Work Data (Transport for NSW, 2011) released by Transport Performance and Analytics (TPA), which is based on the 2011 Census of Population and Housing. It provides data at the Travel Zone geographical scale and includes data on the Origin Travel Zones (OTZ), Destination Travel Zones (DTZ) and mode of transport for every employee across NSW. Data was extracted from *Table 19: Origin TZ x Destination TZ x Mode9*, to calculate the number of employees who travel to work as the driver of a vehicle within the study area. This process entailed:

1. Determining the total number of vehicles entering each Travel Zone within the flood affected study area from outside of the study area;
2. Distributing the calculated number vehicles across the non-residential lots within each Travel Zone based on the lot's size.

Only vehicles that originated from outside of the study area and entered the study area's Travel Zones were included to avoid double counting vehicles already accounted for in the residential vehicle count. This approach means that the non-residential vehicle count does not include those that both live and work inside the study area (even in they live and work in different travel zones within the study area).

Additionally, only vehicle drivers were counted in assigning non-residential vehicles to lots.

The project managers for Australian Turf Club (ATC) (Mostyn Copper) were also consulted to understand the operating procedures and seek information to estimate the number of vehicles and horse floats which may need to evacuate from the equestrian zone and Warwick Farm Race Course (in subsector Hzone). This helped ensure our approach and assumptions are consistent with the typical operations of the race course and the nearby stables.

The ATC advised that while the race course operates every day of the year, there are only one to two events a year that would bring more than 1,000 people to the site. There are also 20 to 25 race days per year on the race course that would have fewer than 1,000 attendees. ATC also advised that in rainy weather, races would be cancelled (i.e. events cancelled due to poor weather in February 2020). There is a hotel located adjacent to the track available for people to stay in and patronage of the hotel is not always linked to race meetings.

Approximately 700 horses train daily at the track in the morning. They said that the majority of racehorses (500 to 600) stable "on course" within the equestrian area on the southern side of Governor Macquarie Drive and use an underground tunnel to travel between the stables and track. They advised that horse floats that may be present on site can transport up to 25 horses at a time. However, they could not advise how many horse floats are kept on site, or how many would be required for evacuation. Despite follow up, we did not receive specific data on the number of horse floats that would be required in the event of an evacuation.

Future development plans were also discussed, including plans to create a new stabling area on the northern side of Governor Macquarie Drive, as the current stabling area is flagged for future rezoning and redevelopment.

To account for this area in the model, we used the number of residential and non-residential for this area as per the above methodology (a total of 211) but allowed 15 m for the vehicle length (as opposed to the standard 6 m vehicle length) for all vehicles coming from this area to account for trailers being towed. Additionally, 245 vehicles were assigned to subsector I15, which encompasses the ATC track and adjacent hotel, accounting for the current parking capacity for visitors and hotel guests.

5.5.2 Scenario 2: Infill

All future scenarios modelled built on the existing base case Scenario 1. Scenario 2 accounted for increased residential and non-residential infill or intensified development and planned road works without any changes to zoning. This was based on data supplied by Council regarding forecasts of the likely dwelling and population growth to 2036. Council utilises Forecast .id data (Profile .id, 2021) as the preferred forecasting tool for demographics.

The data provided by Council was collated to match the study area as best as practically possible as informed by a Forecast .id representative. The Forecast .id data was reduced to match the Travel Zones that sit within the study area by:

- taking the dwelling count from 2016 for each small area and splitting that count by the proportion of the catchment that intersects with the area.
- using the growth profile of the small areas in the forecast data to apportion the growth into the appropriate catchments.

As summarised in Table 10 there may be potential for infill within R2, R3 and R4 residential zones. The potential for lots to increase their number of dwellings depends on their size, as well as a number of other factors specified in Liverpool's Development Control Plans. Therefore, not every lot meeting the size requirement would be able to increase its number of dwellings, but there is potential for more dwellings than currently present in these areas.

It was assumed that in the single R1 General Residential zone within the study area, there is no potential for an increased number of dwellings, although secondary dwellings may be permitted with consent. This is because these lots have recently been developed, and it was assumed this development has maximised the number of permissible dwellings per lot.

In R2 Low Density Residential, only lots that are greater than 400m^2 would have the potential to increase the number of dwellings from one to two per lot. As almost 80% of the R2 lots are larger than 400 sqm and have only one dwelling, there is high potential for an additional secondary dwelling within this zone.

R3 Medium Density additionally has high potential for infill development. Approximately one third of R3 lots are between 400 and 600 m^2 and only have one dwelling. These lots may be permitted to have a secondary dwelling. In addition, under the new NSW Government's Low Rise Housing Diversity Code, manor houses with four dwellings may be permitted on lots larger than 600 m^2. Approximately 43% of the R3 lots are greater than 600 m^2 and have fewer than four dwellings. Once again, there is high potential for these lots to increase their numbers of dwellings under these planning regulations.

R4 High Density Residential also would have a high potential for infill development. While the number of potential dwellings on lots is dependent on a number of factors, approximately half of the lots currently zoned R4 have only one dwelling and are larger than 400 m^2. Approximately 10% of the R4 lots currently have 10 or more dwellings. This alone implies that there is potential for a significant increase in number of dwellings without any changes to the current residential zoning.

Table 10. Current residential zoning and infill potential

Zoning	Lots	Current Dwellings	Current Dwellings per Lot	Potential for Infill
R1 General Residential	77	77	1	It is assumed that these lots have already been recently filled with their maximum permissible number of dwellings.
R2 Low Density Residential	4,524	5,025	1.11	Lots >400 m^2 may have two dwellings, which may apply to the approximately 80% of lots this size which only have one dwelling.
R3 Medium Density Residential	2,373	3,057	1.29	Lots between 400 and 600 m^2 may have two dwellings, which may apply to the approximately one third of lots this size which only have one dwelling. Lots >600 m^{2}may have four dwellings (i.e. manor house), which may apply to the approximately 43% of lots this size which have fewer than four dwellings.
R4 High Density Residential	818	3,806	4.65	High potential for infill.

In addition to the infill potential, there are 38 residential dwellings along Newbridge Road currently included within the evacuation area that are subject to the above-mentioned voluntary purchase scheme by Council due to their flood risk from the Georges River. It is expected that these lots will eventually be rezoned from residential to recreational, therefore decreasing the number of dwellings to zero in this area.

The infill scenario primarily included additional residential vehicles, but also accounted for the planned expansion from the Liverpool Hospital, which was the only non-residential addition. All other planned non-residential development locations were outside of the floodplain.

Based on information supplied by Council planners and projections published by Profile .id, the intensified development under existing zoning scenario incorporated 1,541 additional evacuating vehicles in the following locations within the study area[4]. These are shown in Figure 17. This includes:

- 821 non-residential vehicles added to the Liverpool Hospital location. This is based on a planned increase of 900 parking spaces to Liverpool Hospital (added to the existing car parking area west of the railway) and adjusted based on the current distribution of commuters between study area residents and non-residents (91.2% of workers in this travel zone come from outside of the study area travel zones)
- 720 residential vehicles were added to flood-affected residential lots in the study based on location-specific increases in dwelling density within R3 and R4 zoned areas, utilising the existing vehicle ownership rate, including:
    - 52 residential vehicles added to 6 Drummond St, Warwick Farm (which is a development proposal which was before Council)
    - 93 residential vehicles added to R3 and R4 zones in Chipping Norton
    - 575 residential vehicles added to R3 and R4 zones in Moorebank

It was decided to exclude the Moorebank Intermodal terminal from the evacuation analysis due to the fact that the majority of the developed part of the site is not directly impacted by the Georges River PMF, and additional land filling associated with this development is expected to occur. The site will only be isolated by the PMF. There should be sufficient opportunity to stop people from going into work, so it is not expected that this large number of workers will be evacuating at the same time as the rest of the study area.

5.5.1 Scenario 3: Planning Proposals

Council also advised of the details for planning proposals that are in progress or have been recently finalised within the study area (Table 11). It included approved development under construction at Site C in Moorebank East which gained approval after model set up had begun. Also, rezoning is already gazetted in Shepherd Street with several developments approved and constructed and others not yet approved. The values for additional evacuating vehicles were added to those from Scenario 2. The numbers of vehicles were calculated based on the provided numbers of new dwellings and jobs. Vehicle ownership rates as per the 2016 census were applied (Table 9).

Note that Scenario 2 evacuation also utilised planned road upgrades as discussed in Section 5.4.4.

Commercial and retail floor space and associated job estimates were supplied by Council. The number of vehicles per job were estimated from the Journey to Work data and multiplied by the number of jobs to estimate the number of cars on site. This value was then adjusted to only account for vehicle drivers coming from outside of the study area based on the ratios calculated from Journey to Work 2011 data for each relevant Travel Zone. For example, the number of jobs created in Moorebank East was multiplied by 0.77 to account for vehicle drivers only, and then multiplied by 0.69 to account for only vehicles coming from outside of the study area. This avoided double counting between residential and non-residential evacuating vehicles.

[4] It is recognized that this may be an underestimate due to potential redevelopment and intensification of residential areas where there are currently public housing estates within the floodplain (e.g. Hargrave Park). NSW Land and Housing Corporation (LAHC) currently has 1,298 dwellings in the study area across both Warwick Farm and Cartwright (only subject to creek flooding) with an average occupancy of 2 people per dwelling. LAHC has also informed this study that their development projection for the study area over the next 20 years is 481 additional dwellings, with 45% of the additional dwellings in Warwick Farm and 55% in Cartwright.

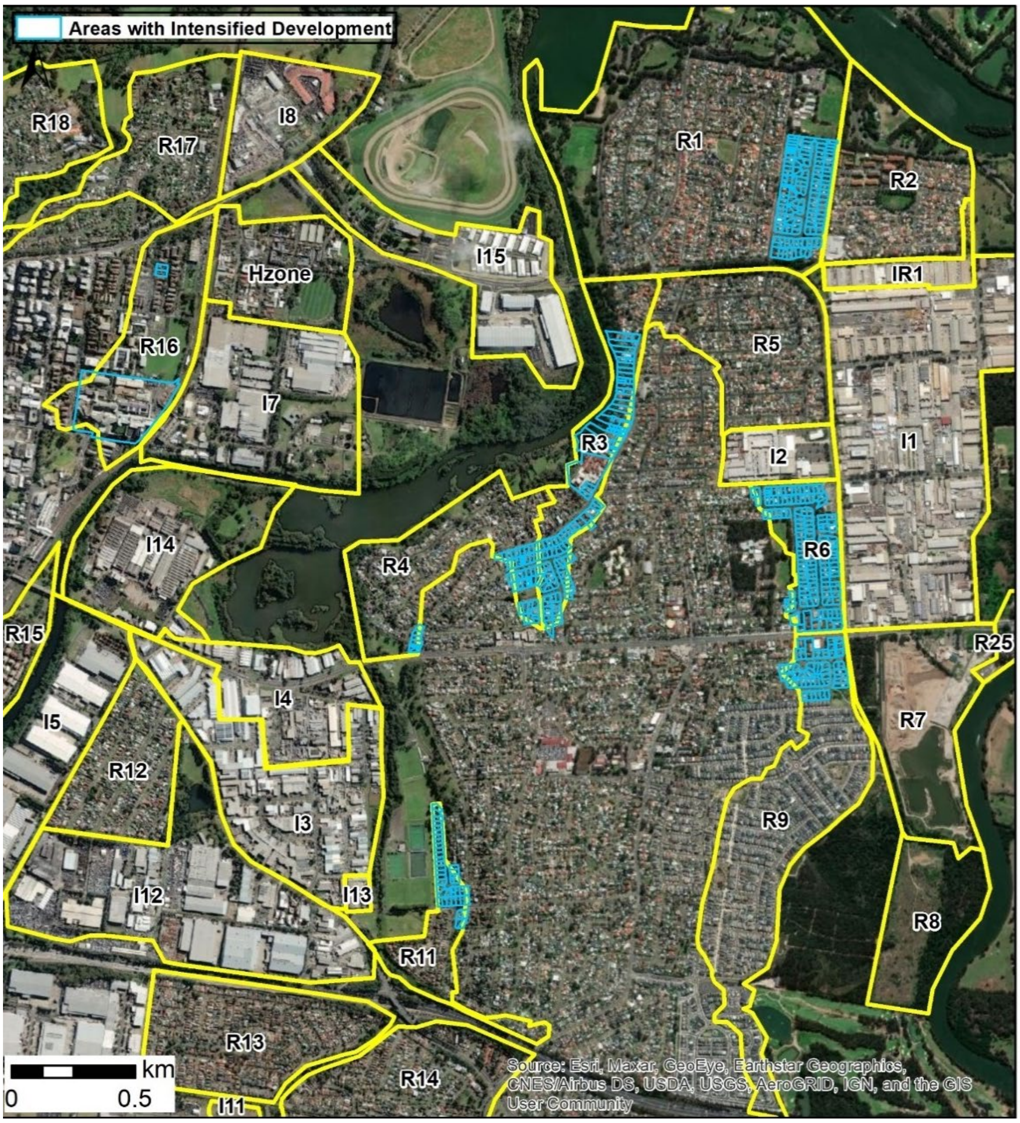


Figure 17. Locations where vehicles were added in scenario 2, showing potential for intensified development

There was a total of 61,671 vehicles added to the study area in the sites specified in Table 11 and shown in Figure 18.

It was assumed that Sites A, B, C and D at Moorebank east would share an exit via a new bridge onto Brickmakers Road from site C. The trigger level for the evacuation of these subsectors was level of a low Point on Brickmakers Road just south of this bridge.

In the case of Site E it was assumed that it would be constructed with an access road which rose continuously from the site to Brickmakers Road. The evacuation trigger for this site was therefore the 1% AEP flood level which was assumed to be the lowest flood level which would impact the habitable parts of the site.

It was acknowledged that development of Moore Point would involve filling habitable parts of the site to above the 1% AEP flood level. However, the evacuation trigger for this subsector is set by its evacuation route. For the modelling it was assumed that evacuation would be triggered when it was forecast that flooding would exceed 7.5m AHD.

For all other planning proposals the evacuation trigger was the same as it was for that cadastral lot in scenarios 1 and 2.

Scenario 3 evacuation also utilised planned road upgrades as discussed in Section 5.4.4.

Table 11. Additional vehicles in Scenario 3: Planning Proposals

Site	New Dwellings	Additional Population[1]	New Residential Vehicles[1]	New Jobs	New Non-Residential Vehicles	Total New Vehicles
Site A	126	391	255	857	459	714
Site B	602	1,866	1,219	361	193	1,412
Site C	179	555	363	--	--	363
Site D	374	1159	758	--[2]	--	758
Site E	2,000	6,200	4,052	207	111	4,163
Site F: Moore Point JLG	14,783	45,827	29,950	23,617	18,282	48,232
Site G: Moore Point Rose Group	536	1,662	1,086	91	70	1,156
Site H: The Grove			--	600	462	462
Site I: 240 Gov Macquarie Dr	500	1200	571	125	80	651
Site J: Warwick Farm Structure Place	1,465	3516	1,673	800	509	2,182
Site K: 33 Shepherd Street[3]	1,200	3,360	1,578	--	--	1,578
Total	21,765	65,736	41,505	26,658	20,166	61,671

1. Based on respective suburb's average people and vehicles per dwelling rates from the 2016 census.

2. There are an estimated 45 employees under Site D's existing deferred commencement consent for a Marina, however the modelling considered the residential planning proposal for the site.

3. This Planning Proposal is already gazetted with some developments approved and constructed and others pending approval.

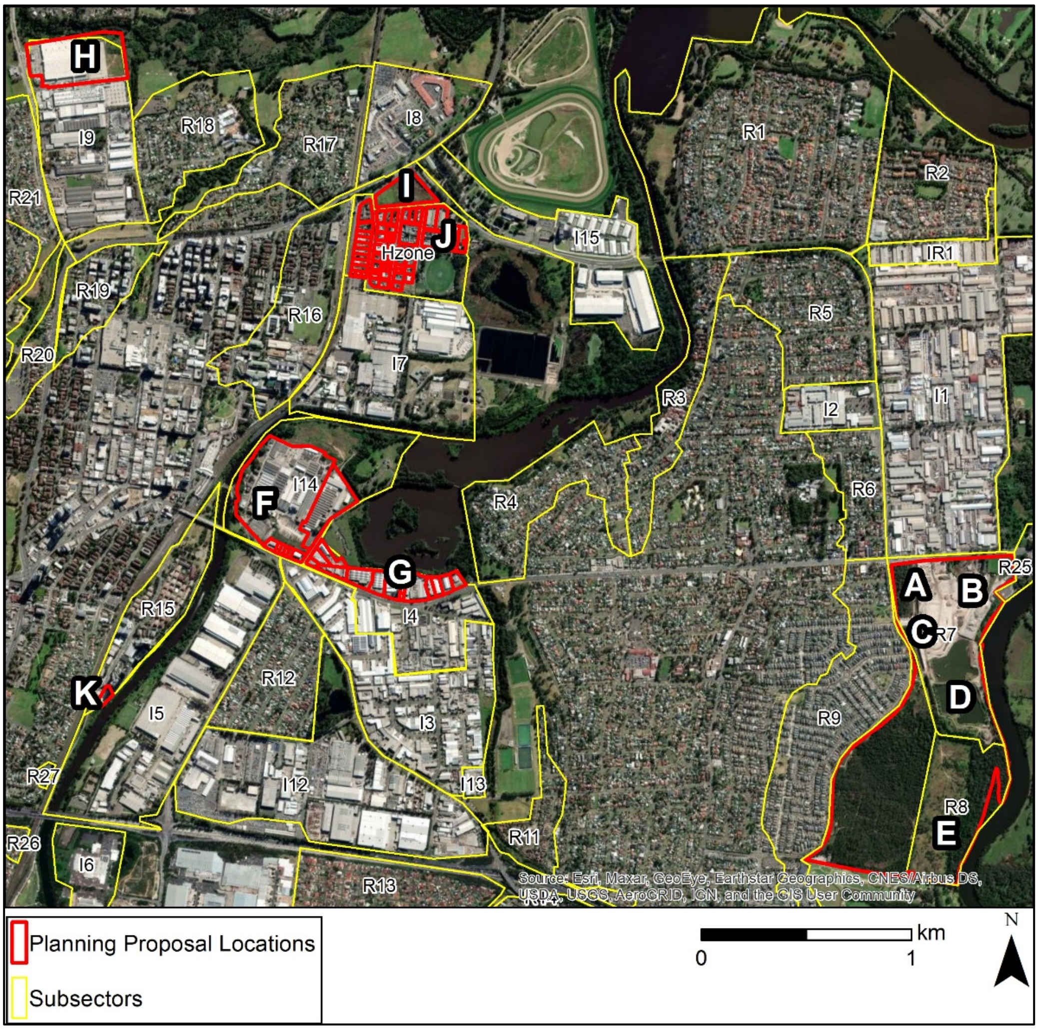


Figure 18. Location of additional planning proposal locations (letters refer to labels in Table 11)

5.5.2 Scenario A: Modified Infill

Following discussions with Council, Scenario 2 was modified and run as Scenario A. It is the same as Scenario 2 but with multiple non-residential vehicle evacuation destinations depending on the origin of the workers. These are:

- M7 north (i.e., the single destination of all vehicles in Scenarios 1, 2 and 3),
- Hume Motorway south,
- Camden Valley Way west, or
- M5 east

Workers' origins were determined from the 2011 Journey to Work data[5], as used in Scenarios 1, 2 and 3. Based on this data, drivers of vehicles working in the study area but not living in the study area come from:

- 30% come from north of the study area
- 30% come from the east of the study area

[5] The 2011 Journey to Work data was used since more recent 2016 Journey to Work data with the associated spatial data is not publicly available.

- 20% come from the south of the study area
- 20% come from the west of the study area

Therefore, from each subsector, the above proportions of non-residential evacuees were sent to the respective destinations.

In the case of those heading North, while many may have arrived at work via the Hume Highway or the Cumberland Highway, these roads cannot be relied upon as flood evacuation routes because of their risk of being cut by either Georges River or Cabramatta Creek flooding. Accordingly, the M7 heading north was the only northbound evacuation route in the model.

Furthermore, the M5 heading East is cut but flooding before all of the vehicles with this destination are able to evacuate. Therefore, vehicles with an eastern evacuation destination had their destination changed to North after t = 7 in the Georges River PMF timing, as they can no longer travel East. The M7 heading North is their only route to roads travelling east.

Non-residential vehicles from each subsector were each sequentially sent north, east, south and west based on the order in which they would leave.

Consideration was also given to the fact that not all residential evacuees would wish to head north on the M7 with many seeking alternative accommodation with family or friends or at commercial accommodation to the west, south or east or even within flood free areas of the study area. As there was no way to estimate in which direction these would head it was conservatively assumed they would all head north.

Where a planning proposal involved a mixed use development it was assumed that the non-residential traffic would leave first which is likely to be the case in a real evacuation with people more willing to leave their work places than their homes.

Note that Scenario A evacuation also utilised planned road upgrades as discussed in Section 5.4.4. The following evacuation route assumptions were made:

- Arrangements would be made to create a flood emergency access route between Homepride Avenue and Orange Grove Road using existing private accessways
- Camden Valley Way would have two lanes each of 600 vehicles per hour capacity and the vehicle destination is west of the M7 on ramp;
- The Hume Highway south of Camden Valley Way would continue south as three lanes (Campbelltown Road) each with a 600 vehicles per hour capacity, which narrows to two lanes and then a single lane before it merges with the M5;
- The M5 after its M7 offramp would continue south as two lanes each of 600 vehicles per hour capacity until it merges with the Hume Highway;
- Once the Hume Highway and the M5 merge they become the Hume Motorway which continues south as a four lane road;
- While the M5 heading east has three lanes, to account for other traffic streams entering it from elsewhere, the model has assumed that it only has a single lane available for traffic coming from the study area. The evacuation destination is east of the University of Western Sydney Campus (past a low point west of that which can be inundated).

It was recognised that Camden Valley Way can be cut by local flooding in the 1% AEP flood and possibly more frequent events where it crosses Cabramatta Creek and theoretically is does not satisfy NSW SES requirements as a regional flood evacuation route. However, it gets cut for about 2 hours or less in the 0.2% AEP Cabramatta Creek flood. However, there is considerable flood free land in Prestons between the M7 and Cabramatta Creek where evacuating vehicles could wait if required. About 500 vehicles can queue on the two west bound lanes of Camden Valley way between Cabramatta Creek and one of its tributaries to the east. In Scenario A, there are 2,710 non-residential vehicles with a West destination.

5.5.3 Scenario B: Modified Planning Proposals

Following discussions with Council, Scenario 3 was modified and run as Scenario B. This included the following modifications:

- Updated numbers of vehicles from proposed residential and non-residential areas for all developments as per Table 12. This included an assumption that there would only be one vehicle for each new residential apartment building;
- Non-residential vehicle traffic evacuates to multiple destinations depending on the origin of the workers as per the ratios and description in Scenario A (i.e. M7 north, Hume Motorway south, Camden Valley Way west or M5 east) and as per the road modifications in Scenario A;
- The two on ramps from the Hume Highway and M5 would have their capacity increased to 900 vehicles per lane per hour through upgrades as advised by TfNSW;
- An added third lane heading north on the M7 as advised by TfNSW.

Note that Scenario B evacuation also utilised planned road upgrades as discussed in Section 5.4.4.

Table 12. Scenario B assumptions and vehicle numbers

Site	New Dwellings	Additional Population[1]	Vehicles per New Dwelling	New Jobs	New Non-Residential Vehicles	Total New Vehicles
Site A	126	391	1	857	459	585
Site B	602	1,866	1	361	193	795
Site C	179	555	2.03	--	--	363
Site D	374	1,159	1	--[2]	--	374
Site E	1,500	4,650	1	207	111	1,611
Site F: Moore Point JLG	12,200	37,820	1	16,648	12,888	25,088
Site G: Moore Point Rose Group	1,854	5,747	1	6,352	4,917	6,771
Site H: The Grove	--		--	600	462	462
Site I and J: Warwick Farm Structure Plan including 240 Gov Macquarie Dr	3,224	7,738	1	925	485	3,709
Site K: 33 Shepherd St[3]	1,200	3,360	1	--	--	1,200
Total	21,259	63,286		25,950	19,515	**40,958**

1. Based on respective suburb's average people per dwelling rate from the 2016 census

2. There are an estimated 45 employees under Site D's existing deferred commencement consent for a Marina, however the modelling considered the residential planning proposal for the site.

3. This Planning Proposal is already gazetted with some developments approved and constructed and others pending approval

In these specific locations, it was assumed that all existing development would be removed before the new development occurred, and so these values were not added to the Scenario 1 or Scenario 2 values within these lots.

6 | Life Safety Model Outputs

6.1 Interpretation of Results

Outputs from the LSM can be presented in a number of ways including interactive animations, videos, graphs and tables. For the purposes of this discussion, screen shots from the animation of the evacuating vehicles have generally been used to illustrate particular points. An AVI files of the model animations have been provided separately so that the outputs can be viewed in more detail than can be conveyed in the static images in this report.

The key to interpreting the screen shots is that:

- Shades of blue represent the extent of the Georges River PMF at a particular time step with deeper shades indicating greater water depth.
- The fine grey lines represent the road network which has been included in the model. This has been edited to block access down inaccessible sections of road which are either permanently closed by a locked gate or are unlikely to be reliable during a flood evacuation because they could be cut by local creek flooding.
- Dark purple squares represent the locations of vehicles at properties which have not yet been ordered to evacuate. Where there are multiple vehicles at a property only one square is visible but in the model there are many vehicles allocated to that location.
- Mauve squares represent vehicles on properties where the occupants have been made aware of the need to evacuate but have not yet evacuated.
- Yellow squares are evacuating vehicles at the location they would be found at the associated time step.
- Red squares are vehicles (or clusters of vehicles) which have been caught by floodwaters
- The time code is shown in the top right corner and displays the hours and minutes relative to the start of flooding in the Georges River PMF design flood event.

As explained in Section 5.4.1, it has been assumed that the evacuation order for each subsector will be given 12 hours prior to its trigger level being reached as this is the anticipated minimum warning time which will be available for flooding exceeding 4.0 m at Liverpool and Milperra Gauges. This means that most subsectors would receive evacuation orders prior to time step 0 in the PMF design flood event.

There are buildings in the model which do not need to be evacuated in the Georges River PMF, which have been included in order to run possible later sensitivity testing taking into account evacuation from local creek flooding while evacuation from the Georges River is also taking place. These remain dark purple for the entire model run.

As advised by the NSW SES, the primary final destination for all evacuation vehicles in the model is traveling north on the M7, although multiple destinations are included for non-residential vehicles in Scenarios A and B. As shown in the screen shots, the majority of traffic evacuates onto the M7 either via the M5 traveling westbound or from the Hume Highway via Camden Valley Way.

6.2 Scenario 1 Results

6.2.1 Raw Results

Appendix B Figures B1 to B6 show excerpts of the Scenario 1 base case LSM at key time steps, which are:

- T = -5:25 hours (Figure B1): The first evacuation wave occurs of vehicles leaving from R25 on Newbridge Road in the east of the study area. These have to evacuate very early before the Georges River cuts Newbridge Road at the western end of the subsector.
- T = -2:55 hours (Figure B2): The next wave of evacuation occurs with vehicles leaving predominantly industrial subareas in west Moorebank (e.g. I3, I5 and I13). Their primary evacuation route is south on Moorebank Avenue to the M5. There are also some low lying homes west of the river (R26) which evacuate onto the Hume Highway at this time.
- T = 0 hours (Figure B3): As the modelled PMF begins to rise, evacuation is underway across the study area. Almost all of Chipping Norton is preparing to evacuate or is already evacuating south onto the M5 via Nuwarra Road and Heathcote Road. The industrial and residential areas in west Moorebank are all preparing to evacuate, evacuating or have already evacuated onto the M5 via Moorebank Avenue. Subsectors in Warwick Farm are preparing or starting to evacuate via the Hume Highway. Lanes of traffic from the M5 and from Camden Valley Way via the Hume Highway are entering the M7 to travel northwest out of the study area. There is significant traffic queueing throughout the Moorebank Peninsula while evacuation traffic on the Hume Highway is travelling more freely.
- T = 5 hours (Figure B4): Floodwater approaches properties on the Moorebank peninsula, including in Chipping Norton. All properties that have not yet evacuated on the Moorebank peninsula are prepared to evacuate, however there is extensive queueing to get onto the M5 via Nuwarra Road and Heathcote Road. The remaining vehicles from subareas in west Moorebank are evacuating. Vehicles from Warwick Farm subsectors I9 and R18 are starting to evacuate but have no evacuation routes on public roads which do not cross a low point on a local creek and so in the model are trapped within their subsectors due to road cuts. Traffic continues to merge onto the M7 from the M5 and from Camden Valley Way/ Hume Highway but with six lanes merging into two there is queueing on the Hume Highway and even longer queues on the M5. Nuwarra Road is at capacity with queued vehicles and other roads leading into it are also experiencing queueing.
- T = 12 hours (Figure B5): Traffic traveling to the M7 is queued on the M5 over the Georges River, and on the Hume Highway. Access onto the M5 from Moorebank Avenue is cut by floodwaters at t = 11 and the M5 itself is cut nearby at t = 12.5. At this latter point the Moorebank peninsula becomes a high flood island. Some vehicles from I1, R1, R2 and IR1 in Chipping Norton have been caught by floodwaters.
- T = 28:30 hours (Figure B6): At the end of modelled PMF, the number of vehicles that are caught by the flood water (red cells) at the end of the model are:
    - I1 (Chipping Norton): 94 vehicles
    - IR1 (Chipping Norton): 6 vehicles
    - R1(Chipping Norton): 11 vehicles
    - R2(Chipping Norton): 22 vehicles
    - **Total: 133 vehicles**

  The subsectors that are trapped due to a lack of flood free road access are:
    - I9 (Warwick Farm): 258 vehicles
    - R18(Warwick Farm): 237 vehicles
    - **Total: 495 vehicles**

The primary evacuation routes utilised in the model are:

- The primary route for Chipping Norton and Moorebank East onto the M5 is via Nuwarra Road and the Heathcote Road on ramp. This route has extensive queueing throughout the model.
- Moorebank West enters the M5 via the Moorebank Avenue on ramp.
- Traffic from the Hume Highway which is a primary route for vehicles from Warwick Farm and Liverpool CBD, enters the M7 via Camden Valley Way.

6.2.2 Applying the Traffic Safety Factor

The modelling results presented in the preceding discussion represent evacuee and evacuation traffic behaviour based on assumptions set out by the NSW SES in its Timeline Evacuation Model. However, LSM does not account for the NSW SES recommended Traffic Safety Factor (TSF). This is normally added to the time taken to evacuate an area to account for the potential for incidents such as vehicle accidents or breakdowns, fallen trees or power lines or water across the road.

Appendix C shows the TSF calculated for each subsector based on the elapsed time that there are vehicles travelling out of the subsector (time on road (TOR)). The difference between the Required Time (which equals TSF + Warning Acceptance Factor + Warning Lag Factor+ TOR) and the Available Time, the subsectors that do not have enough time to evacuate (i.e. a negative Surplus Time) have been identified.

Based on initial calculations, these subsectors are: R18, I9, R17, R27, R11, I1, R1, R2, I2, R16, R5, and R3. However, a more detailed analysis accounting for the time it takes for floodwaters to rise within each subsector with rising road access showed that several of these subsectors are likely do have enough time to evacuate because vehicles will be able to evacuate before flood waters reach them even accounting to the TSF.

The remaining subsectors that would have a problem directly when accounting for TSF are:

- R18 (Warwick Farm)
- I9 (Warwick Farm)
- I1 (Chipping Norton)
- R1 (Chipping Norton)
- R2 (Chipping Norton)
- IR1 (Chipping Norton)

R18 and R9 are a special case because they do not have any evacuation route on a public road which does not involve a low level creek crossing. Thus, these subsectors cannot evacuate irrespective of whether the TSF is taken into account.

Subsectors I1, R1, R2 and IR1, which are all in Chipping Norton, are low flood islands which will all have less time to get past the evacuation route low point before it is cut by floodwaters when the TSF is taken into account. However, because the traffic is queued back into these subsectors and not moving for a few hours before their evacuation routes are cut, accounting for the traffic safety factor makes no difference to the number of trapped vehicles here.

Vehicles that do not make it west of the low point on the M5 located at the Moorebank Avenue underpass would become trapped on the Moorebank peninsula. This includes all vehicles queued in Chipping Norton and Moorebank, and queued on the M5 to the east of this point. As mentioned previously, this point gets cut at t=12.5 in the model. However, to account for a 3 hr TSF, the number of vehicles east of this point were counted in the model at t = 9.5 (Figure 19). A total of 2,367 vehicles, originating from the following subsectors, would be trapped within the Moorebank Peninsula. Note that these numbers include those that are eventually overtaken by floodwaters.

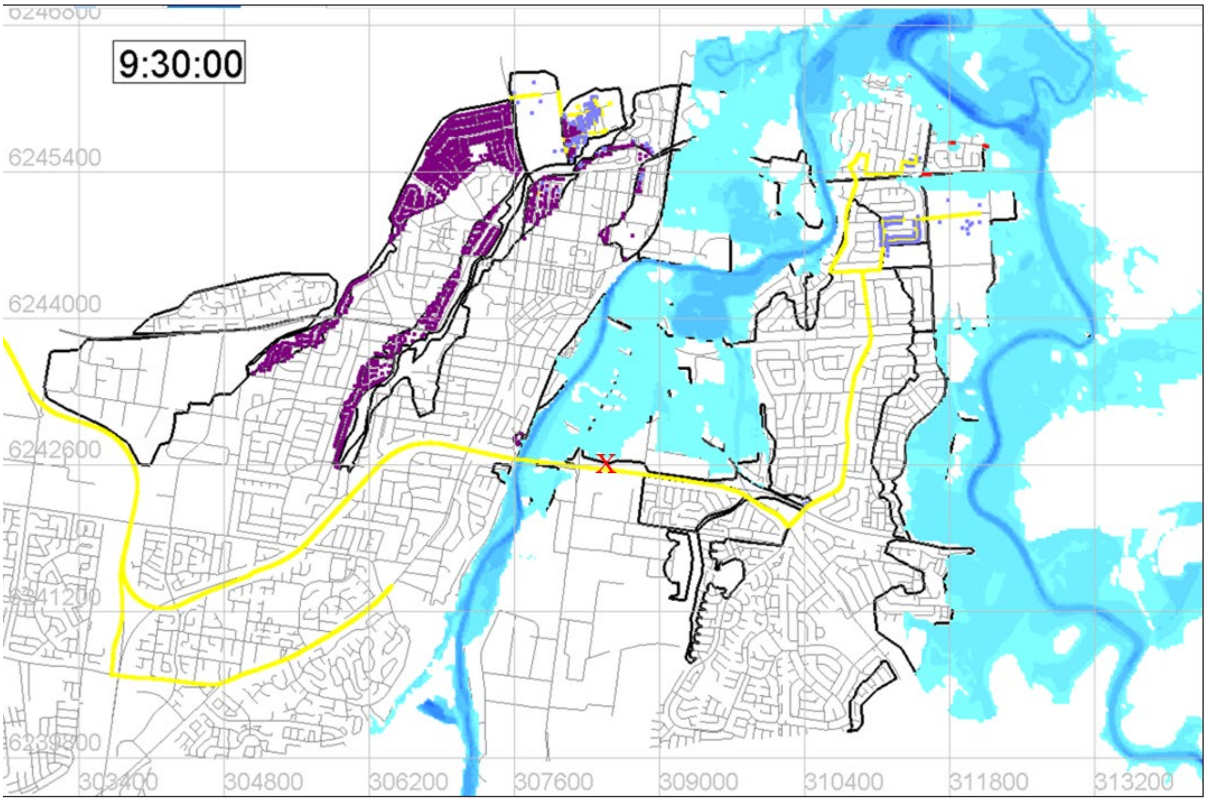


Figure 19. Georges River PMF timestep 9.5 with X at road cut location on the M5 (Scenario 1: Base Case)

6.2.3 Scenario 1 Summary

The results of Scenario 1: Base Case are summarised in Table 13 and Figure 20. To assist in interpreting the table:

- Vehicles on a road (driving or queuing) when the road is inundated by floodwaters are referred to as "caught" by floodwaters.
- Vehicles that do not have a possible evacuation route on public roads (that do not cross a low point on a local creek/ flooded road) are "trapped due to a lack of flood free access" and cannot evacuate from their subsectors.
- It is estimated that the model accounts for, on average, less than two people per vehicle (an average of between 1.5 to 2 people per residential vehicle and one person per non-residential vehicle).

Table 13. Scenario 1: Base Case (2016) Results

Caught by flood waters	Trapped due to a lack of flood free road access	Trapped on the Moorebank Peninsula[1]
I1 (Chipping Norton): 94 vehicles	I9 (Warwick Farm): 258 vehicles	I1(Chipping Norton): 695 vehicles
IR1 (Chipping Norton): 6 vehicles	R18 (Warwick Farm): 237 vehicles	I2(Chipping Norton): 88 vehicles
R1 (Chipping Norton): 11 vehicles		IR1 (Chipping Norton): 1 vehicle
R2(Chipping Norton): 22 vehicles		R1 (Chipping Norton): 469 vehicles
		R2 (Chipping Norton): 368 vehicles
		R3 (Chipping Norton): 16 vehicles
		R5 (Chipping Norton): 674 vehicles
		R6 (Chipping Norton): 50 vehicles
		R11 (Moorebank): 6 vehicles
Total: 133 vehicles	**Total: 495 vehicles**	**Total: 2,367 vehicles**

1. These numbers include those that are eventually overtaken by floodwaters in Chipping Norton.

These results indicate that 2,862 vehicles (with one to two people per vehicle), or about 10% of the approximately 27,500 total modelled vehicles, do not successfully evacuate and are affected by flooding in Scenario 1.

6.3 Scenario 2 Results

While Scenario 2 includes 1,541 additional vehicles compared to the base case, evacuation benefits from additional road capacity. In particular, the planned two-lane addition to the M5 over the Georges River (included based on advice from Council) improves evacuation capacity from Moorebank and Chipping Norton because some of the traffic from the M5 goes onto the Hume Highway and utilises spare capacity on that road and its on-ramp to the M7 which was not being fully utilised in the base case.

Appendix B Figures B7 to B9 show excerpts of the Scenario 2 at key time steps where they differ from the base case. These are:

- T = 5 hours (Figure B7): As in the base case, there is still some queueing to get onto the M5 via Nuwarra Road, however this is reduced due to the additional two westbound M5 lanes. There is additional queuing on the Hume Highway to get onto the M7 via the Camden Valley Way compared to the base case because some M5 traffic has been diverted onto the Hume Highway.
- T = 12 hours (Figure B8): By the time the M5 westbound is cut by floodwaters, more vehicles have been able to evacuate from the Moorebank peninsula compared to the base case (i.e. no vehicles from R1 are caught by floodwaters, and 20 fewer vehicles from R2 are caught by floodwaters). There is significant queuing on the Hume Highway, which is back up to Liverpool, slowing evacuation from Warwick Farm and Liverpool CBD. This did not happen in the base case and has been caused by traffic from the M5 taking up capacity on the Hume Highway
- T = 28.5 hours (Figure B9): At the end of the modelled PMF, accounting for the TSF, 155 vehicles are caught by flood waters (red cells)

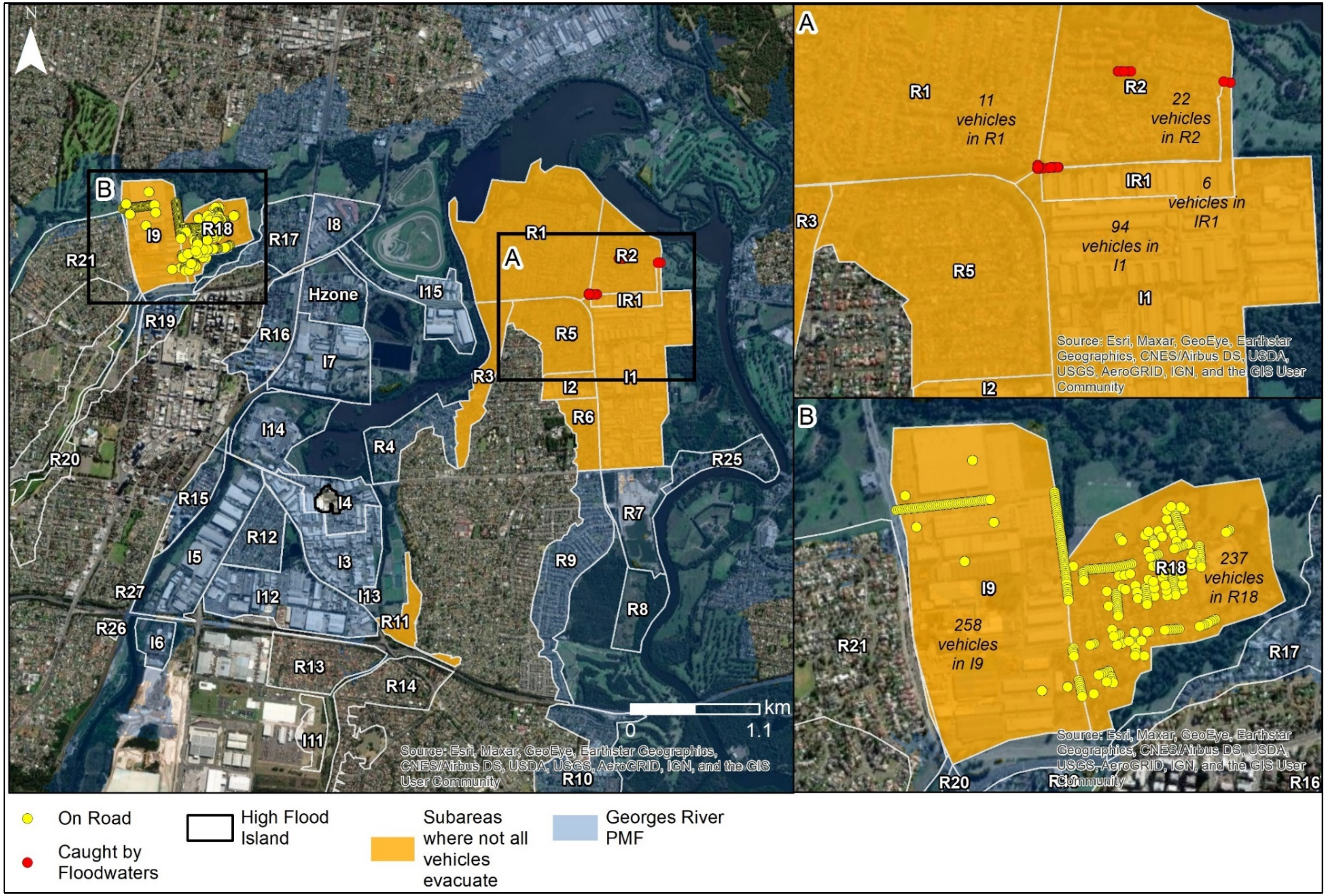


Figure 20. End results of Scenario 1 showing subsectors where vehicles do not successfully evacuate, and vehicles trapped on the road or caught by floodwaters.

This is 22 vehicles more than in the base case, and the vehicles are from different subsectors. Whereas the base case had a total of 133 vehicles from northern Chipping Norton caught by floodwaters, in Scenario 2, this is reduced to 106 vehicles. The remaining 49 vehicles caught by flood waters are from R16, which is the subarea including Liverpool Hospital. It is noted that the model sends vehicles along the shortest route to the M7 and where these vehicles are trapped in Liverpool there are other flood free routes above the PMF which are available, so they are not likely to actually get trapped.

The subsectors that are trapped due to a lack of flood free road access are the same as in the base case:

- I9 (Warwick Farm): 258 vehicles
- R18 (Warwick Farm): 237 vehicles
- **Total: 495 vehicles**

A total of 399 vehicles are trapped on the Moorebank peninsula when the M5 gets cut at t = 9.5. Note that these numbers include those that are eventually overtaken by floodwaters.

The primary evacuation routes utilised in the model are:

- Chipping Norton and Moorebank East use the M5 via Nuwarra Road and the Heathcote Road on ramp. The traffic moves more quickly on the M5 westbound due to the additional M5 lanes diverting of some of that traffic onto the Hume Highway.
- Moorebank West enters the M5 via the Moorebank Avenue on ramp, which has less queueing compared to the base case due to the additional M5 lanes diverting of some of that traffic onto the Hume Highway.
- Scenario 2 has more queueing on the Hume Highway than the base case, as vehicles travel to the M7 via Camden Valley Way. This is the primary route for vehicles from Warwick Farm and Liverpool CBD. This additional queuing is because some of the M5 traffic is diverted onto the Hume Highway.

The results of Scenario 2: Infill are summarised in Table 14 and Figure 21.

Table 14. Scenario 2: Future Infill with Existing Zoning Results

Caught by flood waters	Trapped due to a lack of flood free road access	Trapped on the Moorebank Peninsula[1]
I1 (Chipping Norton): 94 vehicles	I9 (Warwick Farm): 258 vehicles	I1 (Chipping Norton): 57 vehicles
IR1 (Chipping Norton): 10 vehicles	R18 (Warwick Farm): 237 vehicles	I2 (Chipping Norton): 21 vehicles
R2 (Chipping Norton): 2 vehicles		IR1 (Chipping Norton): 1 vehicle
R16 (Liverpool): 49 vehicles		R1 (Chipping Norton): 125 vehicles
		R2 (Chipping Norton): 83 vehicles
		R5 (Chipping Norton): 106 vehicles
		R11 (Moorebank): 6 vehicles
Total: 155 vehicles	**Total: 495 vehicles**	**Total: 399 vehicles**

[1]*Note that these numbers include those that are eventually overtaken by floodwaters in Chipping Norton.*

These results indicate that 943 vehicles (with one to two people per vehicle), or about 3% of the approximately 29,000 total modelled vehicles, do not successfully evacuate and are affected by flooding in Scenario 2.

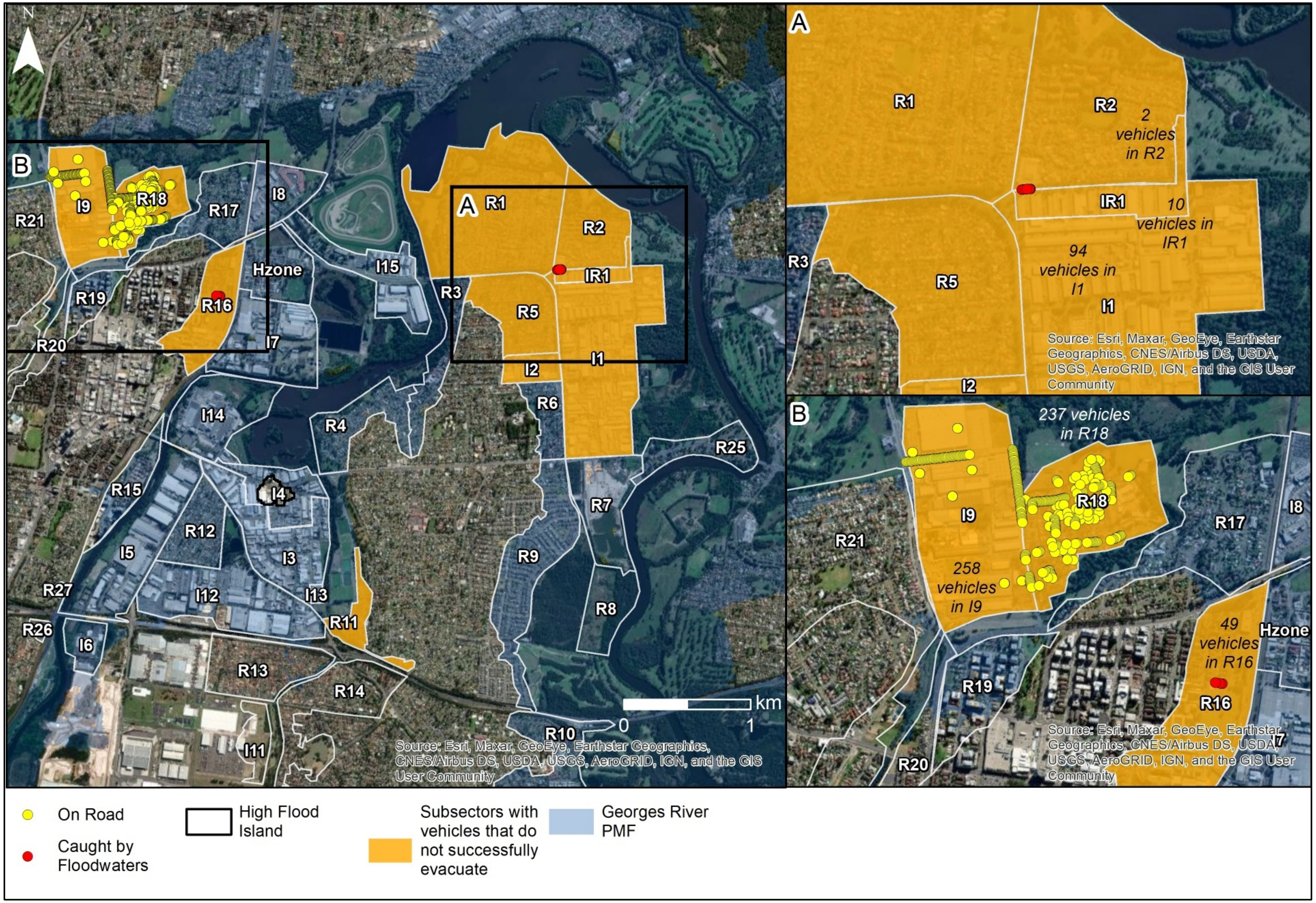


Figure 21. End results of Scenario 2 showing subsectors where vehicles do not successfully evacuate, and vehicles trapped on the road or caught by floodwaters.

6.4 Scenario 3 Results

Scenario 3 includes the addition of 61,671 vehicles in the study area. Appendix B Figures B10 to B14 show excerpts of Scenario 3 LSM at key time steps where they differ from the base case. These are:

- T = -2:55 hours (Figure B10): Due to the large number of additional vehicles, there is immediately queuing as soon as evacuation starts in western Moorebank. There is a bottleneck as traffic enters the M5 westbound via Moorebank Avenue.
- T = 0 hours (Figure B11): Compared to the base case, there is more queueing throughout the entire study area. While there is road capacity still available on the M5 due to the addition of the two additional westbound lanes, there are bottlenecks at the M5 on ramps at Moorebank Avenue and Heathcote Road which are both single lane. There is also significant queuing on the Hume Highway and Camden Valley Way to get onto the M7 from Liverpool and Warwick Farm.
- T = 5 hours (Figure B12): Despite the additional westbound M5 road capacity compared to the base case, there are traffic bottlenecks at the M5 on ramps at both Moorebank Avenue and Heathcote Road. Compared to the base case, there are many more vehicles remaining on properties ready to evacuate in Moorebank (i.e. I4 and R12) where they cannot yet leave, as the roads are too full to accommodate additional vehicles. In addition, there is significant queuing to get onto the M7 via the Hume Highway. In Warwick Farm, there are also many vehicles ready to evacuate that cannot leave due to lack of road capacity, while in the base case, vehicles in this area had already been evacuated.
- T = 12 hours (Figure B13): There remains extensive queuing on all primary evacuation routes, as vehicles have been caught by flood waters throughout the study area in Chipping Norton, Moorebank, Warwick Farm and Liverpool. There are vehicles stranded on the roads and on the properties on a high flood island that forms in I4 in west Moorebank, that reduces in size as PMF flood waters continue to rise. There are still vehicles that are ready to evacuate but cannot due to lack of road capacity in Chipping Norton, Warwick Farm and Moorebank.
- T = 28:30 hours (Figure B14): At the end of the modelled PMF, accounting for TSF, 51,199 vehicles are caught by flood waters (red cells)

As opposed to Scenarios 1 and 2 where only four subareas had vehicles caught by flood waters, Scenario 3 results in vehicles trapped in flood waters throughout the entire study area, in Moorebank, Chipping Norton, Liverpool and Warwick Farm.

The subsectors that are trapped due to a lack of flood free road access are the same as in the base case, however there are more vehicles that have been unable to evacuate from I9 because there are more vehicles in that area due to the planning proposal:

- I9 (Warwick Farm): 720 vehicles
- R18 (Warwick Farm): 237 vehicles
- **Total: 957 vehicles**

A total of 8,679 vehicles (including those that are eventually overtaken by floodwaters) are trapped on the Moorebank peninsula when the M5 gets cut. There are 9,673 vehicles also trapped on the roads in I4 in western Moorebank, where a small high flood island remains.

The results of Scenario 3: Planning Proposals are summarised in Table 15 and Figure 22.

Table 15. Scenario 3: Future Planning Proposals

Caught by flood waters		Trapped due to a lack of flood free road access	Trapped on roads/ Moorebank Peninsula
R1 (Chipping Norton): 956	R2 (Chipping Norton): 647	I9 (Warwick Farm): 720	I4 (Moorebank): 9,673 vehicles trapped on the high flood island
I1 (Chipping Norton): 1,514	R5 (Chipping Norton): 35	R18 (Warwick Farm): 237	8,579 vehicles trapped on the Moorebank Peninsula[1]
IR1 (Chipping Norton): 104	R6 (Chipping Norton): 258		
I14 (Moorebank): 38,171	R7 (Moorebank): 996		
I4 (Moorebank): 891	R8 (Moorebank): 1,353		
I5 (Moorebank): 33	R9 (Moorebank): 956		
R12 (Moorebank): 122	R15 (Liverpool): 510		
I12(Moorebank): 659	I7 (Liverpool): 782		
R16 (Liverpool): 1,421	R17 (Warwick Farm): 74		
Hzone (Warwick Farm): 1,717			
Total: 51,199 vehicles		**Total: 957 vehicles**	**Total: 18,252 vehicles**

[1]*Note that these numbers include those that are eventually overtaken by floodwaters in Chipping Norton and Moorebank.*

These results indicate that at least 61,829 vehicles (with one to two people per vehicle), or about 69% of the approximately 89,200 total modelled vehicles, do not successfully evacuate and are affected by flooding in Scenario 3 (note that, to avoid double counting, this estimate does not include the count of additional vehicles trapped on the Moorebank Peninsula but not caught by floodwaters in Table 15).

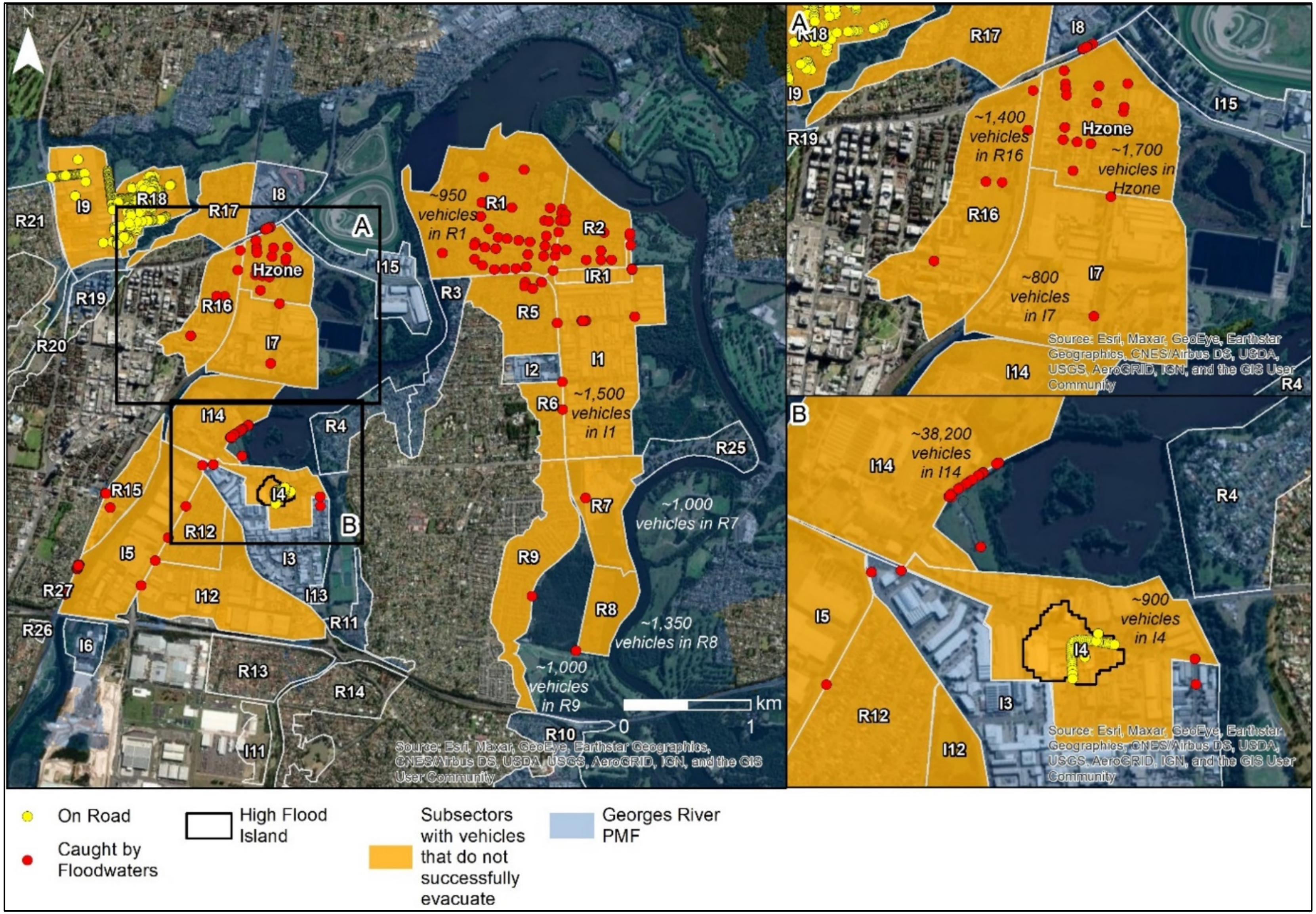


Figure 22. End results of Scenario 3 showing subsectors where vehicles do not successfully evacuate, and vehicles trapped on the road or caught by floodwaters.

6.5 Scenario A Results

Scenario A represents an improvement from Scenario 2, as non-residential traffic has additional evacuation destinations and a private evacuation route has been included to account for I9 and R18 evacuation. There are slightly fewer vehicles trapped in total compared to Scenario 2. These vehicles come from the same subsectors as Scenario 2, however slightly more vehicles are trapped from some subsectors and slightly fewer from other subsectors. This is likely due to the random merging of vehicles in the model. Appendix B Figures B15 through B18 show excerpts of the Scenario A model run at key time steps. These are:

- T = -2:55 hours (Figure B15): Vehicles leave predominantly industrial subareas in west Moorebank (e.g. I3, I5 and I13). The primary evacuation routes are south on Moorebank Avenue to the M5, or on the Hume Highway for vehicles originating from west of the river (e.g. R26). Non-residential vehicles also travel east on the M5. Vehicles whose destinations are west or south are travelling west on Newbridge Road to the Hume Highway.
- T = 5 hours (Figure B16): As in the previous scenarios, there is still some queueing to get onto the M5 via Nuwarra Road, however this is reduced compared to previous scenarios. Evacuation of western Moorebank is occurring more quickly compared to Scenario 2. There is less queuing on the Hume Highway to get onto the M7 via the Camden Valley Way compared to Scenario 2.
- T = 8:35 hours (Figure B17): At this time, the first vehicles are overtaken by floodwaters in Chipping Norton (IR1). This is because of the amount of queuing on Nuwarra Road, preventing all of northern Chipping Norton from evacuating before the roads flood. It is also noted that vehicles are able to evacuate from I9 and R18 due to the provision of flood-free road access through subsector I9.
- T = 28.5 hrs (Figure B18): At the end of the modelled PMF, accounting for TSF, there are 97 vehicles caught by floodwaters (red cells).
- When the Moorebank Peninsula is cut off by floodwaters, accounting for TSF, there are 227 vehicles trapped on the Moorebank peninsula accounting for TSF. The above vehicles caught by floodwaters are included in the numbers below, but all of these vehicles do not necessarily get overtaken by floodwaters as they rise, as there is some queueing capacity on the roads above the floodwaters.

The detailed results of Scenario A are summarised in Table 16 and Figure 23.

Table 16. Scenario A: Modified Future Infill Results

Caught by flood waters	Trapped on the Moorebank Peninsula[1]	Trapped due to a lack of flood free road access
I1 (Chipping Norton): 93 vehicles	I1 (Chipping Norton): 19 vehicles	
IR1 (Chipping Norton): 4 vehicles	I2 (Chipping Norton): 21 vehicles	
	IR1 (Chipping Norton): 7 vehicles	
	R1 (Chipping Norton): 64 vehicles	
	R2 (Chipping Norton): 4 vehicles	
	R5 (Chipping Norton): 106 vehicles	
	R11 (Moorebank): 6 vehicles	
Total: 97 vehicles	**Total: 227 vehicles**	**None**

[1]*Note that these numbers include those that are eventually overtaken by floodwaters in Chipping Norton.*

These results indicate that 227 vehicles (with one to two people per vehicle), or less than 1% of the approximately 29,000 total modelled vehicles, do not successfully evacuate and are affected by flooding in Scenario A.

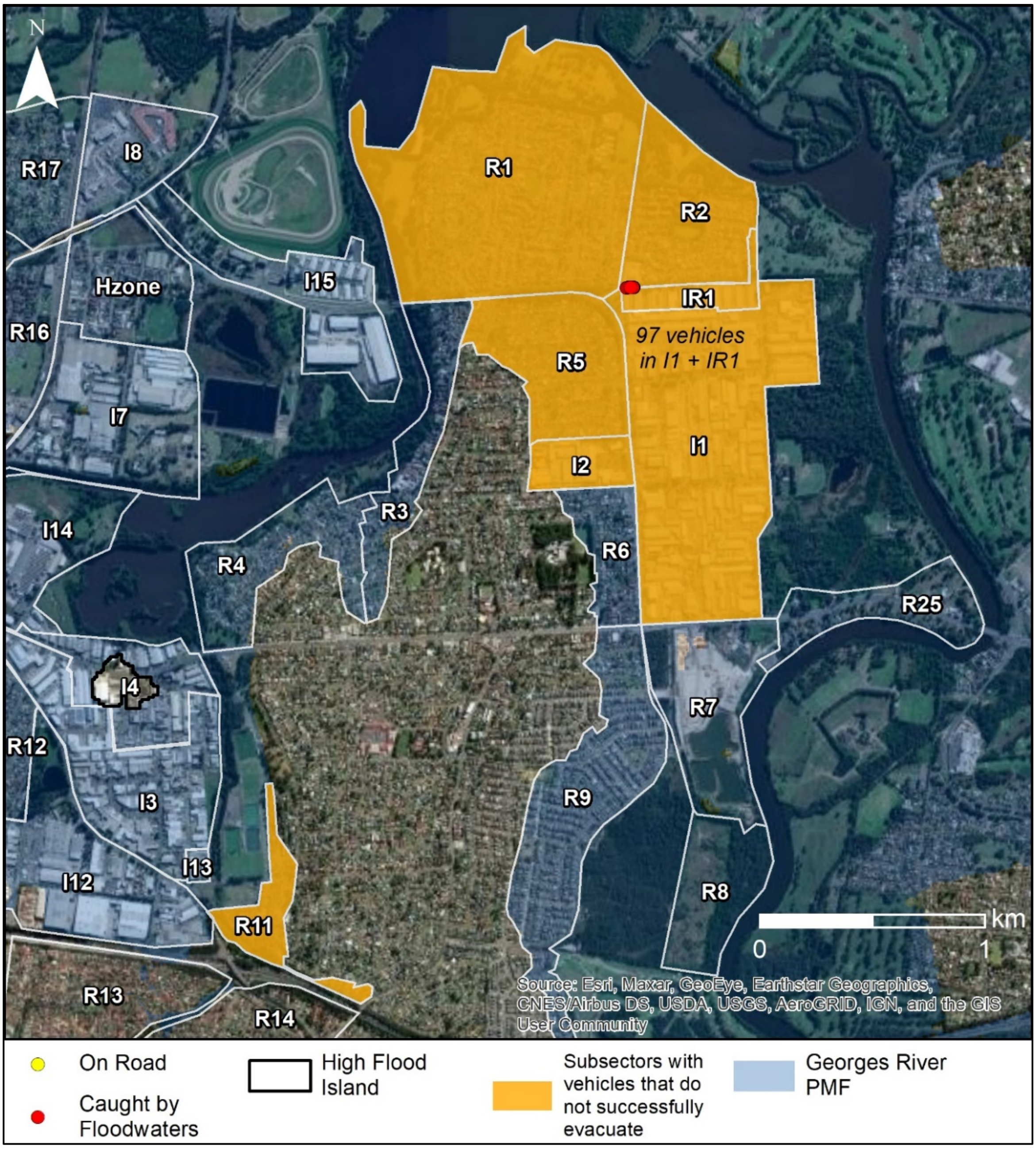


Figure 23. End results of Scenario A showing subsectors where vehicles do not successfully evacuate, and vehicles trapped on the road or caught by floodwaters.

6.6 Scenario B Results

Scenario B represents an improvement from Scenario 3, as there are fewer evacuating vehicles and non-residential traffic have additional evacuation destinations. Appendix B Figures B19 to B23 show excerpts of the Scenario B model run at key time steps. These are:

- T = -2:55 hours (Figure B19): Vehicles leave industrial and residential subareas in west Moorebank (e.g. I3, I5 and I13). The primary evacuation routes are south on Moorebank

Avenue to the M5, or on the Hume Highway for vehicles originating from west of the river (e.g. R26). Non-residential vehicles also travel east on the M5.

- T = 0 hours (Figure B20): By this point, there is queueing throughout the study area. There is queueing throughout Chipping Norton and Moorebank to get on the M5 via Nuwarra Road, in Moorebank west to get on the M5 via Moorebank Avenue, and in Warwick Farm on the Hume Highway to get onto the M7 via the Camden Valley Way. Non-residential vehicles are also still travelling east on the M5.
- T = 5:00 hours (Figure B21): There is extensive queueing throughout the study area, including in Moorebank, Chipping Norton, Liverpool and Warwick Farm. Many vehicles throughout these areas are not able to enter the roads yet since they are at capacity.
- T = 8:05 hours (Figure B22): The first vehicles are overtaken by floodwaters in I3 as floodwater rise in western Moorebank. Floodwaters approach houses in Chipping Norton, Warwick Farm and Moorebank East, which have not yet fully evacuated. It is also noted that vehicles are able to evacuate from I9 and R18 due to the provision of flood-free road access through subsector I9.
- T = 28:30 hours (Figure B23): At the end of the modelled PMF, accounting for TSF, there are 32,178 vehicles caught by floodwaters (red or orange cells).
- When the Moorebank Peninsula is cut off by floodwaters, accounting for TSF, there are 8,040 vehicles trapped on the Moorebank peninsula accounting for TSF. The above vehicles caught by floodwaters are included in the numbers below.

The results of Scenario B are summarised in Table 17 and Figure 24.

Table 17. Scenario B: Modified Future Planning Proposals Results

Caught by flood waters	Trapped on the Moorebank Peninsula[1]	Trapped due to a lack of flood free road access
R1 (Chipping Norton): 955 vehicles	R1 (Chipping Norton): 1,134 vehicles	
R2 (Chipping Norton): 635 vehicles	R2 (Chipping Norton): 868 vehicles	
R5 (Chipping Norton): 36 vehicles	R3 (Chipping Norton): 314 vehicles	
IR1 (Chipping Norton): 102 vehicles	R5 (Chipping Norton): 722 vehicles	
I1 (Chipping Norton): 1,311 vehicles	R6 (Chipping Norton): 322 vehicles	
R16 (Liverpool): 53 vehicles	IR1 (Chipping Norton): 103 vehicles	
R17 (Warwick Farm): 74 vehicles	I1 (Chipping Norton): 1,660 vehicles	
I7 (Liverpool): 1,155 vehicles	I2 (Chipping Norton): 206 vehicles	
I4 (Moorebank): 2,903 vehicles (note: many of these are trapped on the small high flood island in I4)	R9 (Moorebank): 99 vehicles	
I14 (Moorebank): 23,391 vehicles	R11 (Moorebank): 6 vehicles	
Hzone (Warwick Farm): 1,563 vehicles	I4 (Moorebank): 2,584 vehicles	
	I14 (Moorebank): 22 vehicles	
Total: 32,178 vehicles	**Total: 8,040 vehicles**	**None**

[1] *Note that these numbers include those that are eventually overtaken by floodwaters in Chipping Norton and Moorebank.*

These results indicate that at least 32,178 vehicles (with one to two people per vehicle), or about 48% of the approximately 67,500 total modelled vehicles, do not successfully evacuate and are affected by flooding in Scenario B (note that, to avoid double counting, this estimate does not include the count of additional vehicles trapped on the Moorebank Peninsula but not caught by floodwaters in Table 17).

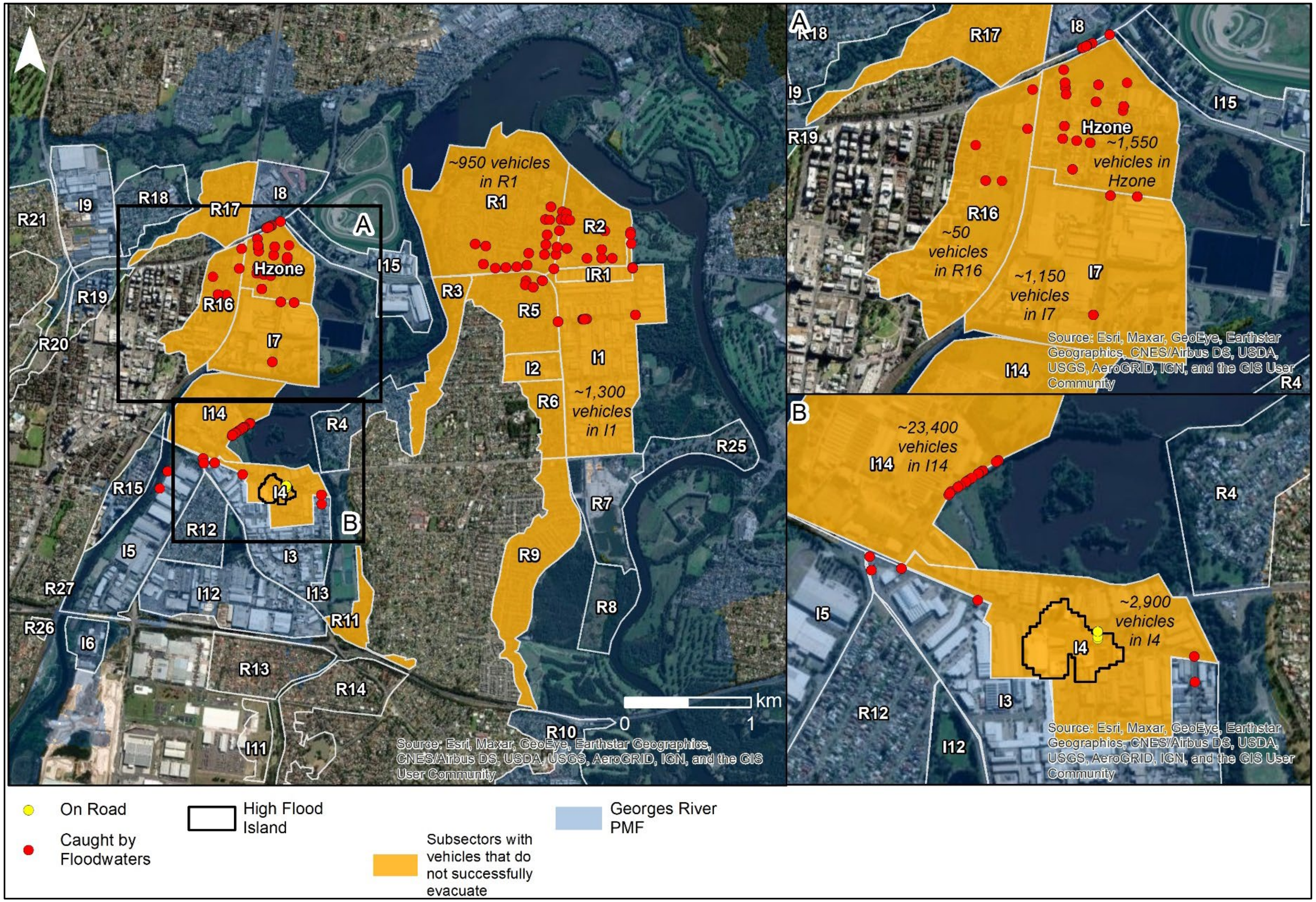


Figure 24. End results of Scenario B showing subsectors where vehicles do not successfully evacuate, and vehicles trapped on the road or caught by floodwaters.

6.7 Sensitivity Analysis

With any modelling it is appropriate to consider the sensitivity of the outputs to the model's assumptions and inputs.

It would be fair to say that most, but not all, of the assumptions used in the modelling, including those recommended by the NSW SES, are conservative and so the modelling results presented in this report present a worst case, extremely low probability scenario.

While it is important to understand the worst possible case when undertaking analyses with regard to loss of life, particularly when tens of thousands of people are involved, when evacuation consequences are inconvenient rather than fatal (such as long traffic queues), more likely outcomes may be tolerable.

The following observations are made with regard to the sensitivity of the model outputs to changing key parameters.

6.7.1 Flood Behaviour

It has been assumed that the Georges River flood will be rising as fast as the design PMF. While it is possible that floods smaller than a PMF could rise as quickly as a PMF, the assumed rate of rise is likely to be at the upper end of the scale with regard to rates of rise across the full spectrum of flood probabilities.

Nevertheless, it is possible that some floods could rise more quickly than the design flood. One way to determine where the flood used in the modelling sits in that regard would be to undertake a Monte Carlo analysis of different temporal spatial rainfall distributions across the catchment. However, this exercise may not be practical for the Georges River catchment due to the high level of computational capacity required. Alternatively, selected additional flooding scenarios could be considered for the assessment of evacuation performance beyond the scope of this study, and the modelled outputs from this study could be interpreted to determine the potential evacuation constraints during other flooding events.

Provision of and Requirements for Flood Warning (NSW SES, 2019) states that the target warning lead time for the Liverpool and Milperra gauges above 4.0 m gauge height is 12 hrs. It defines the Target Warning Lead Time as the minimum lead time that will be provided before the height or the flood class level is exceeded. It makes no statements about this being dependent on the rate of rise of the flood because presumably it is dictated by the travel time of fallen rain and river flows from the upstream gauge locations to Liverpool whereas the rate of rise is determined by the amount of rain which has fallen. Therefore, the warning time available is a minimum of 12 hrs regardless of the rate of rise of the flood. It is noted that a more comprehensive flood forecasting and warning system for the Georges River may be able to extend the available warning time and therefore reduce evacuation constraints. This might include development of a Georges River Probabilistic Forecast product.

However, were a flood to rise faster than has been modelled that would compress the duration of the evacuation and more subsectors are likely to be using evacuation routes simultaneously which would increase congestion and queuing and is likely to result in more vehicles being trapped by floodwaters.

Any slower rate of rise than that used in the modelling would provide more time for evacuees to depart and result in less risk of evacuees being trapped.

On balance, most floods would have more time for evacuation than has been modelled rather than less.

6.7.2 Number of Premises Evacuating

The number of existing premises in 2016 is likely to be quite accurate and the number of premises in future planning proposals can be controlled by the urban planning process. The main unknown in the modelling of the future development scenarios is the extent of infill development and intensification which will take place under existing zonings. While planning controls permit duplexes and granny flats on average sized blocks, town houses on large blocks and residential flat buildings on R3 and R4 zoned land, there is nothing preventing growth in dwelling numbers beyond what has been assumed in the modelling. The numbers used in the modelling are the best available forecasts but they could be high or low.

Where infill development takes place will have a significant impact on evacuation capacity.[6]

The model has been set up so that creek and overland flow flooding can also be incorporated to test the impact of concurrent flooding from another source during a Georges River flood. This sensitivity analysis is yet to be run. In the current model scenarios, only areas impacted by Georges River flooding evacuate.

Although there are no warning systems for flooding of the creeks and the NSW SES is unlikely to have sufficient lead time to issue evacuation orders, people may self-evacuate and add to the evacuation traffic on the road network. This is less likely to be problematic from flooding on Brickmakers Creek, Cabramatta Creek and Maxwell’s Creek as they would be evacuating onto the Hume Highway in a location where in most scenarios it has some spare capacity. Furthermore, there are numerous streets between these creeks and the Highway where vehicles could queue above the reach of floodwaters.

Flooding from Anzac Creek may be more problematic as it may increase the evacuation loads on Nuwarra Road and Heathcote Road which already have capacity issues which are preventing vehicles evacuating in some scenarios.

The 2016 Census indicates that dwellings in Liverpool LGA had an average occupancy rate of about 95% on Census night. That means that when a flood occurs about 5% of the dwellings could be unoccupied and therefore not have to evacuate. As this discounting has not been applied then the modelling may be overestimating the number of evacuating residential vehicles by about 5%.

Overall, the number of premises evacuating in the modelling is likely to be at the upper end of possible estimates.

6.7.3 Number of Evacuating Vehicles

The numbers of vehicles per dwelling have been derived from Census data and while the number of vehicles per person has been increasing in Australia and Liverpool LGA, the number of people per dwelling has been declining (steady in Liverpool LGA from 2011 to-2016). It is therefore unlikely that the number of vehicles per dwelling would continue to increase substantially. This is particularly likely to be the case in those parts of the study area which are close to the Liverpool CBD and are well serviced by public transport.

[6] Since completing the modelling it has become apparent that there may have been development since the census dates used but which was not included in the infill data provided by Council. In the case of non-residential development the 2011 Census travel to work data has been used and there has been a significant development on Governor Macquarie Drive opposite the race course stables as well as on the corner of Alfred Road and Wendlebury Road since that date. In the case of residential development there is recent development in Shepherd Street which is not picked up by the infill development (although it is included in the Planning Proposal scenario) and there may also be scattered small scale residential intensification.

It is also arguable that assuming one vehicle per dwelling for new apartments is conservatively high, particularly as it would be possible to impose development controls which limited the number of vehicles at new developments.

Another conservative assumption in the modelled scenarios is that everyone who is outside of the floodplain when evacuation is called will be able to return to their homes in the 12-hour warning window and then evacuate from there. In the sort of extreme rainfall that would require large scale evacuation from the Georges River it is probable that flooding is occurring across the broader Sydney Metropolitan Area and road and public transport networks will not be operating efficiently. Therefore, some people will not be able to reach their homes because their route home is either flooded or otherwise disrupted and so the estimated numbers of vehicles leaving from residential premises would be an overestimate.

It is much harder to estimate the number of vehicles evacuating from business premises and the method used would represent the absolute maximum number were all employees at work at the same time. Where a factory has two 12 hours shifts for instance, then only half of the vehicles estimated to be at those premises in the modelling would be there at any one time.

Not many businesses operate 24/7 and a business which is open as much as 70 hours per week is unoccupied for nearly 60% of the time. It is therefore unlikely that all businesses and all dwellings will have to evacuate simultaneously. Furthermore, with evacuation orders being issued about 12 hours in advance, it should be possible to tell many people not to come to work if businesses are not open at the time that the evacuation order is given.

If evacuation is ordered when people are at work then the situation is more complicated. The duration of the total evacuation in the PMF scenario modelled is close to 24 hours. While businesses are likely to close during the evacuation and therefore there is an opportunity to ensure that less flood prone businesses are occupied when their evacuation needs to be triggered, those employees will leave work at the end of their shift earlier in the evacuation. Therefore, it is possible that the modelled scenario underestimates the traffic on the road network early in the flood when lower premises are evacuating, and higher premises are leaving at the end of a normal day's work but merging with evacuation traffic.

The evacuating traffic from the equestrian zone was even more difficult to estimate. The number of vehicles in the area increases during race meets but those are cancelled in the weather which generates floods. There are numerous stables with many horses and during an evacuation it is likely that the owners would want to evacuate the animals. Large numbers of horses can be transported in many small horse floats or a small number of very large horse floats. It either case multiple trips are likely to have to be made as there would not be sufficient floats to evacuate all of the horses in one trip. Furthermore, when these vehicles are queuing, they are likely to take up more road space than a 6m length assumed in the modelling. The modelling has therefore probably underestimated the traffic impacts from evacuating the equestrian zone, however, the future planning for that area is to change its land use so in the planning proposal scenarios these underestimates had no impact.

All of the above suggests that the number of evacuating vehicles being used in the model is an upper bound number.

6.7.4 Flood Warning Times

The warning times used to guide evacuation triggers in the model are the minimum times which the Bureau of Meteorology is willing commit to. NSW SES has advised that for the Georges River these are based on observed fallen rain and measured stream gauging as well as some rainfall forecasting. In a real event there may be longer warning times available, particularly if the flooding evolves more slowly. The BoM flood warning timeframe of 12 hours may be able to be increased with the development of a Georges River Probabilistic Forecast product or other features of a more comprehensive flood forecasting and warning system.

6.7.5 Warning Dissemination Time

The modelling assumes all houses are door knocked to receive an evacuation order. It does not make any allowance for people receiving an evacuation order by electronic broadcast, direct contact from neighbours, friends or relatives, or by observing others evacuating nearby. While they may receive the message more quickly than assumed it is unlikely that the majority will receive it more slowly and so the capacity of evacuation routes is unlikely to be underutilised because of slower warning dissemination than assumed in the model.

It is noted that all evacuation models assume a departure profile based on various curves, taking into account warning diffusion processes and time taken to initiate protective action. The TEM assumes a linear departure pattern as a simplification. NSW SES has advised that research indicates that the choice of departure curves has limited impact on results as the capacity of the evacuation network in inclement weather is the main limiting factor.

6.7.6 Departure Delays

The two-hour delay between people receiving an evacuation order and actually leaving is a NSW SES recommendation. While post-flood surveys Molino Stewart has undertaken for the NSW and Victorian SES suggest that is about the right order of magnitude for people who evacuate, those same surveys suggest that the vast majority of residents do not evacuate at all when ordered to do so. Most would probably await the arrival of floodwaters at their doorstep before leaving and then it would be too late for vehicular evacuation and, for those who get isolated by floodwaters, too late for pedestrian evacuation.

While this suggests that the model may be significantly overestimating the amount of actual traffic congestion on the road, it may mean that it significantly underestimates the number of people who safely evacuate ahead of rising floodwaters.

This evacuation model is in effect modelling the capacity of the transport network to see how many people can evacuated within the 12-hour warning timeframe given a 100% compliance rate.

6.7.7 Route Capacities

Urban roads can have a capacity of between 1,200 to 1,400 vehicles per hour per lane and freeways a rate of 2,000 vehicles per hour or more at a free flow speed of 100km/hr (Austroads). A rate of 600 vehicles per hour per lane as per the NSW SES TEM (Opper et al., 2009) is conservatively low and is the rate recommended for modelling the departure of vehicles from car parks.

NSW SES has advised that this traffic flow rate accounts for poor driving conditions due to inclement weather. It has advised that this rate has been reviewed by an external peer review group for the current HN Flood Strategy and is similar to evacuation rates observed in evacuations in the USA during inclement weather. Lower effective lane capacities and lower vehicle free speeds are often observed during inclement weather in the Sydney Metropolitan area.

It is unlikely that the rate will be significantly less than this.

However, it is acknowledged that the model does not account for through traffic which may be using the roads. While flooding could close the Hume Highway, Cumberland Highway and Newbridge Road to through traffic early in a flood, the M5 and M7 are likely to remain open to through traffic well into the event and this could reduce the available road capacity for evacuation. Nevertheless, using 600 vehicles per hour per lane for the motorways arguably allows for some through traffic taking up capacity.

The modelling also assumes that there is no provision for contraflow traffic on any of the evacuation routes. Any route which has contraflow would have its capacity increased. Contraflow for flood evacuation is not supported by NSW SES because of its resource demands and the fact that contraflow lanes do not flow at the same rate as other lanes.

6.7.8 Traffic Destinations

While the model makes a reasonable estimate of the distribution of non-residential traffic to different destinations based on Journey to work data, it has assumed all residential evacuees will head north on the M7 towards the M4 and the Homebush Evacuation Centre. It is noted that in reality, most people will make their own accommodation arrangements with only the residual travelling all the way to evacuation centre/s. However, there is no data available to be able to estimate how many people will evacuate to certain locations where they have friends or family.

Some will be able to find temporary accommodation with friends or relatives in flood free areas within the study area but above the reach of the PMF. Similarly, many evacuees will be able to head south (i.e. Campbelltown), east or west because that is where they can readily find temporary accommodation. However, since most of the metropolitan area is north of Liverpool and that the mass care facility would be in the Sydney Olympic Park precinct, it is reasonable to assume that most residential traffic will travel north on the M7. Nevertheless, the assumed number of vehicles converging on The M7 is likely to be an overestimate.

Although this assumption results in significant queues on the M5 and the Hume Highway leading into the M7, a comparison of Scenarios 2 and 3 with Scenarios A and B shows that sending some non-residential traffic in directions other than northward relieves this queueing somewhat. This in turn revealed that regardless of what is happening on the highway and motorways, there are significant capacity issues on some of the roads feeding onto these regional roads. In other words, many of the evacuation capacity issues are occurring within the network before evacuees have a choice about which direction they will head out of the study area.

7 | Implications for Evacuation Planning and Strategic Planning

7.1 Existing Challenges

7.1.1 Orange Grove Road and Hargrave Park Place Areas

The Floodplain Constraints Categorisation Study (FloodMit, 2020) identified that Orange Grove Road Place (subsector I9 in this study) is affected by both Cabramatta Creek and Brickmakers Creek. This study found that it does not have a reliable evacuation route on public roads as all roads leading from it can be cut by creek flooding.

Similarly, this study found that the part of the Hargrave Park Place Area which is between the two creeks (subsector R18) does not have a reliable flood evacuation route on public roads. The FloodMit study reported that 56% of that Place Area is below the residential flood planning level.

These subsectors fall outside of the extent of the Georges River flood model due to truncation of the flood model. However, this area would be impacted by the Georges River flooding based on an extrapolation of the flood levels at the model extent along the contours using the digital elevation model (DEM) of this area.

During investigations a possible flood free evacuation route through private roadways within the industrial premises was identified (Figure 25) and included in Scenarios A and B. Modelling showed that this would facilitate the timely evacuation of these areas without interfering with the evacuation of others.

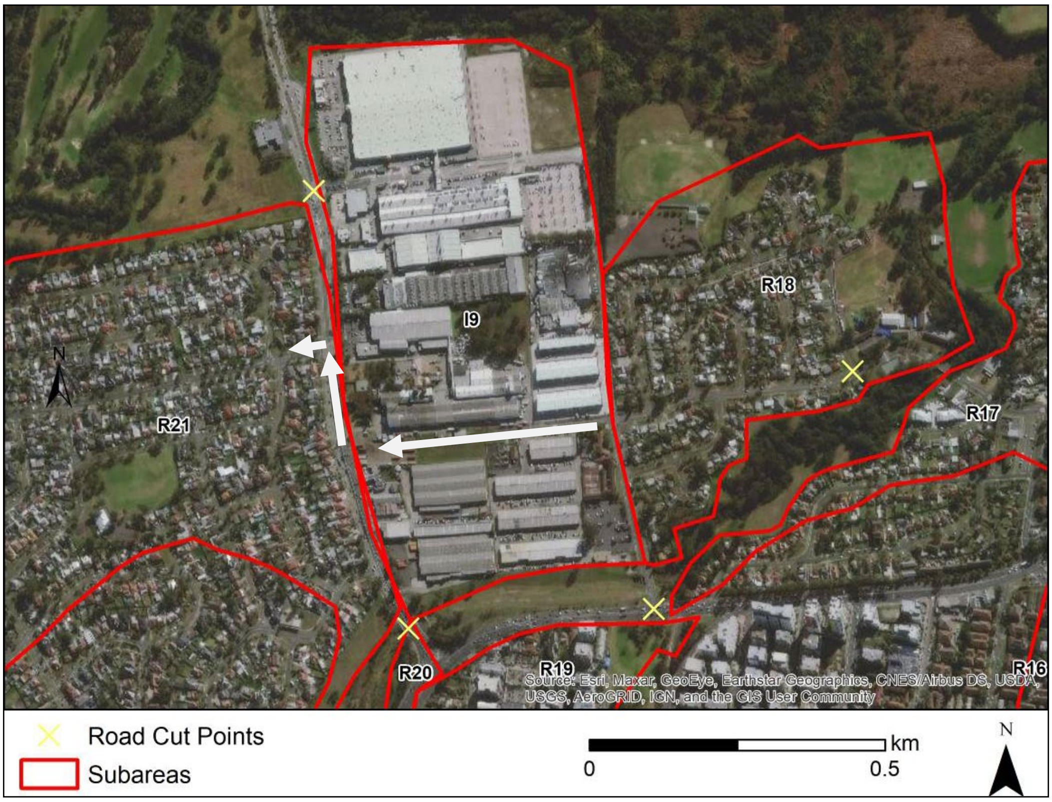


Figure 25. Possible vehicular evacuation route through private property

7.1.2 Residential Flood Islands

The following residential subsectors were identified as low flood islands and are listed in order of frequency of evacuation trigger:

- R25 – Newbridge Road East (approximately 38 current dwellings or 114 people)
- R15 - Shepherd Street/Riverpark Drive (at least 553 current dwellings or 1,548 people, noting this is likely to be an underestimate due to recent development)
- IR1 – Residential component is Riverside Road Chipping Norton (approximately 8 current dwellings or 24 people)
- R1 – Chipping Norton North of Governor Macquarie Drive (approximately 783 current dwellings or 2,349 people)
- R12 – between Moorebank Avenue and Heathcote Road (approximately 331 current dwellings or 1,026 people)
- R2 – Chipping Norton North of Governor Macquarie Drive (approximately 502 current dwellings or 1,506 people)

In addition, Sammut Crescent Chipping Norton, which is in R4, has a group of 11 houses (approximately 33 people) which are at the end of a cul-de-sac which can be isolated early in a flood.

The modelling suggests that under existing conditions all of these areas would have sufficient time to safely evacuate but should they delay evacuation residents may become trapped and then overwhelmed by flood waters. If emergency resources are limited their efforts need to focus on the timely evacuation of these subsectors.

Houses in Newbridge Road East start flooding in a 20% flood but they are part of a voluntary purchase scheme and over time are likely to be removed from the floodplain.

Shepherd Street, Riverside Road and Sammut Crescent get isolated in a 5% AEP flood

A 1% AEP flood is needed before parts of R12 becomes isolated, but it is virtually completely isolated and inundated in a 0.5% AEP flood.

A 0.2% flood is needed before parts of Chipping Norton are isolated.

The whole Moorebank Peninsula is a high flood island which becomes isolated when flooding exceeding a 0.2% AEP event cuts the on ramp from Moorebank Avenue, all other access to the peninsula having been cut at lower flood levels. A slightly higher flood would overtop the M5 and flow into the Moorebank Avenue underpass. Should this happen, it would take days to drain because the drainage system is only designed for local runoff.

As infill development increases on the Moorebank peninsula the flood modelling suggests that evacuation traffic queues on Nuwarra Road could create evacuation challenges for residents on Riverside Road. It may be necessary to use low forecast flood level to trigger their evacuation but that would increase the frequency with which they would need to evacuate and on some occasions, it would prove in hindsight to have been unnecessary.

7.1.3 Industrial Flood Islands

The industrial subsectors which are low flood islands are, in order of frequency of evacuation trigger:

- I5 – between Moorebank Avenue and the Georges River (1,162 modelled employees/ vehicles)
- I3 – Between Anzac Creek and Heathcote Road (953 modelled employees/ vehicles)
- I13 – Junction Road (38 modelled employees/ vehicles)
- I15 – Governor Macquarie Drive Warwick Farm (359 modelled employees/ vehicles)

- I1 – Chipping North (1,955 modelled employees/ vehicles)
- I7 – Scrivener Street Place Area (2,378 modelled employees/ vehicles)
- IR1 – Barry Road Chipping North (156 modelled employees/ vehicles)
- I12 – Between Moorebank Avenue and Heathcote Road (1,319 modelled employees/ vehicles)

The modelling indicates that all of these should have time for safe evacuation if evacuation orders are followed in a timely manner.

IR1 is the industrial properties fronting Barry Road. It is challenging to evacuate because the premises are raised more than 1m above the road which is quite flat and floods rapidly once the river breaks its banks in a 5% AEP flood. Furthermore, the modelling suggests that timely evacuation may become more challenging as residential infill development takes up more of the evacuation capacity of Nuwarra Road.

Similarly, the balance of the Chipping Norton industrial area (I1) has properties which can get isolated when the low lying parts of Riverside Road and Childs Road flood. The modelling suggests that these properties are at greatest risk of not being able to evacuate as residential infill development occurs.

It may be necessary to trigger the evacuation of these two subsectors at a lower forecast river level to ensure they have time to evacuate as residential densities increase.

Together I5, I3, I13 and I12 make up the Georges River South Place Area. Parts of this area is impacted by 5% AEP flooding with significant isolation in the 2% AEP event but complete isolation not occurring until the 0.2% flood.

In addition, I4 and I14 are high flood islands and they constitute the Georges River North Place area. They become isolated in a 2% AEP flood.

Under existing conditions and with projected infill development it is expected that these areas will continue to have sufficient time to evacuate.

7.1.4 Evacuation Capacity Improvements

Another way of dealing with the growing evacuation challenge on the Moorebank Peninsula would be to increase the evacuation capacity. The model has sent all of the evacuating vehicles from Chipping Norton along Nuwarra Road which is a single lane road to near its intersection with Heathcote Road. While Heathcote Road is a two lane road, its on ramps onto the M5 are single lane.

While parts of Chipping Norton could use Brickmakers Drive as an evacuation route, once that joins Nuwarra Road it once again narrows to a single lane. It is noted, however, that there is a very wide road reserve on Nuwarra Road and the M5 underpass so there may be capacity to provide an additional lane through there. Once at Heathcote Road one stream of traffic would need to be directed onto Heathcote Road and the other through to Wattle Grove Road and Anzac Road from where they could enter the M5 via Moorebank Avenue.

This arrangement may only be suitable early in a flood evacuation because in larger floods Brickmakers Road gets flooded and also evacuees from Hammondville and Holsworthy need to use Anzac Road. It would also be dependent on emergency services having sufficient resources to direct traffic at the Heathcote Road intersection.

While a flood larger than a 0.2% event would be needed to cut the M5 at Moorebank Avenue, this could be overcome if the proposed additional M5 lanes across the Georges River could be provided with a higher level of flood immunity. This would ensure that the peninsula did not get isolated and the M5 did not remain closed for long periods in more extreme events.

Route capacities may also be increased through the provision of contraflow traffic however, this would only be of significant benefit if there are no downstream capacity constraints. For example, there would be little benefit in providing a second lane of evacuation capacity through contraflow if the two lanes then had to merge into one to enter a motorway. The contraflow lane would not reduce evacuation time but might provide some additional space for vehicles to queue above the reach of floodwaters. It is noted that NSW SES does not support the use of contraflow for flood evacuation.

7.1.5 Alternative Evacuation Modes

The NSW SES evacuation planning for the Georges River relies upon motor vehicle evacuation and that is why vehicular evacuation has been the focus of the modelling in this study. Nevertheless, not everyone has access to a motor vehicle for evacuation. Based on 2016 ABS Census data (available at the Statistical Area [SA]1 level), a significant number of dwellings in the study area do not have a vehicle. In some suburbs in Liverpool and Warwick Farm (i.e. R16 and R17) over 30% of dwellings do not have a vehicle (Figure 26). It is estimated that there are around 4,000 people without a vehicle at home in Liverpool and Warwick Farm. On the Moorebank peninsula, where car ownership is higher; it is estimated that 550 people do not have a vehicle at their home.

Warwick Farm (particularly subsector R17) is noted as an area requiring special consideration, as it contains a number of public housing developments. NSW Land and Housing Corporation (LAHC) currently has 1,298 dwellings in the study area across both Warwick Farm and Cartwright (the latter only subject to creek flooding) with an average occupancy of 2 people per dwelling. LAHC has also informed this study that its development projection for the study area over the next 20 years is 481 additional dwellings, with 45% of the additional dwellings in Warwick Farm and 55% in Cartwright. LAHC notes that these tenants are older and have higher rates of disability and mobility issues when compared to the general population, and currently 37% of tenants in the Liverpool LGA are eligible for seniors housing. As indicated by subsector R17, where 43% of dwellings do not have a vehicle, these residents are also more likely to not have access to a vehicle.

The suggestion has been made that pedestrian or rail evacuation could be relied upon for some, or all, of the flood evacuation.

In response, the NSW SES has advised that large scale rail evacuation in Sydney cannot be relied upon as a primary evacuation strategy or where vehicular evacuation fails during flood events because of the unreliability of the rail network during major storm events. For example, in April 2015, Sydney Trains estimated nearly 200 significant incidents to Sydney Trains and NSW Trains, and approximately 585 peak and non-peak services were affected during a 3-day period of storms (TfNSW, 2017).

NSW SES has also advised that pedestrian evacuation is limited by a number of factors including safety challenges of pedestrians and vehicles sharing routes, the large number of officials required to coordinate the evacuation on-ground, pedestrians being exposed to the weather, and the limited capacity to carry important documents and possessions.

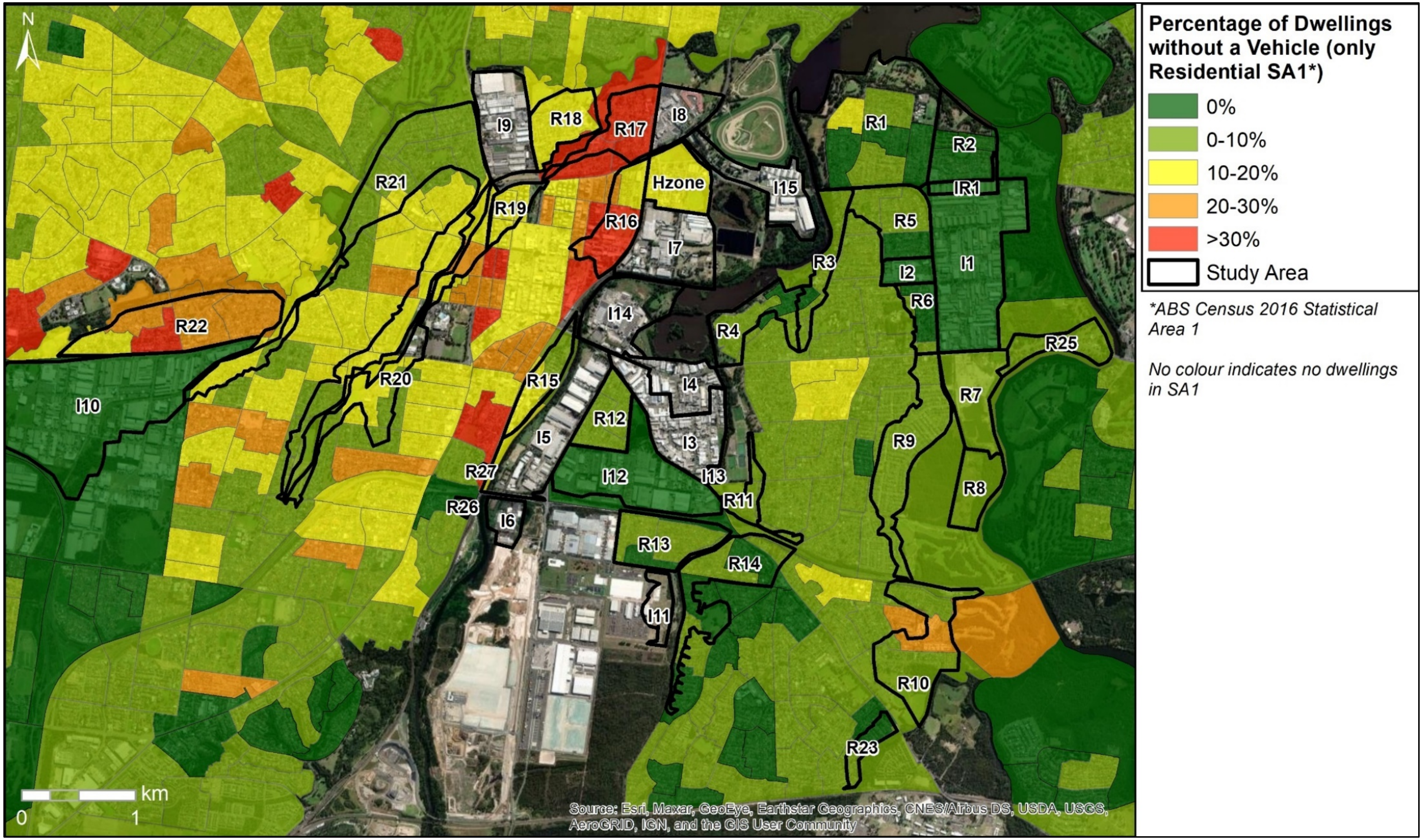


Figure 26. Percentage of dwellings without a vehicle in the study area (based on 2016 ABS Census data at the Statistical Area [SA] 1 level.

7.2 Future Challenges

7.2.1 General

The following section focusses on the evacuation challenges specific to each development. However, there are some considerations which are common to more than one of the planning proposals:

Existing "Spare" Capacity - The results of Scenario B can provide some indication of the scale of development that could be included without compromising evacuation capability in the study area. However, it is stressed that this only allows for a high-level calculation, and the capacity would have to be modelled in order to test the impact of a reduction in vehicles from certain developments. These nominal capacities are discussed in the following sections. Note the vehicles which escape the floodwaters but are trapped on the Moorebank Peninsula have not been accounted for in those calculations.

Evacuation Route Upgrades - It would be important to ensure that any road infrastructure upgrades that are to be relied upon to improve flood evacuation are fully approved and funded before the development which they support is approved.

People Without Access to Vehicles – As explained in Section 7.1.5, there are already many people in the study area who do not own a motor vehicle. It is possible that some of the proposed apartment developments in close proximity to Liverpool Station could be approved with less than one parking space per dwelling meaning that there would be an expectation that a proportion of the population will not own a car. This would increase the number of people who do not have a vehicle who would have to evacuate during a flood.

7.2.2 The Grove

The evacuation modelling suggests that there should be sufficient road capacity for the evacuation of The Grove proposal providing that a flood free evacuation route connection is created between Homepride Avenue and Orange Grove Road. Without this connection existing residential and commercial development in the area is unable to have assurance of safe evacuation.

7.2.3 Shepherd Street

The modelling suggests that there is sufficient road capacity for the evacuation of proposed development on Shepherd Street[7]. The challenge in this location is the inundation of the Shepherd Street underpass. If evacuees delay they may be trapped between the river and the rail line. There are two ways in which this residual risk can be managed.

The first would be to provide an emergency level crossing of the railway line at Atkinson Street (Figure 27). This would require approval from Sydney Trains but such an arrangement has been provided in two locations of the Hawkesbury floodplain near Mulgrave Station and Windsor Station. This could either be a vehicular and pedestrian crossing or only a pedestrian crossing and be opened by emergency services when the Shepherd Street underpass is flooded. This would not only benefit future development but also existing developments in the subsector.

[7] Note that it has been determined that the number of existing vehicles requiring evacuation from Shepherd Street has likely been underestimated due to recent apartment developments but many of these are included in the vehicles estimates for the Planning Proposal scenario.

However, it is noted that this option would require the closure of the rail corridor after the cessation of train services on the line to the south of Liverpool rail station and would need to be examined further with the rail operator and emergency services.

The second method would be to make provision for sheltering in place because some parts of the precinct are flood free and others are low hazard in a PMF flood.

Figure 27. Atkinson Street looking west across railway line

7.2.4 Warwick Farm Structure Plan

The evacuation modelling makes it clear that there is insufficient road capacity to cater for the evacuation of the planning proposals for the Warwick Farm racing precinct. Closer investigation shows that there are a number of reasons for this.

Firstly, the proposed scale of the development in the precinct would see about 3,700 vehicles evacuating from the precinct, mostly via Warwick Street onto the Hume Highway. These vehicles alone would occupy the road for more than six hours at the modelled rate of 600 vehicles per hour.

Secondly, the industrial area to the south (I7) starts evacuating only half an hour earlier and has nearly 2,400 vehicles which need to evacuate through the Munday Street Place Area, occupying the same evacuation road for about four hours. This means that when the evacuee response delays and traffic safety factors are taken into consideration, the total evacuation time exceeds the available warning time by a few hours.

Thirdly, at the same time that these two subsectors are evacuating onto the Hume Highway at Warwick Farm, so are subsectors I15, I8 and R17 which is taking up much of the capacity of the three lanes on the Hume Highway meaning that the proposed development has to queue before evacuating.

Finally, because the area is relatively flat, there is very little time between when the lowest parts of the subsector begin to flood and the whole precinct is flooded. Everyone, has to evacuate from the precinct and the surrounding precincts simultaneously with no opportunity for those on higher ground to delay their evacuation.[8]

Other than reducing the scale of the proposed development, there is not a lot which can be done to mitigate the above challenges. Providing two exit lanes on Warwick Street might assist if it does not create capacity issues on the Hume Highway.

In Scenario B, there are 2,845 vehicles caught in floodwaters in Liverpool and Warwick Farm, which is in part due to the additional vehicles associated with the planned development in Warwick Farm. The Warwick Farm developments account for 3,709 additional vehicles in Scenario B. This would imply that the road network has the potential spare capacity for 864 vehicles from Warwick Farm in Scenario B. Reducing vehicle lengths to 6m in this area within the model may increase the number of vehicles able to evacuate from the area but accounting for proposed growth in public housing north of the Hume Highway may decrease this number.

Sheltering within buildings is not advisable as the area is surrounded by hazardous floodwaters in the PMF for more than 24 hours and for up to 8 hours in a 0.2% AEP flood.

The precinct is not a flood island and rises gently towards the Hume Highway which then rises rapidly as it crosses the rail line to higher ground west of the railway walking out ahead of rising flood waters should vehicular evacuation fail would be an option.

7.2.5 Moore Point

The planning proposals for Moore Point far exceeds the capacity of the road network to cater for their evacuation during a flood. Together they would result in nearly 32,000 vehicles having to evacuate in advance of a flood under the current settings. Although the developments themselves would be constructed to be above the flood planning level, Newbridge Road is cut by flooding in a 2% AEP flood near the Bridges Road intersection (Figure 28). And vehicular evacuation would need to be completed before that occurred.

Newbridge Road has two west bound lanes and even if exit roads from the developments could be configured to match this road capacity, it would take more than 26 hours for all of the vehicles to evacuate from the precinct without allowing for warning acceptance, warning lag and traffic safety factors. This compares to the 12 hours warning time which is available.

While in theory some of the development could evacuate east on Newbridge Road, this would not be advisable because the only flood free evacuation route in that direction is along Nuwarra Road and that is likely to exceed its capacity with forecast infill development.

Some of the development could also theoretically head south on Heathcote Road and or Moorebank Avenue but the modelling has shown that would have an impact on other traffic currently using those roads.

This planning proposal either needs to be reduced substantially in scale or an alternative to vehicular evacuation has to be accepted as the primary flood emergency response for the precinct.

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[8] On review of the model results it would appear that in Scenario B we did not change vehicle lengths from 15 m to 6 m in this area to account for the fact that there would not be the horse floats in the future. This will also be contributing to the capacity constraints and would need to be corrected and rerun to get a more accurate estimate of available capacity.

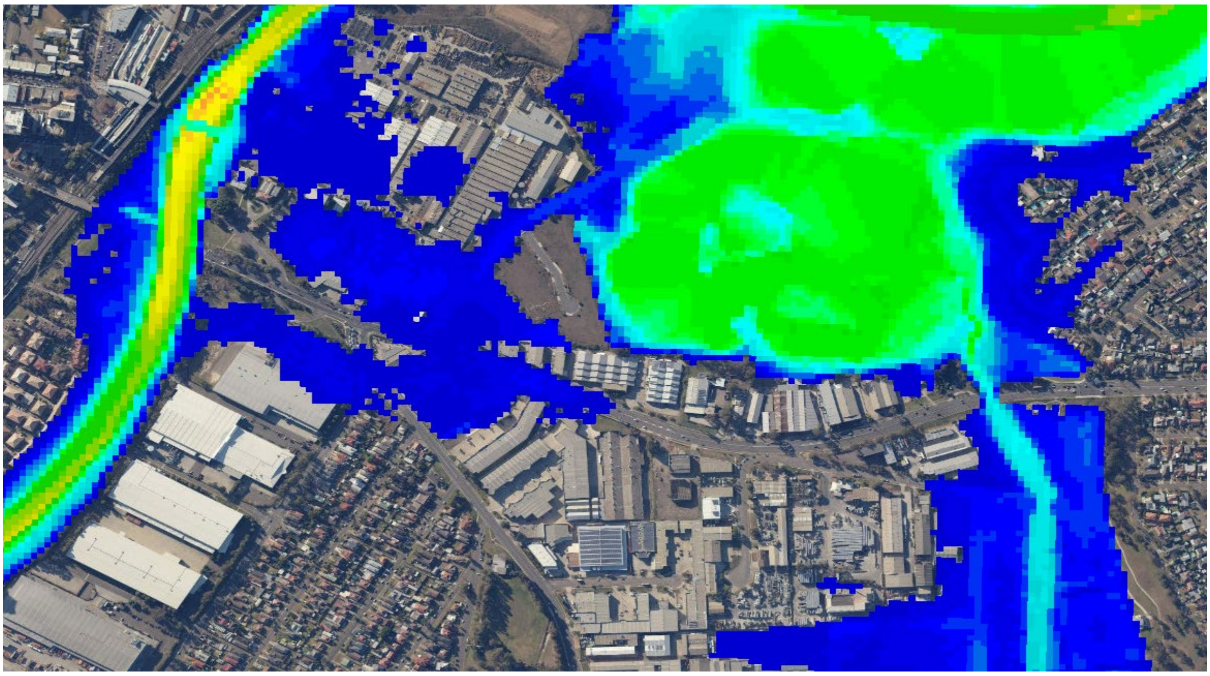

Figure 28. 2% AEP flood extent

In Scenario B there are 26,294 vehicles caught in floodwaters in Moorebank, which is largely due to the additional vehicles associated with the planned development in Moore Point. The Moore Point developments account for 31,859 additional vehicles in Scenario B. This would imply that the road network could have capacity for 5,565 vehicles from Moore Point, accounting for the road upgrades included in Scenario B.

Sheltering in place would be problematic because the area is surrounded by hazardous flood waters for more than 24 hours in a PMF and tens of thousands of people would be sheltering. The chance of loss of life due to a secondary emergency or inappropriate behaviours is high.

Pedestrian evacuation might be viable but that itself presents several challenges:

- Because of the low point in the middle of the precinct, the western part of the precinct would need to evacuate west over Newbridge Road bridge which is higher than the PMF and the eastern side of the development would have to evacuate east on Newbridge Road over Anzac Creek which has flood immunity up to the 0.5% AEP flood. This would create two different destinations for evacuees
- The NSW SES plans do not currently make provision for multiple local evacuation centres during extreme flood events, only smaller scale floods
- Evacuation centres usually only cater for a proportion of the population that cannot find their own accommodation. These centres would have to cater for tens of thousands of people arriving on foot most likely in inclement weather.
- Ground levels and pedestrian links will need to be designed so that people exiting at ground level, or alternatively from other floors, from buildings have a continuously rising evacuation route to land above the PMF level

7.2.6 Moorebank East

The five development sites at Moorebank East would add substantial evacuation traffic to the Moorebank peninsula which may approach its evacuation capacity with infill development under current zonings. While the model shows that all of the proposed development in Moorebank East would be able to evacuate in time, it only does so by blocking the evacuation of residential and non-residential vehicles evacuating from Chipping Norton.

In Scenario B there are 3,039 vehicles caught in floodwaters in Chipping Norton, which is largely due to congestion on Nuwarra Road and which is exacerbated by the planned development vehicle numbers from Moorebank East. In this scenario, Moorebank East accounted for 3,728 additional vehicles. This could imply that only approximately 700 vehicles in Moorebank East could be added to the road network before vehicles are caught by floodwaters in Chipping Norton. However, it is noted that Site C, which includes 363 vehicles in the model, has development approvals. This would take up half of the available road capacity, accounting for the planned road upgrades included in Scenario B. It is also noted that there could be many more vehicles which escape the floodwaters but are potentially stranded on the peninsula because of the blocking effect of these developments.

The widening of a section of Nuwarra Road and the use of Brickmakers Drive and Anzac Road early in the evacuation, as suggesting in Section 7.1.4, might go some way to mitigating this impact and facilitate some additional development in Moorebank East.

A rising pedestrian evacuation route has also been approved for this site to be used in case vehicular evacuation failed. This is important because this whole area is surrounded by hazardous floodwaters for more than 24 hours in the PMF.

8 | Conclusions and Recommendations

8.1 Conclusions

This study has identified several Georges River flood evacuation findings and challenges for Liverpool LGA, including the following key points.

8.1.1 Current Evacuation Findings and Challenges

- Even under present conditions, there are challenges to flood evacuation from the Georges River PMF within the study area. This is primarily due to capacity constraints on Nuwarra Road, which results in long queuing and vehicles being caught in floodwaters and stranded on roads. The model suggests that more than 130 vehicles could be caught by floodwaters in Chipping Norton, and over 2,300 trapped on the Moorebank Peninsula when the M5 is cut by floodwaters.
- In the most extreme flood events, the M5 will flood at the Moorebank Avenue underpass and, because its drainage is only designed for local rainfall, could be closed for several days due to ponded water. This could prevent some evacuees from leaving the peninsula and would disrupt through traffic for weeks. A planned additional westbound lane crossing the Georges River at this location could be constructed in such a way to ensure access to Moorebank Peninsula in even the most extreme floods.
- Subsectors I9 and R18 in Warwick Farm, which are subjected to both Georges River and creek flooding, may be unable to evacuate due to a lack of a reliable evacuation route on public roads that are not at risk of being cut by creek flooding.
- The following residential subsectors were identified as low flood islands, where occupants may get trapped and overwhelmed by floodwaters if they don't leave promptly. Emergency services may need to focus resources on these areas to ensure timely evacuation. They are (listed in order of frequency of evacuation trigger):
  - R25 – Newbridge Road East (approximately 38 current dwellings or 114 people)
  - R15 - Shepherd Street/Riverpark Drive (at least 553 current dwellings or 1,548 people, noting this is likely to be an underestimate due to recent development)
  - IR1 – Residential component is Riverside Road Chipping Norton (approximately 8 current dwellings or 24 people)
  - R1 – Chipping Norton North of Governor Macquarie Drive (approximately 783 current dwellings or 2,349 people)
  - R12 – between Moorebank Avenue and Heathcote Road (approximately 331 current dwellings or 1,026 people)
  - R2 – Chipping Norton North of Governor Macquarie Drive (approximately 502 current dwellings or 1,506 people)
- The following industrial subsectors were identified as low flood islands (listed in order of frequency of evacuation trigger):
  - I5 – between Moorebank Avenue and the Georges River (1,162 modelled employees/ vehicles)
  - I3 – Between Anzac Creek and Heathcote Road (953 modelled employees/ vehicles)
  - I13 – Junction Road (38 modelled employees/ vehicles)
  - I15 – Governor Macquarie Drive Warwick Farm (359 modelled employees/ vehicles)
  - I1 – Chipping North (1,955 modelled employees/ vehicles)
  - I7 – Scrivener Street Place Area (2,378 modelled employees/ vehicles)
  - IR1 – Barry Road Chipping North (156 modelled employees/ vehicles)

    - I12 – Between Moorebank Avenue and Heathcote Road (1,319 modelled employees/ vehicles)
- While the NSW SES evacuation planning for the Georges River relies upon motor vehicle evacuation, there are currently thousands of people within the floodplain that do not have access to a vehicle (over 30% of dwellings in some areas). It is recognised that both rail and pedestrian evacuation have their limitations and may not be able to be relied upon. Furthermore, they are generally not supported by the NSW SES.
- Failing to evacuate or deliberately Sheltering in Place in the Georges River floodplain is particularly risky considering buildings can be isolated and inaccessible to emergency services for more than 24 hours in the PMF.

8.1.2 Future Evacuation Findings and Challenges

- The planned two-lane addition to the M5 over the Georges River would improve evacuation capacity from Moorebank and Chipping Norton for existing development, as it would improve traffic flow onto the M7 via the Hume Highway.
- Future infill development within currently zoned land may be able to be accommodated through the provision of planned road upgrades in the study area, particularly the additional lanes on the M5 over the Georges River.
- Major evacuation capacity constraints are apparent when accounting for future planning proposals in the study area. Modelled Scenario B resulted in over 32,000 vehicles caught by floodwaters across the study area and over 8,000 stranded on the Moorebank Peninsula. Table 18 summarises the key challenges for future development in the study area.

Table 18. Constraints on Future Development

Development	Challenge
The Grove	Requires a flood free evacuation route connection between Homepride Avenue and Orange Grove Road
Shepherd Street	May require an emergency level crossing of the railway line at Atkinson Street
Warwick Farm Structure Plan	Insufficient road capacity to cater for the evacuation of the planning proposals
Moore Point	Insufficient road capacity to cater for the evacuation of the planning proposals
Moorebank East	Approved and proposed development in Moorebank East would be able to evacuate in time but proposed development blocks the evacuation of Chipping Norton

- “Spare” evacuation capacity has been investigated at a high level for some of the large planning proposals included in Scenario B. However, it is stressed that this is only a high-level calculation, and the capacity would have to be modelled in order to test the impact of a reduction in vehicles from certain developments. Also note that the vehicles which escape the floodwaters but are trapped on the Moorebank Peninsula have not been accounted for in those calculations.
    - **Moorebank East:** Modelling suggests that that the road network could have capacity for approximately 700 evacuating vehicles from Moorebank East, accounting for the

road upgrades included in Scenario B. Given that the model included more than 360 vehicles from approved Site C, this would leave only half of the capacity for development at Sites A, B, D and E.

- **Moore Point:** Scenario B suggests that the road network may have capacity for approximately 5,500 evacuating vehicles from Moore Point, accounting for the road upgrades included in Scenario B.
- **Warwick Farm:** Scenario B suggests that the road network could have capacity for 850 evacuating vehicles from Warwick Farm in Scenario B, accounting for the road upgrades included in Scenario B.

8.2 Recommendations

Based on the findings of this study, the following recommendations are made to address Georges River flood evacuation challenges for Liverpool LGA.

8.2.1 Current Flood Evacuation Challenges

- Ensure that the proposed additional lanes on the M5 across the Georges River are configured to reduce the probability of flooding isolating the Moorebank Peninsula
- Investigate the provision of an additional southbound lane on Nuwarra Road between Brickmakers Drive and Heathcote Road to reduce the queuing that severely limits the evacuation of Chipping Norton onto the M5
- Investigate an emergency level crossing at Atkinson Street to improve the evacuation capability of current developments on Shepherd Street and Riverpark Drive
- Investigate an emergency flood evacuation route through private property between Homepride Avenue and Orange Grove Road (Figure 25 is one possibility) to ensure a flood-free evacuation route for the existing commercial, industrial and residential developments in the areas
- Investigate development of a comprehensive flood forecasting and warning system in the Georges River Catchment to increase the warning time for evacuation
- Investigate the benefits of an intelligent traffic system (ITS) to see whether this could increase evacuation route capacities at route bottlenecks
- Investigate whether contraflow arrangements are likely to increase flood evacuation capacity
- Use data and consider outcomes from this study to inform preparation of Volume 2 and 3 of the Georges River and Woronora River Valley Flood Emergency Sub Plan
- Identify means of safely managing the thousands of people on the floodplain who do not have access to private motor vehicles, many of whom may have mobility challenges. This might include pedestrian evacuation, mass transport or sheltering in place.

8.2.2 Planning Proposals

- Many of the above listed recommendations to deal with "current" challenges may also facilitate evacuation capacity improvements for future planning proposals
- Development at Moorebank East should be restricted, considering it is estimated that half of the evacuation capacity is taken up by the already-approved Site C development. An additional lane on Nuwarra Road should be investigated to see whether it would provide sufficient additional evacuation capacity to enable further development at Moorebank East without compromising the safe evacuation of existing development in Chipping Norton

- Development at Shepherd Street has a relatively low flood evacuation risk and is unlikely to compromise the evacuation of nearby developments. Emergency access in the area could be improved through the provision of an emergency level crossing at Atkinson Street
- The Grove in Warwick Farm should only be approved if a flood free emergency evacuation route can be created between Homepride Avenue and Orange Grove Road
- The planning proposals for Moore Point and the Warwick Farm Structure Plan either need to be substantially scaled back or:
  - more time to evacuate is provided through an improved warning system
  - improved evacuation route capacity is provided through road upgrades, contraflow traffic arrangement and/or an ITS
  - alternatives to private motor vehicle evacuation is catered for through mass transport, pedestrian evacuation or sheltering in place.

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Appendix A | Subsector Trigger Levels

Molino Stewart Subsector	Classification	Initial Trigger Level	Staging of evacuation	Initial Trigger PMF Time Step (12 hrs before trigger level reached)
R25 (Chipping Norton)	Low flood island	Flooding of evacuation route	All	-7.5
I5 (Moorebank)	Low flood island	Flooding of factories	All	-5.0
I3 (Moorebank)	Low flood island	Flooding of factories	All	-5.0
R26 (Liverpool)	Rising road access	Flooding of houses	By level	-5.0
I13 (Moorebank)	Low flood island	Flooding of evacuation route	All	-5.0
R4 (Chipping Norton)	Sammut Place is a low flood island while rest of sector has an overland escape route but whole peninsula is a High flood island	Flooding of houses	By level except Sammut which leaves pre t=8.0. Then until t=11.0	-4.5
I15 (Warwick Farm)	Low flood island	Flooding of evacuation route	All	-4.5
I1 (Chipping Norton)	Low flood island	Flooding of factories	By level until t=11.5	-4.5
I8 (Warwick Farm)	Rising road access	Flooding of properties	All	-4.5
I14 (Moorebank)	High flood island	Flooding of evacuation route	All	-4.5
I7 (Liverpool)	Low flood island. Road on western side of bridge gets cut at t=12.5	Flooding of buildings	By level until t=12.5	-4.5
R3 (Chipping Norton)	Rising road access to Newbridge Road but whole peninsula is a High flood island	Flooding of evacuation route	By level until t=11.5	-4.0
I4 (Moorebank)	High flood island	Flooding of buildings	All	-4.0
R15 (Liverpool)	Low flood island	Flooding of evacuation route	All	-4.0
I6 (Moorebank)	Rising road access to Moorebank Ave but whole peninsula is a High flood island	Flooding of factories	All	-4.0
Equestrian (Hzone) (Warwick Farm)	Rising road access	Flooding of houses	By level	-4.0
IR1 (Chipping Norton)	Low flood island	Flooding of evacuation route	All	-4.0
R1 (Chipping Norton)	Low flood island	Flooding of evacuation route	By level until t=10.0	-4.0

Molino Stewart Subsector	Classification	Initial Trigger Level	Staging of evacuation	Initial Trigger PMF Time Step (12 hrs before trigger level reached)
R11 (Moorebank)	Rising road access to Nuwarra Road but whole peninsula is a High flood island	Flooding of houses	By level until t=11.0	-4.0
R12 (Moorebank)	Low flood island	Flooding of houses	All	-4.0
I12 (Moorebank)	Low flood island	Flooding of buildings	All	-4.0
R2 (Chipping Norton)	Low flood island	Flooding of houses	By level until t=10.0	-4.0
R17 (Warwick Farm)	Rising road access	Flooding of houses	By level	-4.0
R10 (Hammondville)	Rising road access to Heathcote Road but whole peninsula is a High flood island	Flooding of properties	By level until t=11.0	-3.5
R27 (Liverpool)	Rising road access	Flooding of houses	By level	-3.5
R7 (Moorebank)	Low flood island	Flooding of evacuation route	All	-3.0
R8 (Moorebank)	Rising road access to Nuwarra Road but whole development will be at virtually same level and then peninsula is a High flood island	Flooding of houses	All	-2.5
R5 (Chipping Norton)	Rising road access to Nuwarra Road but whole peninsula is a High flood island	Flooding of houses	By level until t=11.0	-2.5
I2 (Chipping Norton)	Rising road access to Nuwarra Road but whole peninsula is a High flood island	Flooding of factories (to the north)	By level until t=11.0	-2.5
R9 (Moorebank)	Rising road access to Nuwarra Road but whole peninsula is a High flood island	Flooding of houses	By level until t=11.0	-2.5
R18 (Warwick Farm)	Rising road access	Flooding of houses	By level	-2.5
R6 (Chipping Norton)	Rising road access to Nuwarra Road but whole peninsula is a High flood island	Flooding of houses	By level	-1.5
I9 (Warwick Farm)	Rising road access	Flooding of buildings	All	-1.0

Molino Stewart Subsector	Classification	Initial Trigger Level	Staging of evacuation	Initial Trigger PMF Time Step (12 hrs before trigger level reached)
R16 (Liverpool)	Rising road access	Flooding of houses	By level	-0.5
R23 (Holsworthy)	Rising road access to Heathcote Road but whole peninsula is a High flood island	Flooding of houses	All	0.0
R19 (Liverpool)	Rising road access	Flooding of houses	By level	7.5
R21 (Warwick Farm)	Rising road access	Flooding of houses	By level	10.0

Appendix B| Model Outputs

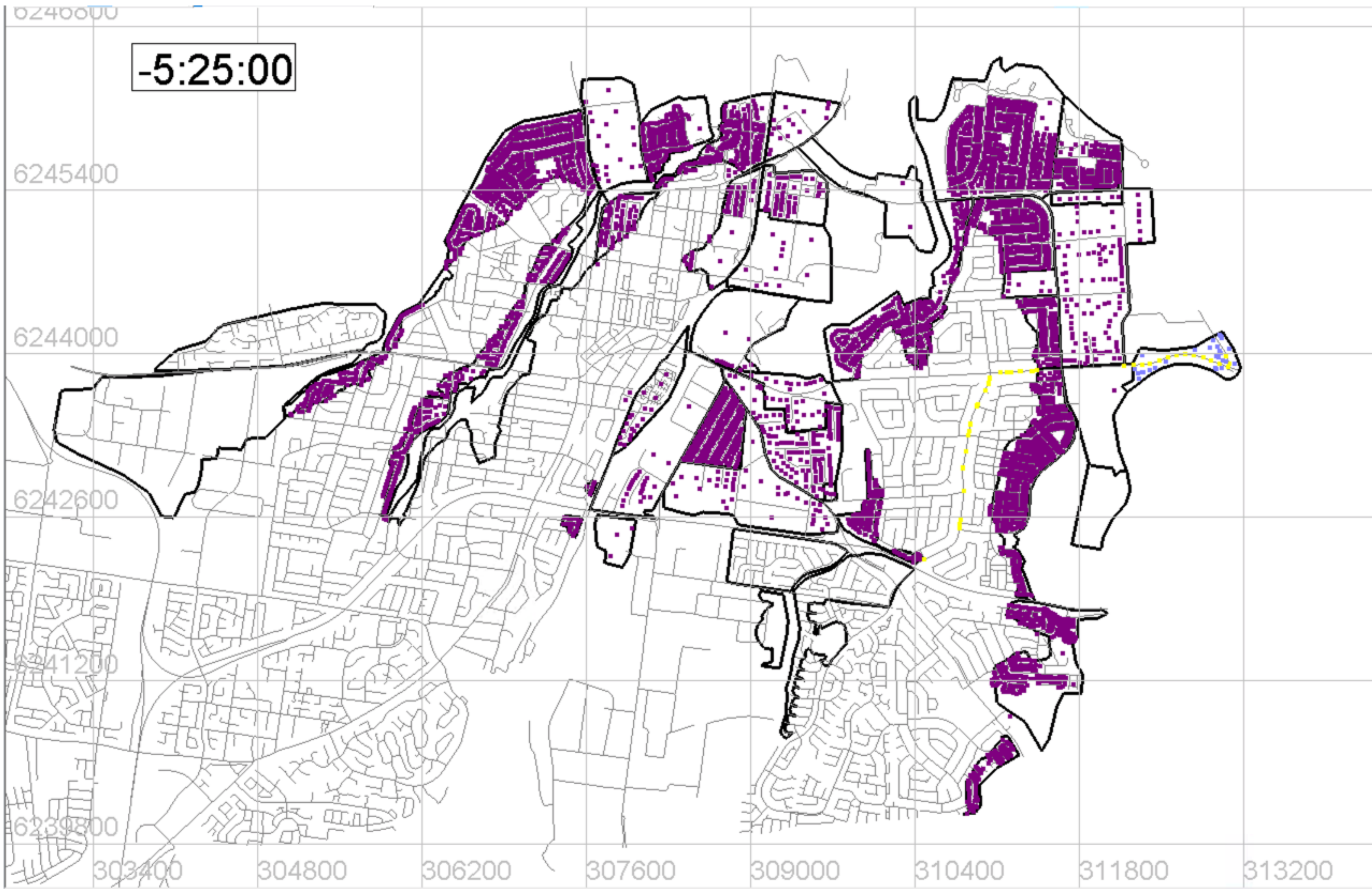

Figure B1. Georges River PMF timestep -5:25 (Scenario 1: Base Case)

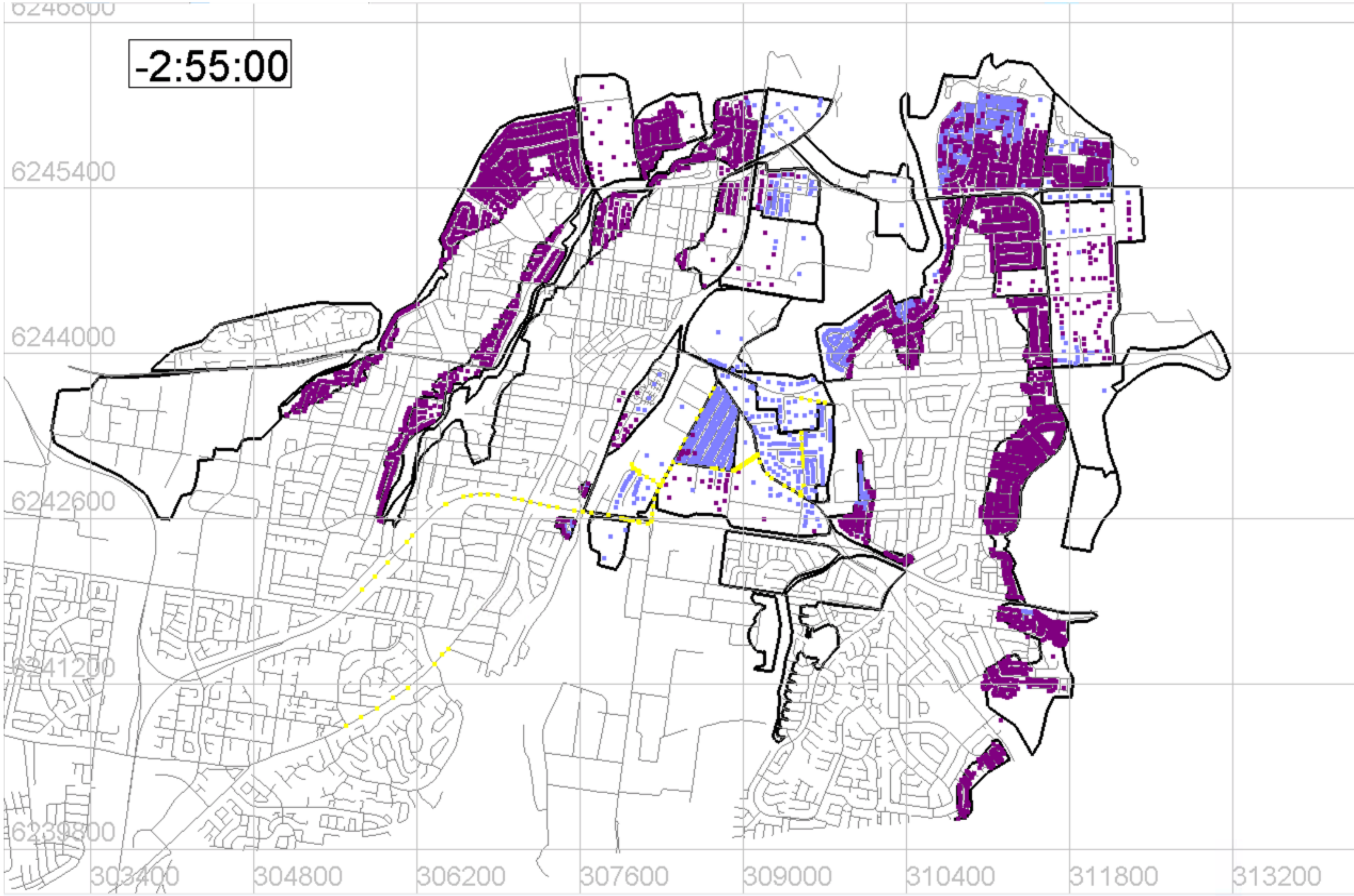

Figure B2. Georges River PMF timestep -2:55 (Scenario 1: Base Case)

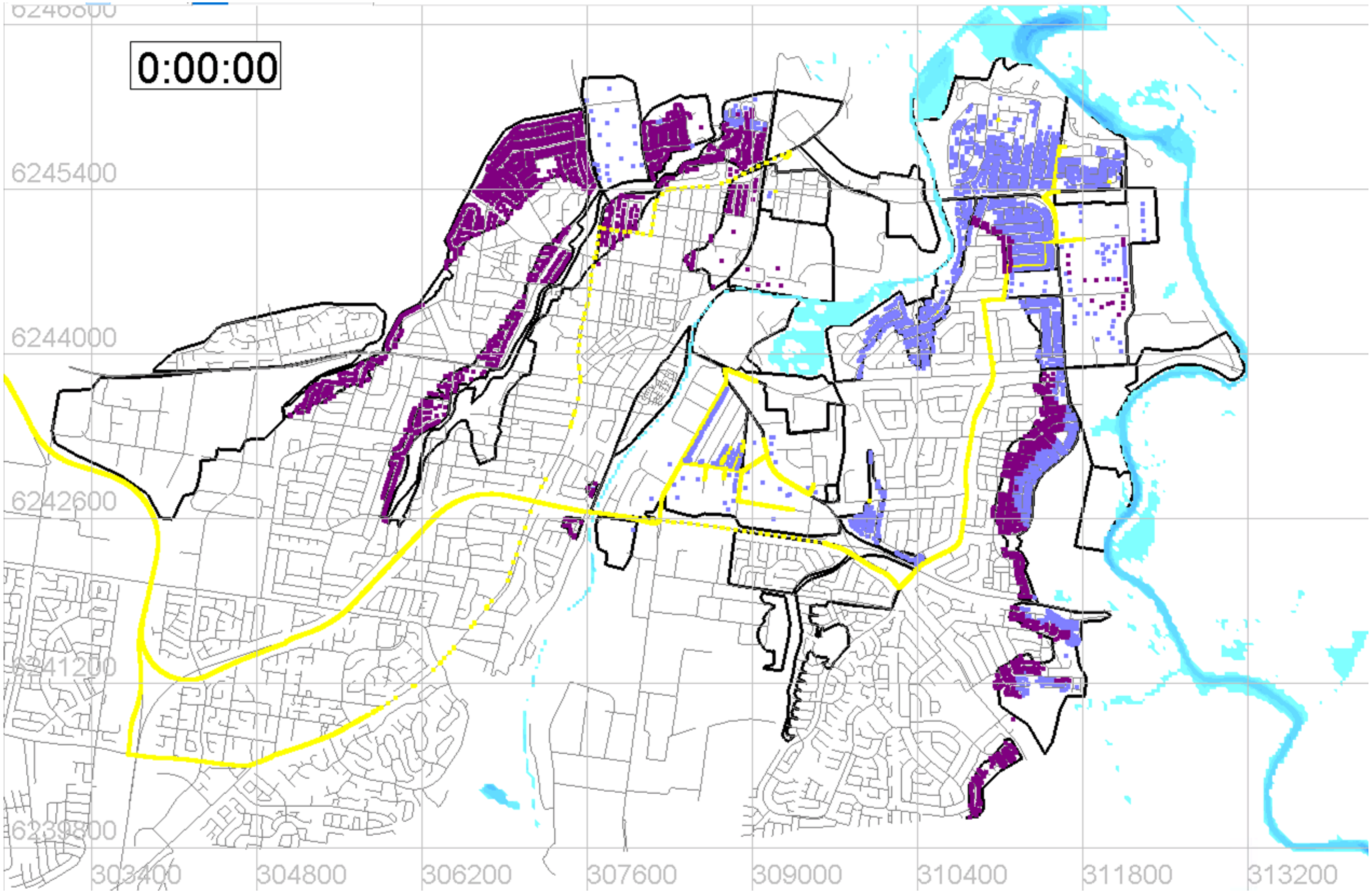

Figure B3. Georges River PMF timestep 0:00 (Scenario 1: Base Case)

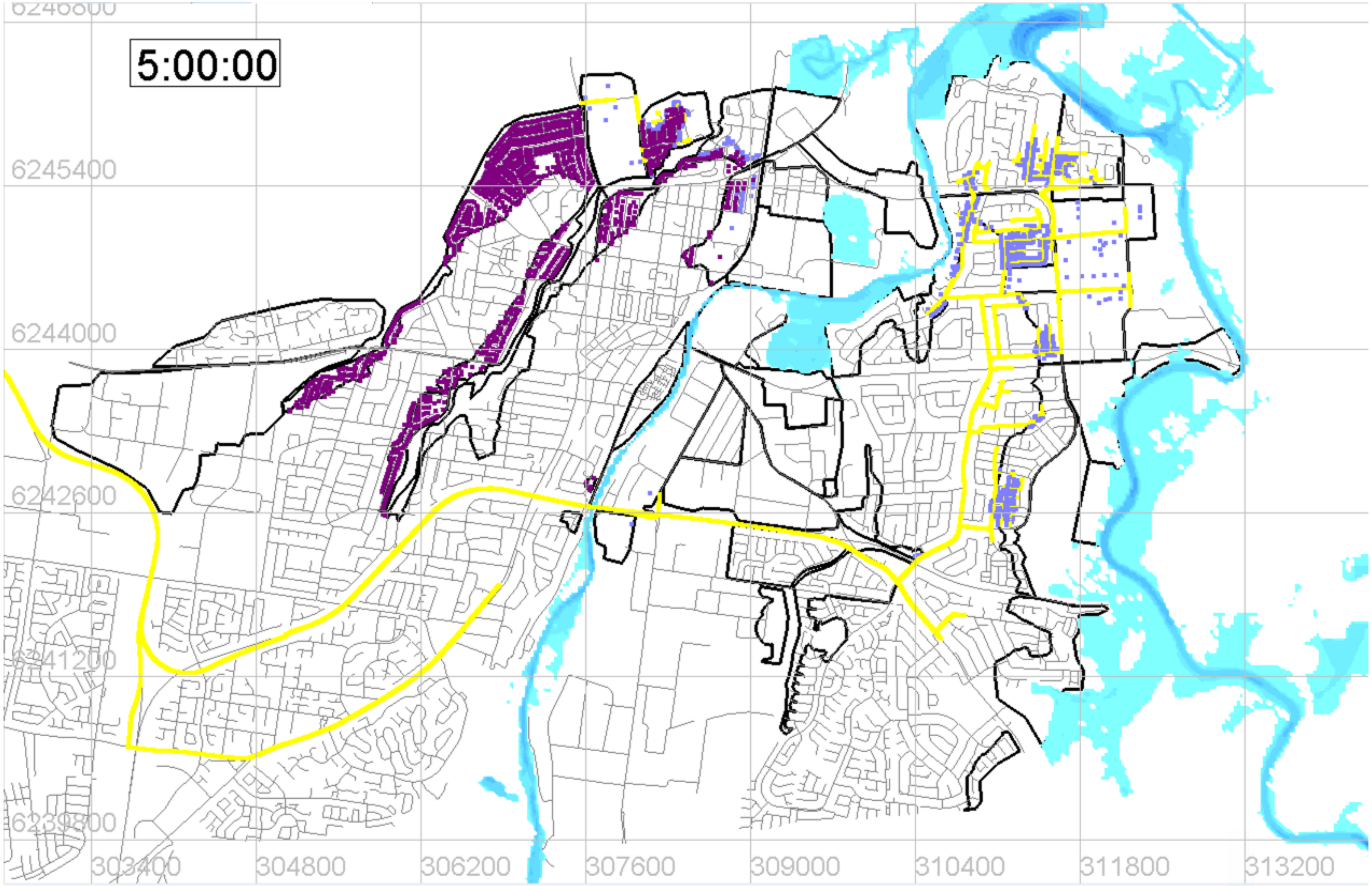

Figure B4. Georges River PMF timestep 5:00 (Scenario 1: Base Case)

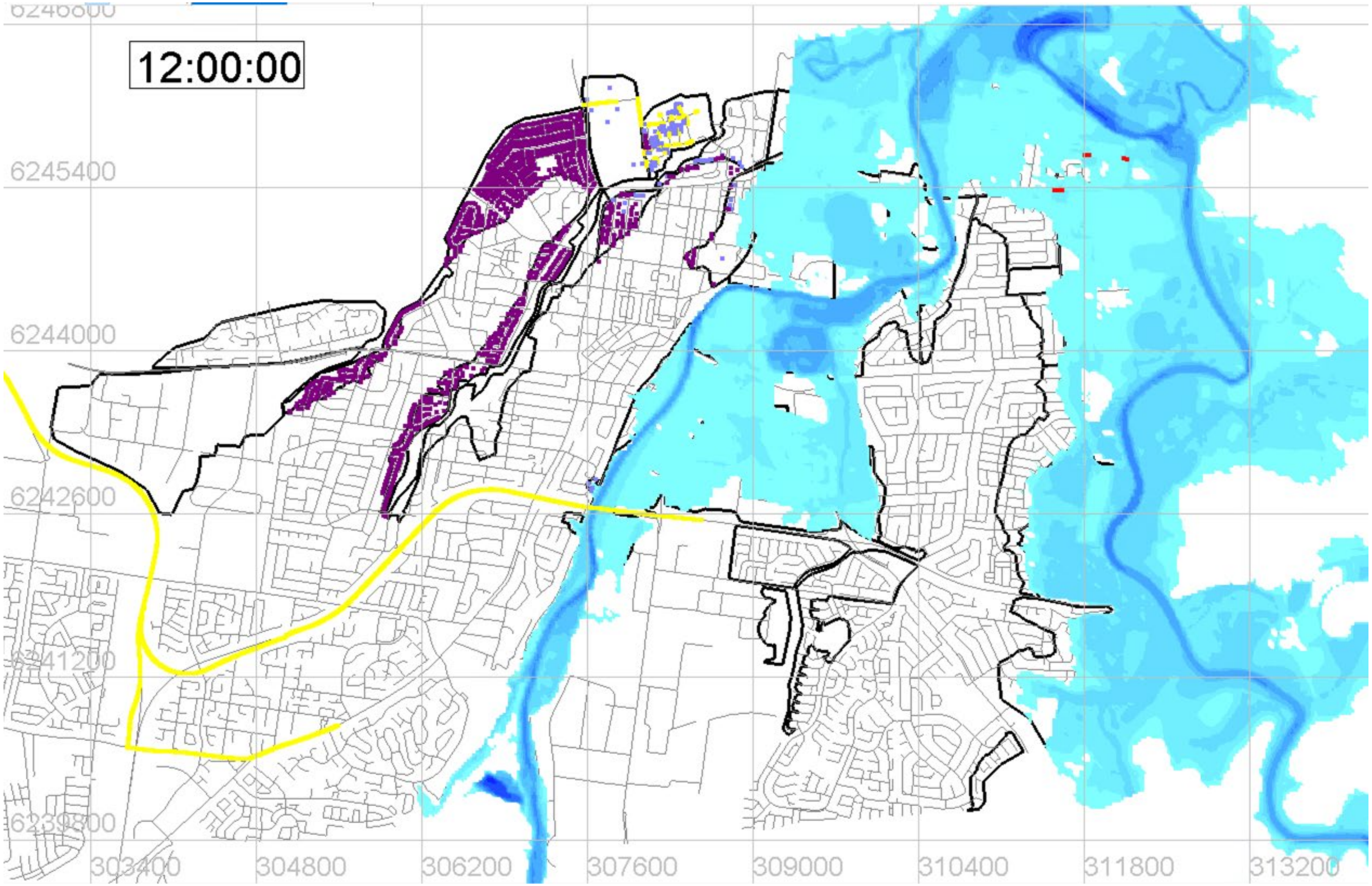

Figure B5. Georges River PMF timestep 12:00 (Scenario 1: Base Case)

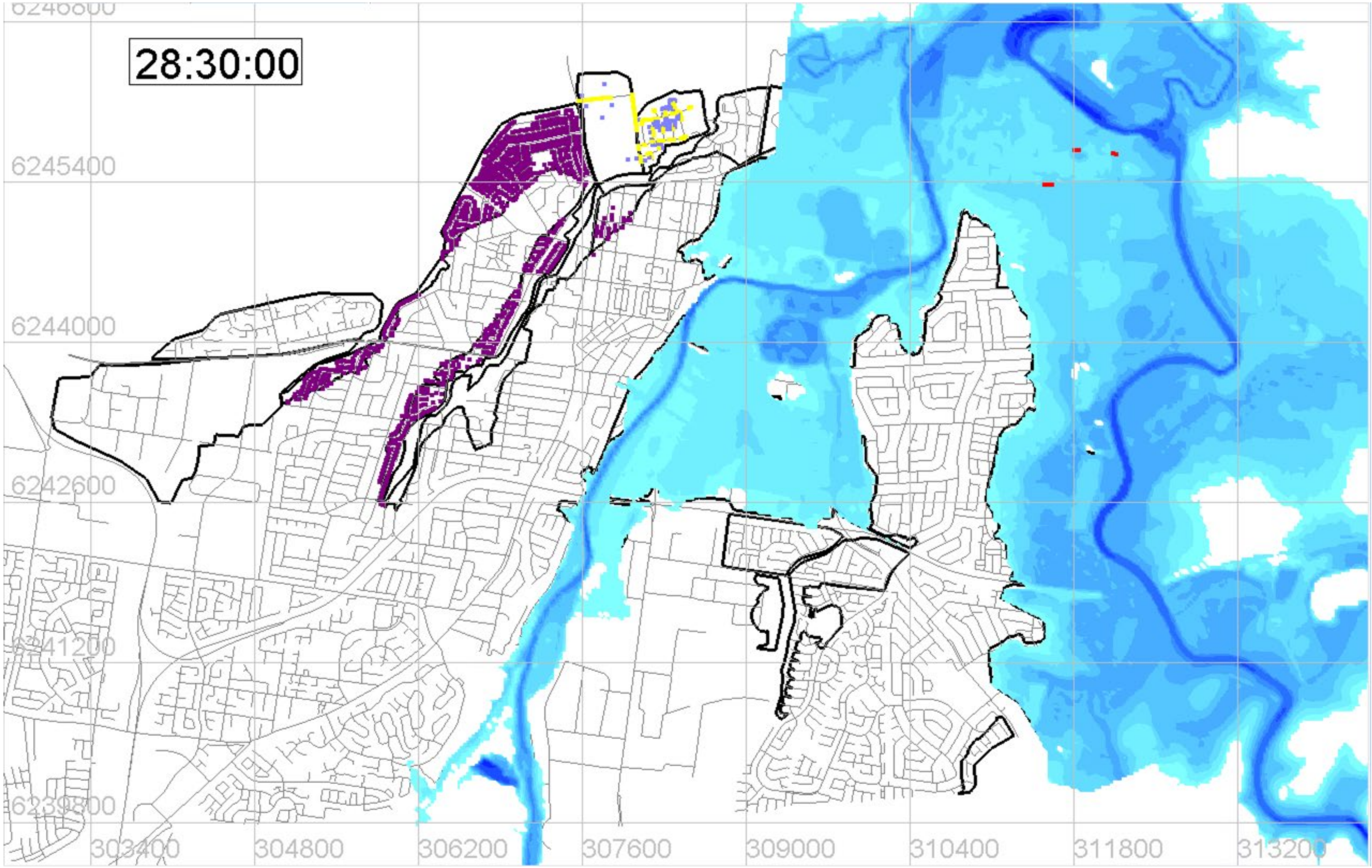

Figure B6. Georges River PMF timestep 28:30 (Scenario 1: Base Case)

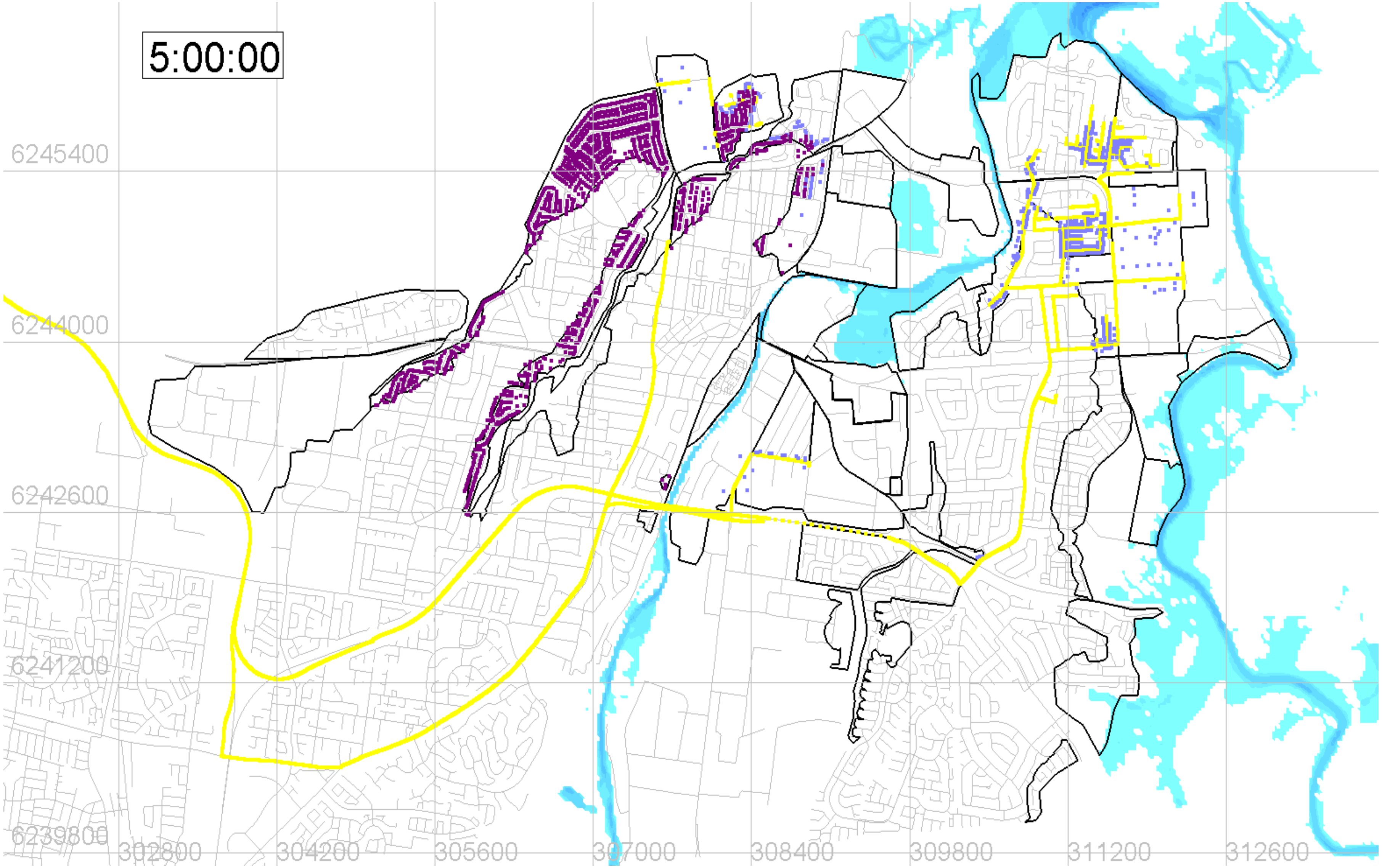

Figure B7. Georges River PMF timestep 5:00 (Scenario 2: Intensified Development under Existing Zoning)

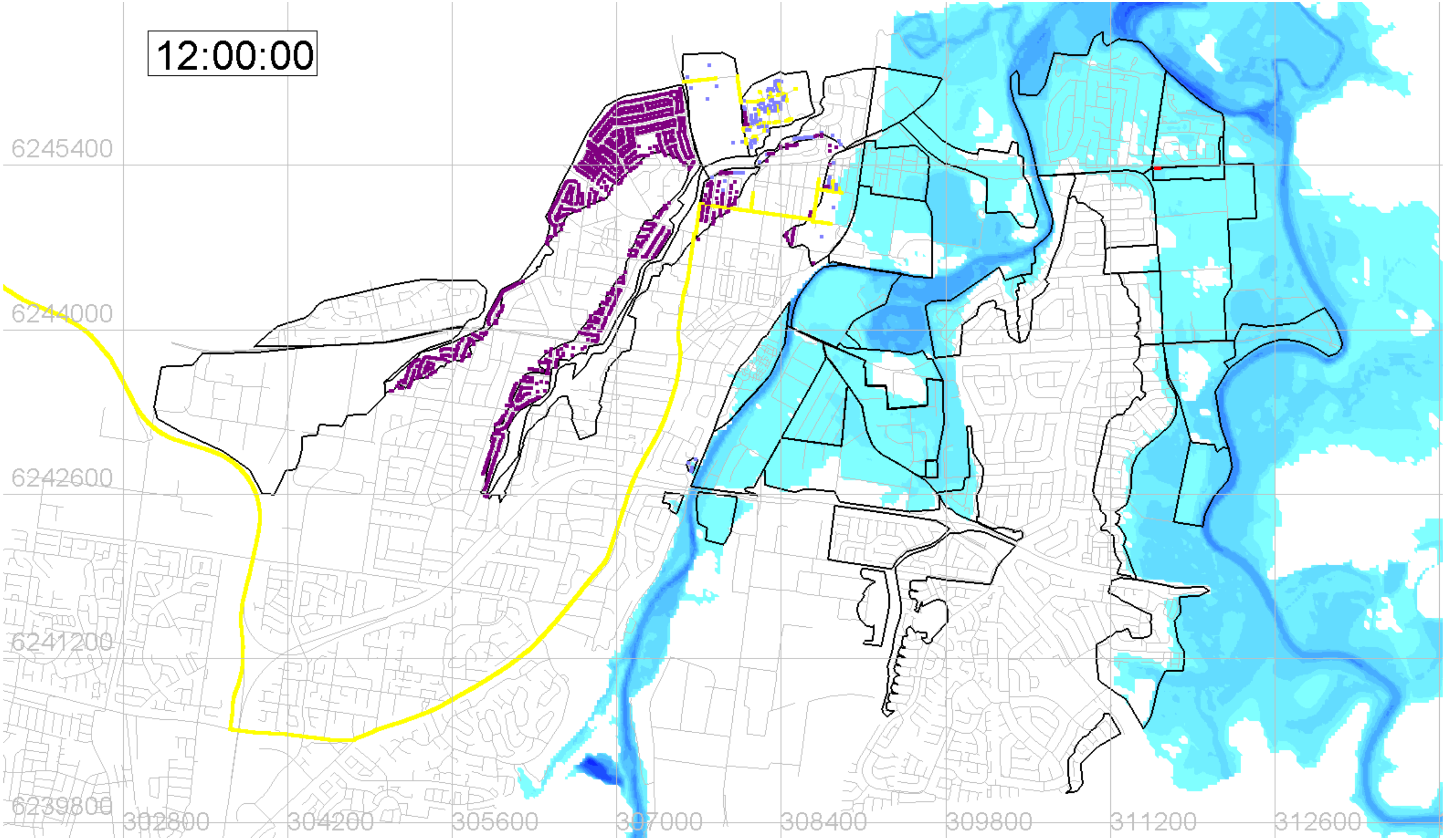

Figure B8. Georges River PMF timestep 12:00 (Scenario 2: Intensified Development under Existing Zoning)

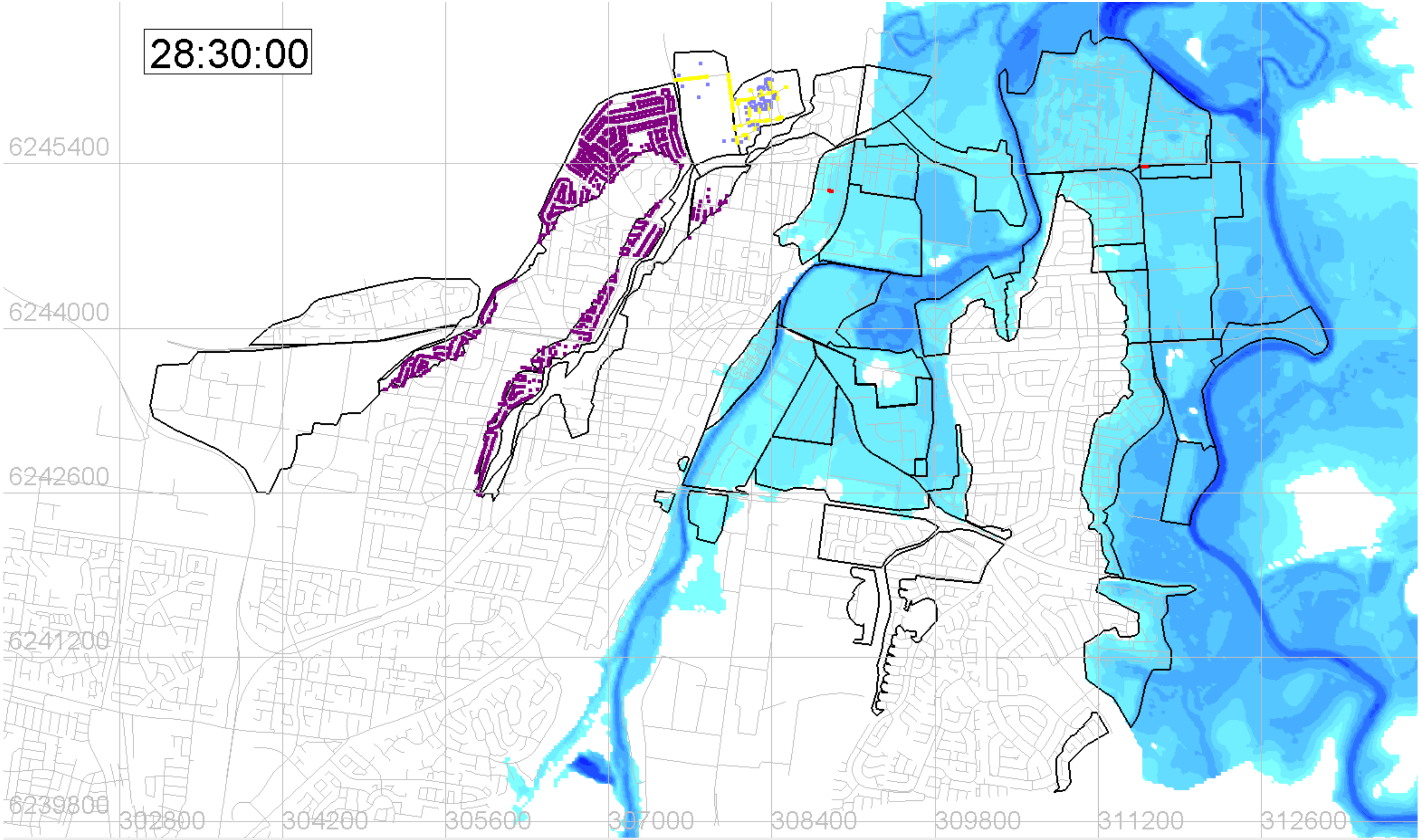

Figure B9. Georges River PMF timestep 28:30 (Scenario 2: Intensified Development under Existing Zoning)

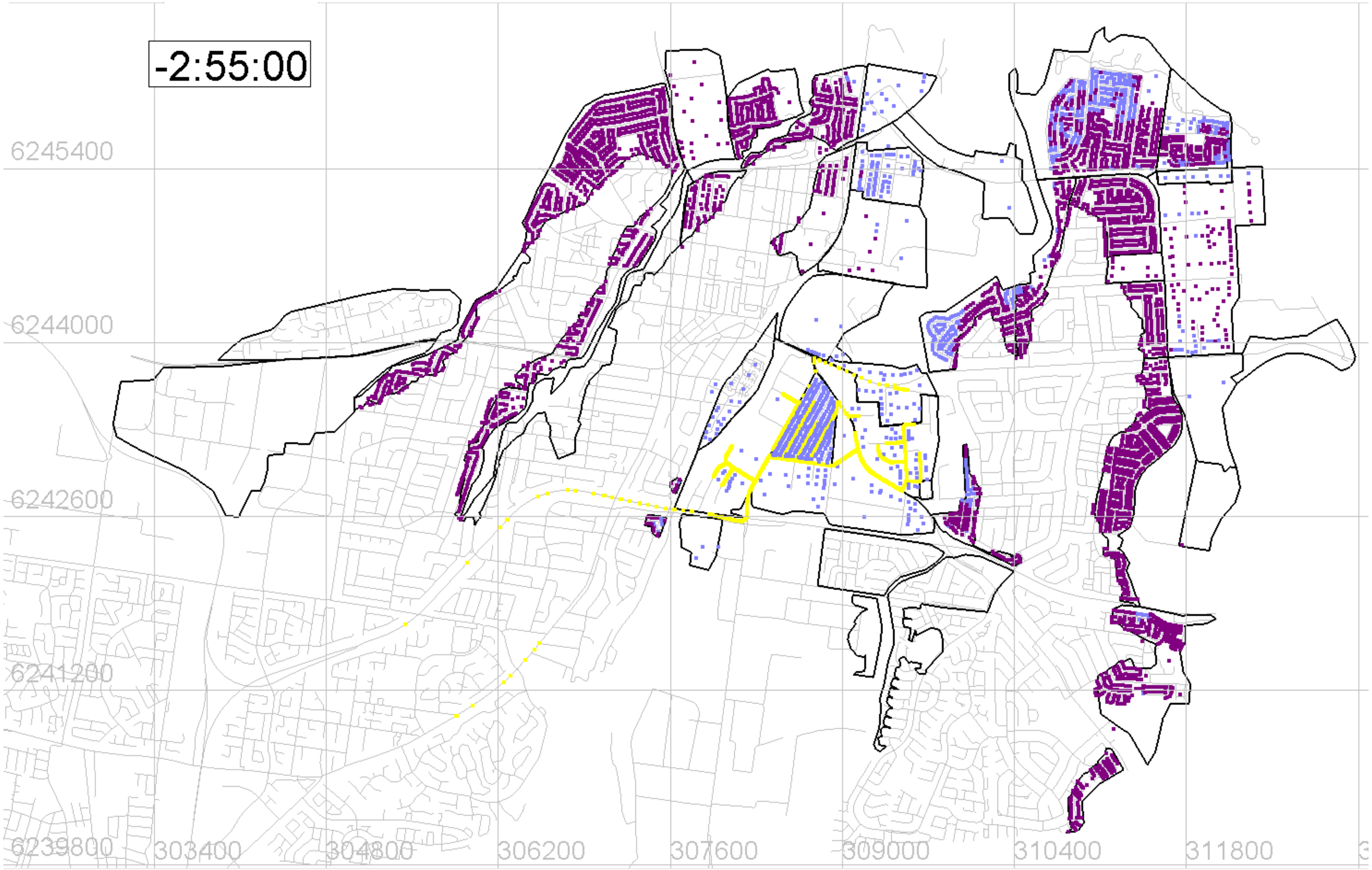

Figure B10. Georges River PMF timestep -2:55 (Scenario 3: Planning Proposals)

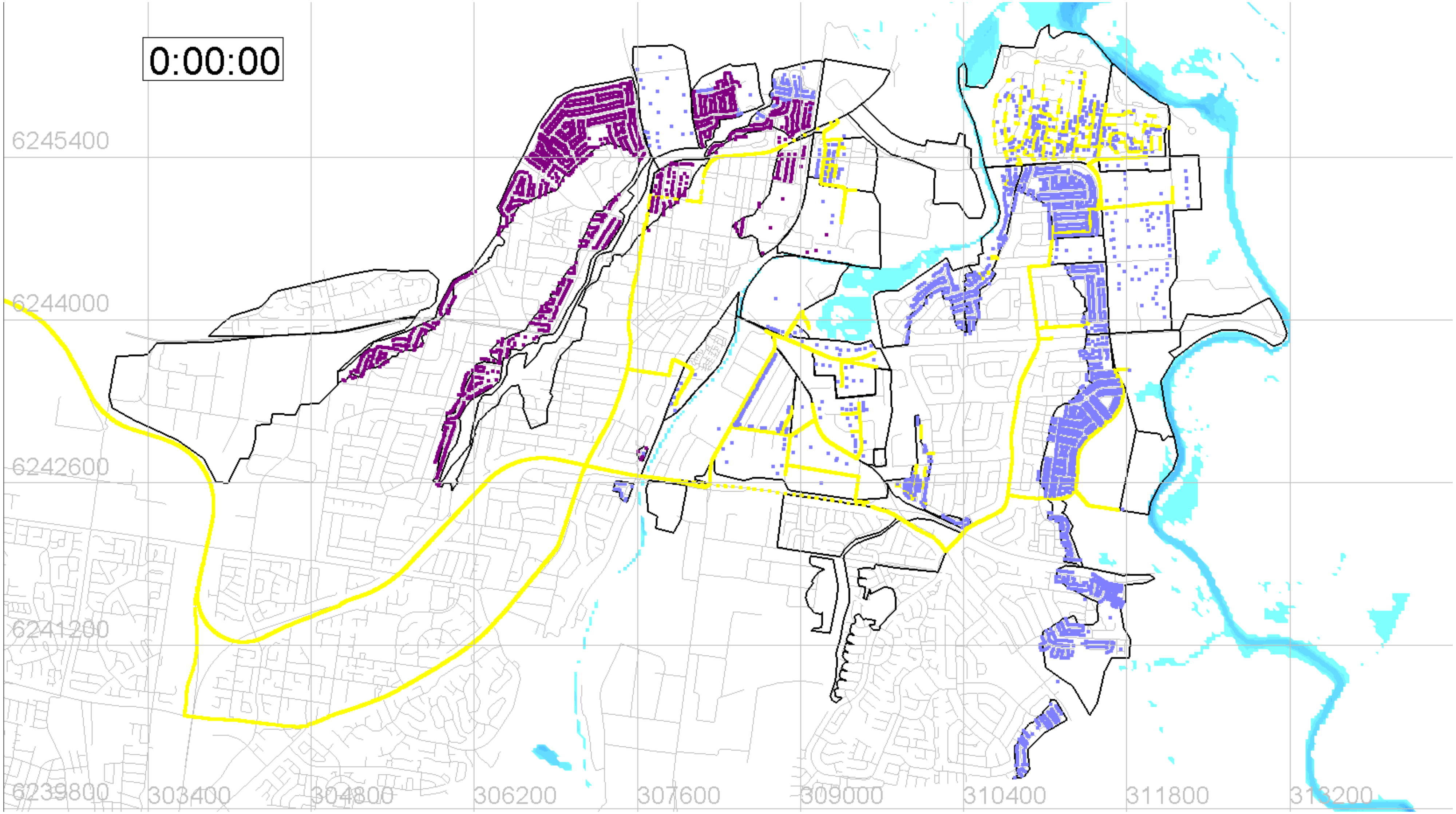

Figure B11. Georges River PMF timestep 0:00 (Scenario 3: Planning Proposals)

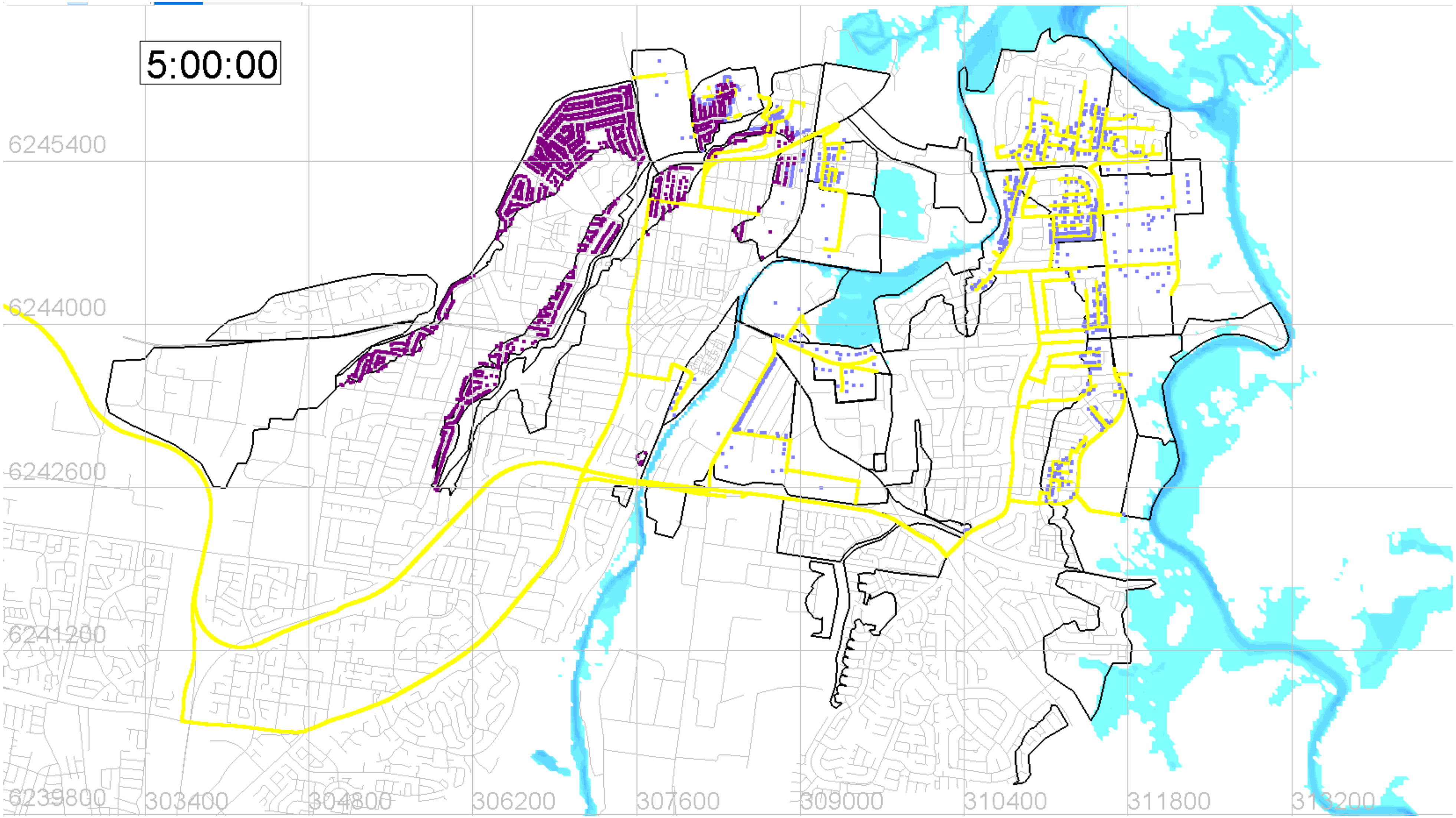

Figure B12. Georges River PMF timestep 5:00 (Scenario 3: Planning Proposals)

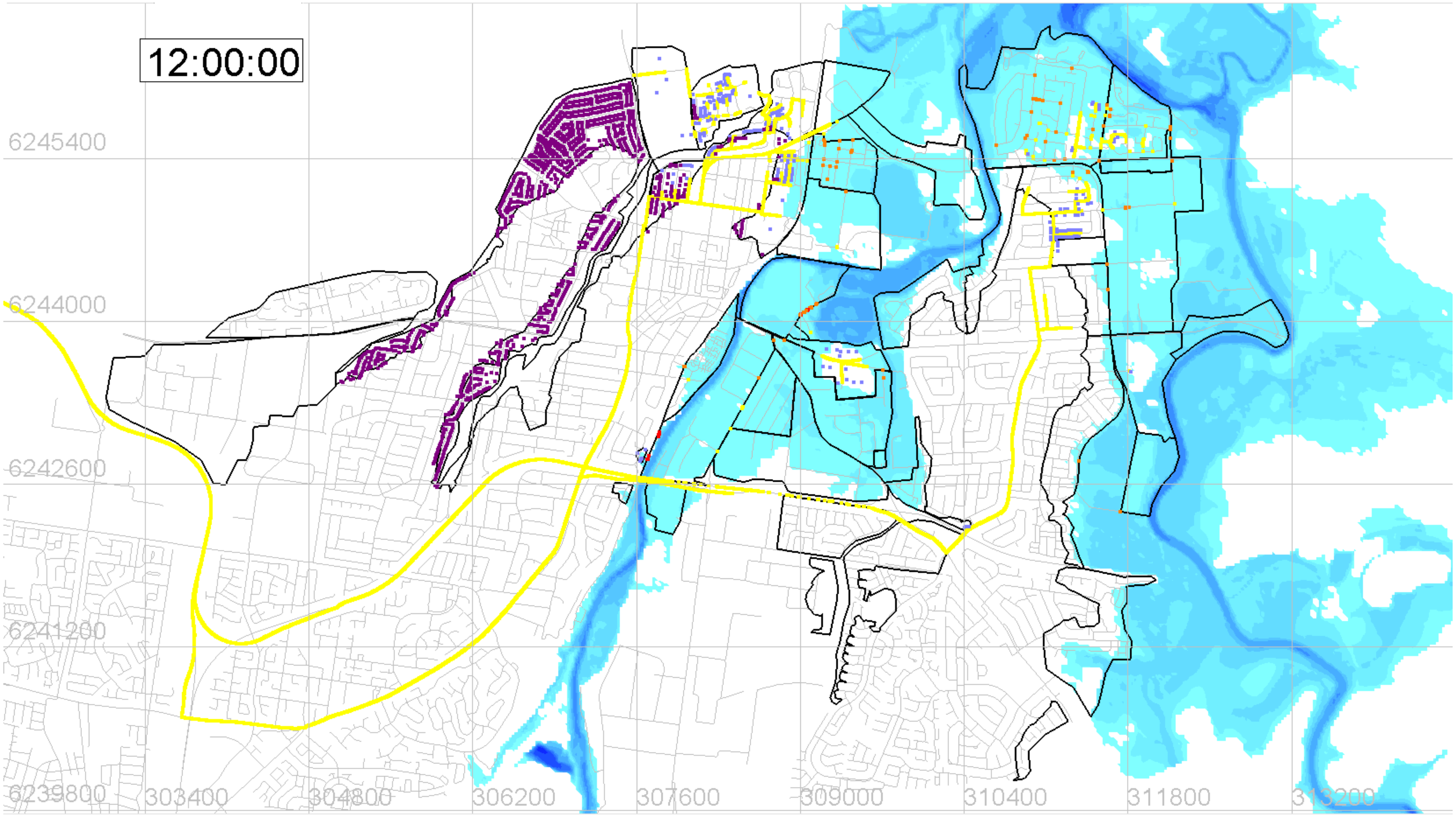

Figure B13. Georges River PMF timestep 12:00 (Scenario 3: Planning Proposals)

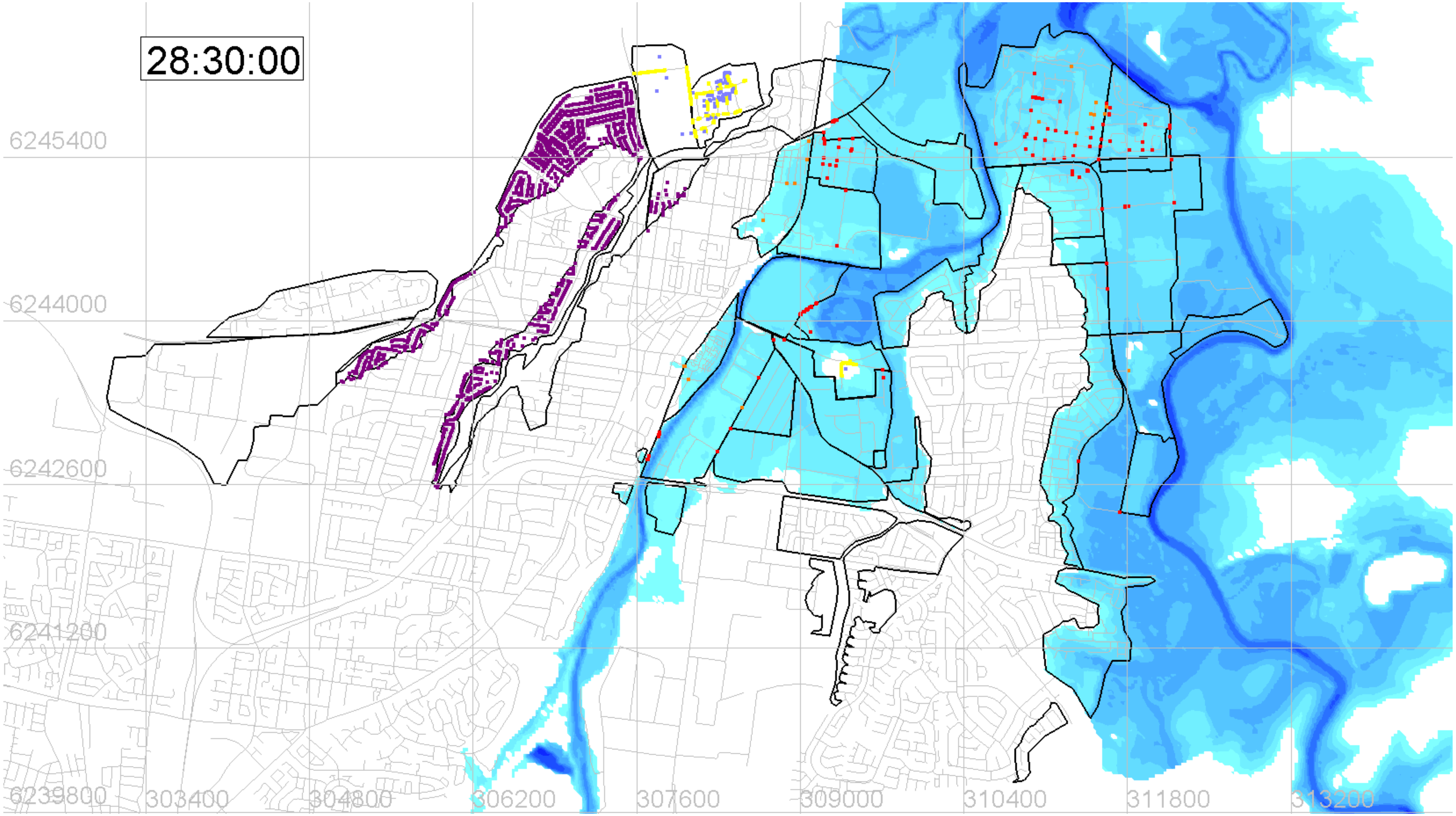

Figure B14. Georges River PMF timestep 28:30 (Scenario 3: Planning Proposals)

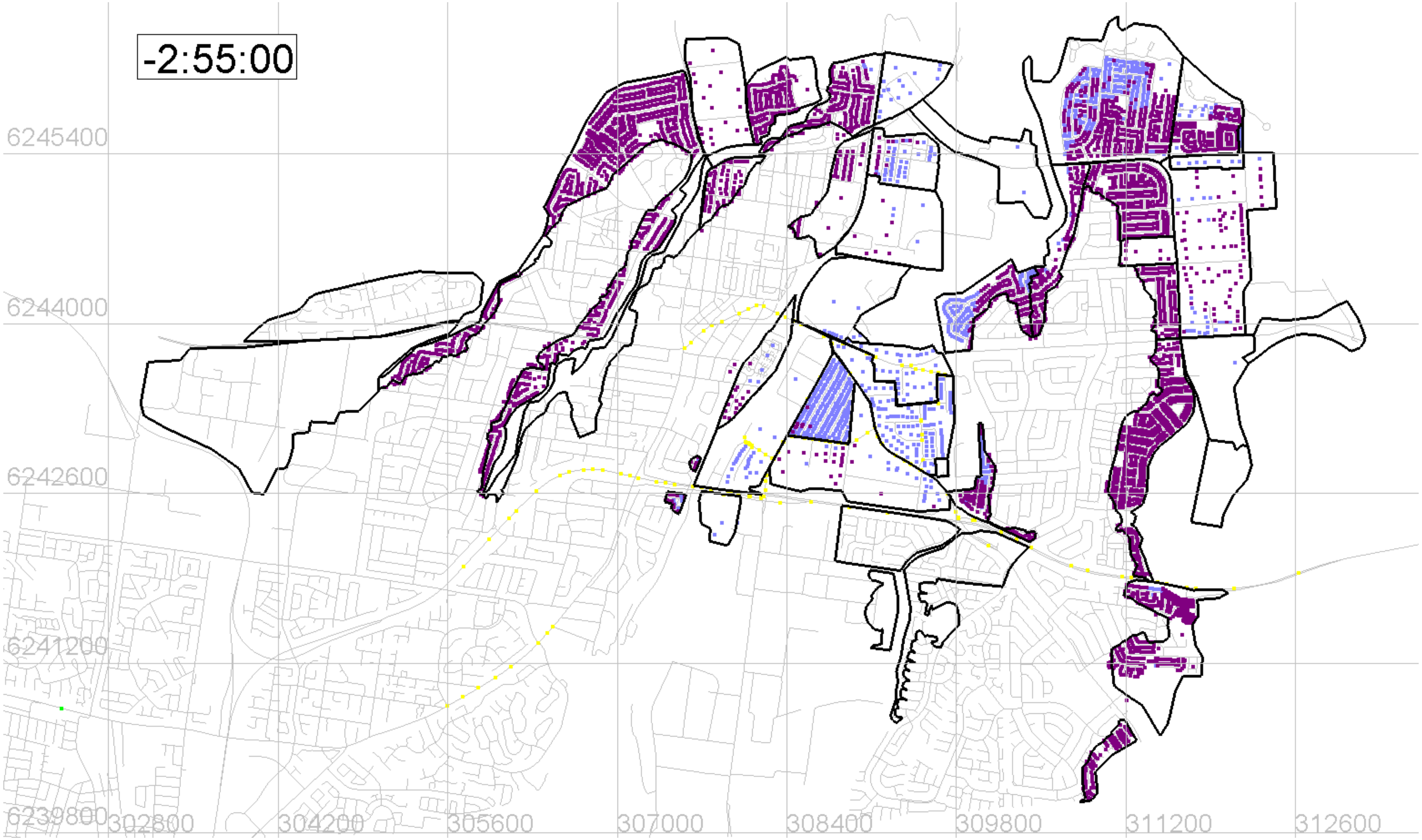

Figure B15. Georges River PMF timestep -2:55 (Scenario A)

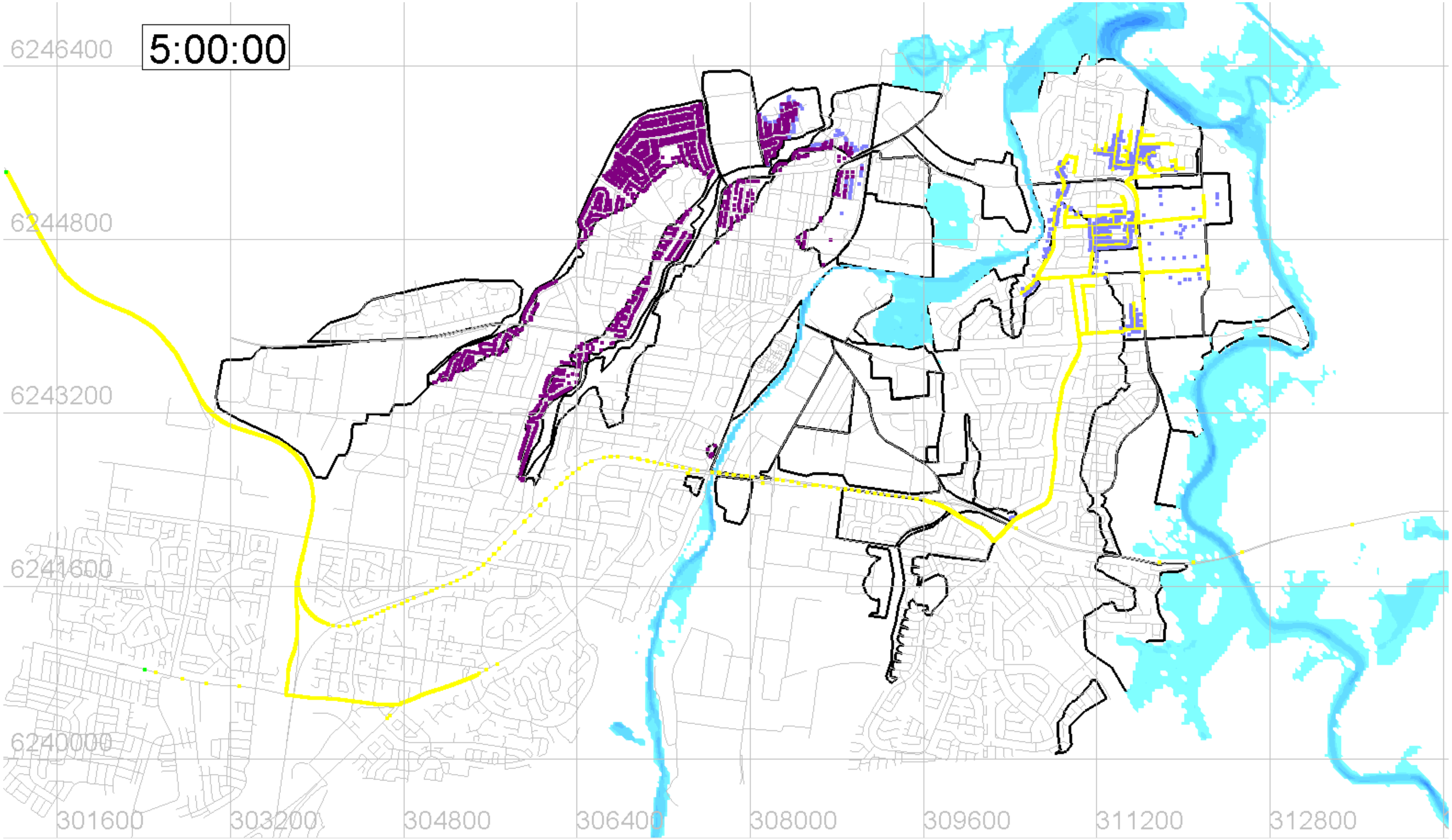

Figure B16. Georges River PMF timestep 5:00 (Scenario A)

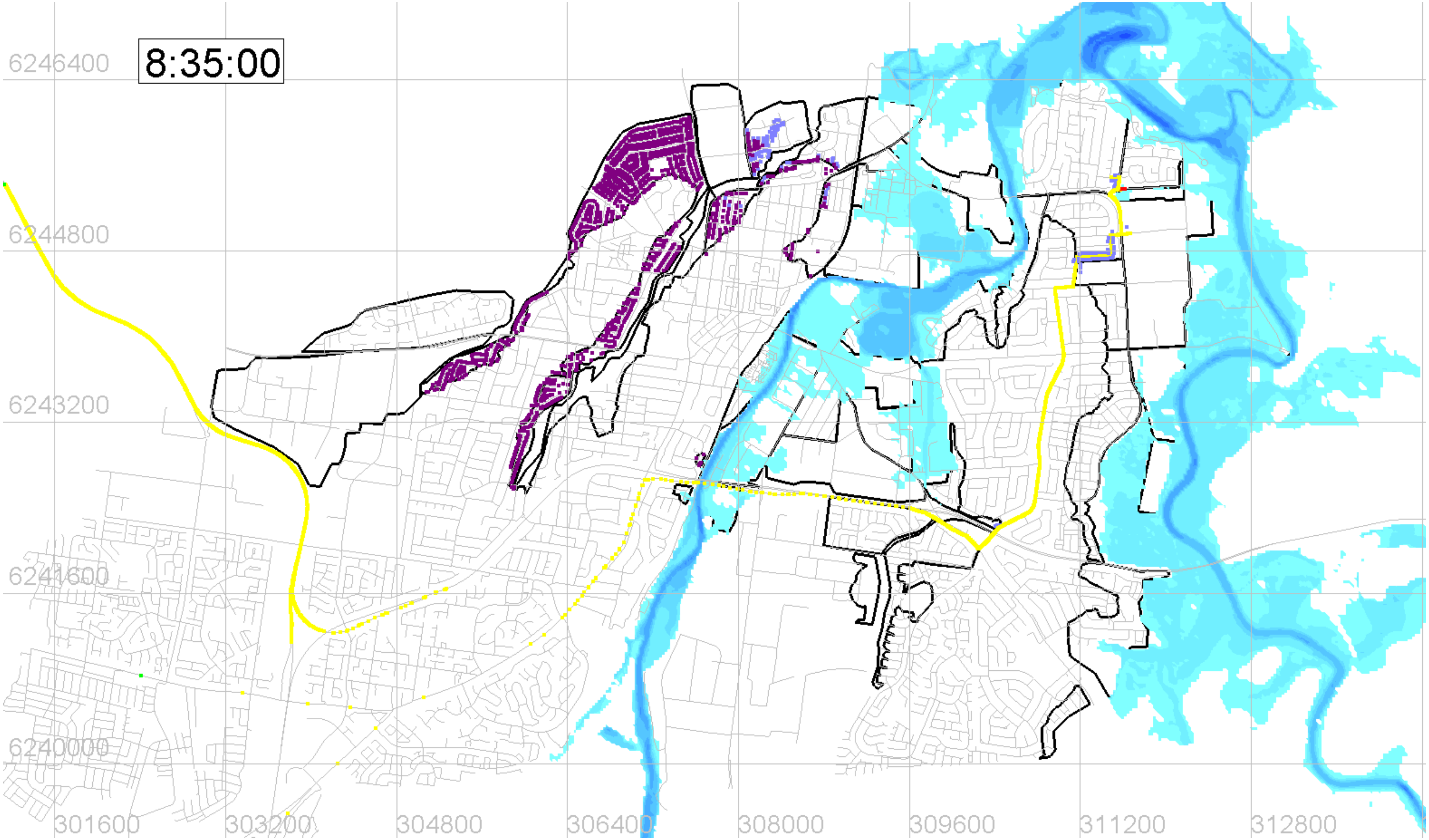

Figure B17. Georges River PMF timestep 8:35 (Scenario A)

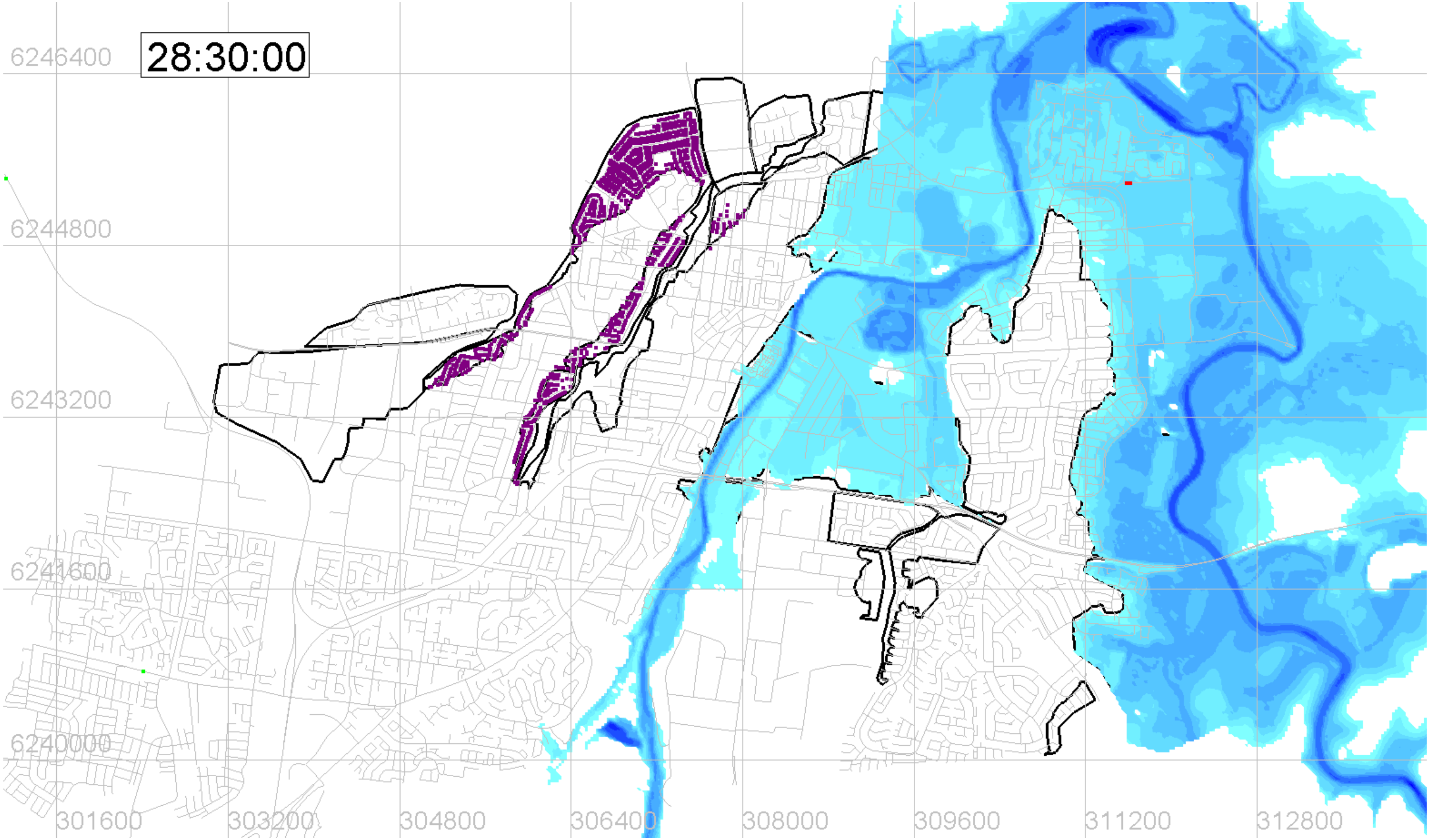

Figure B18. Georges River PMF timestep 28:30 (Scenario A)

Figure B19. Georges River PMF timestep -2:55 (Scenario B)

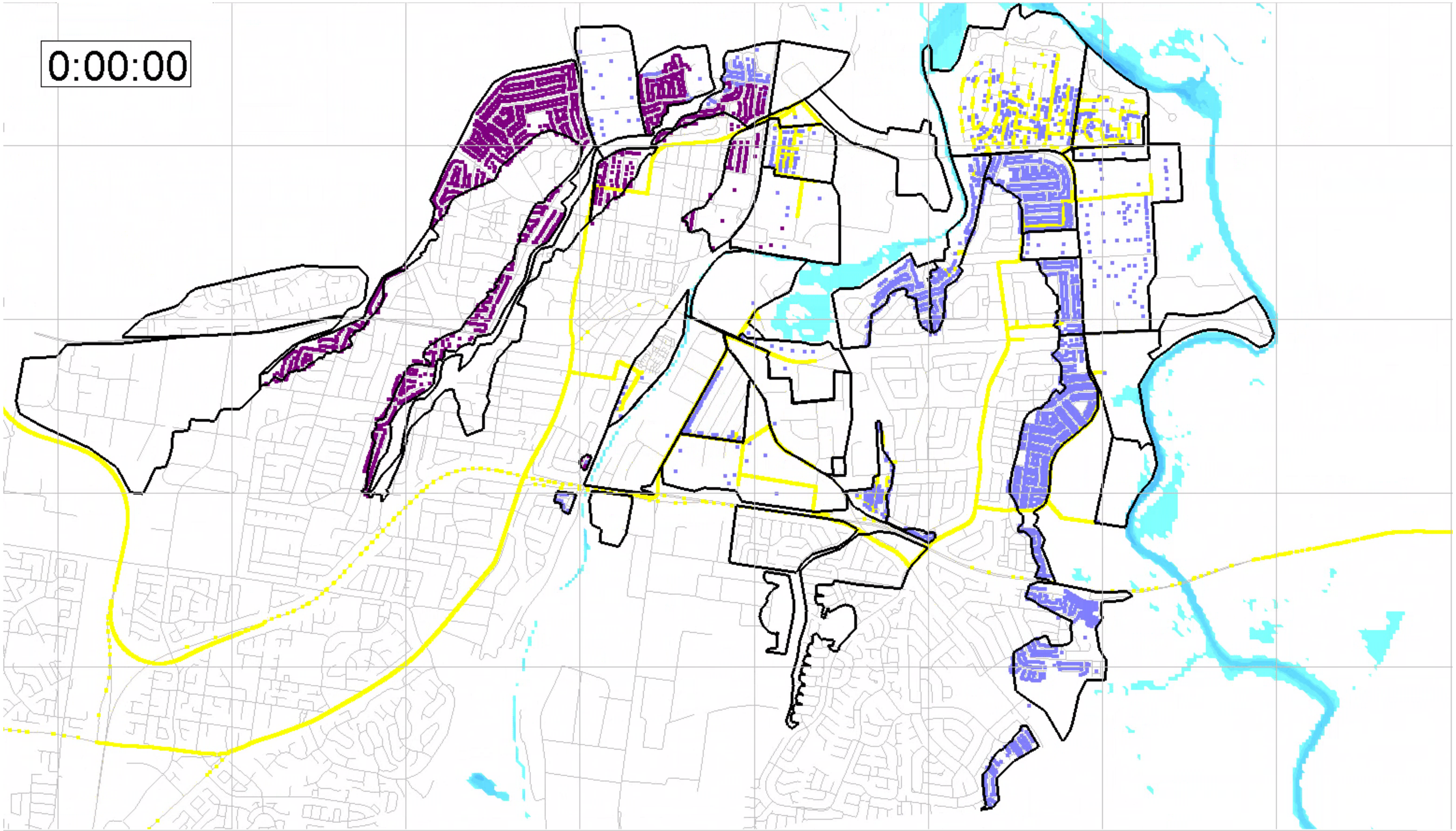

Figure B20. Georges River PMF timestep 0:00 (Scenario B)

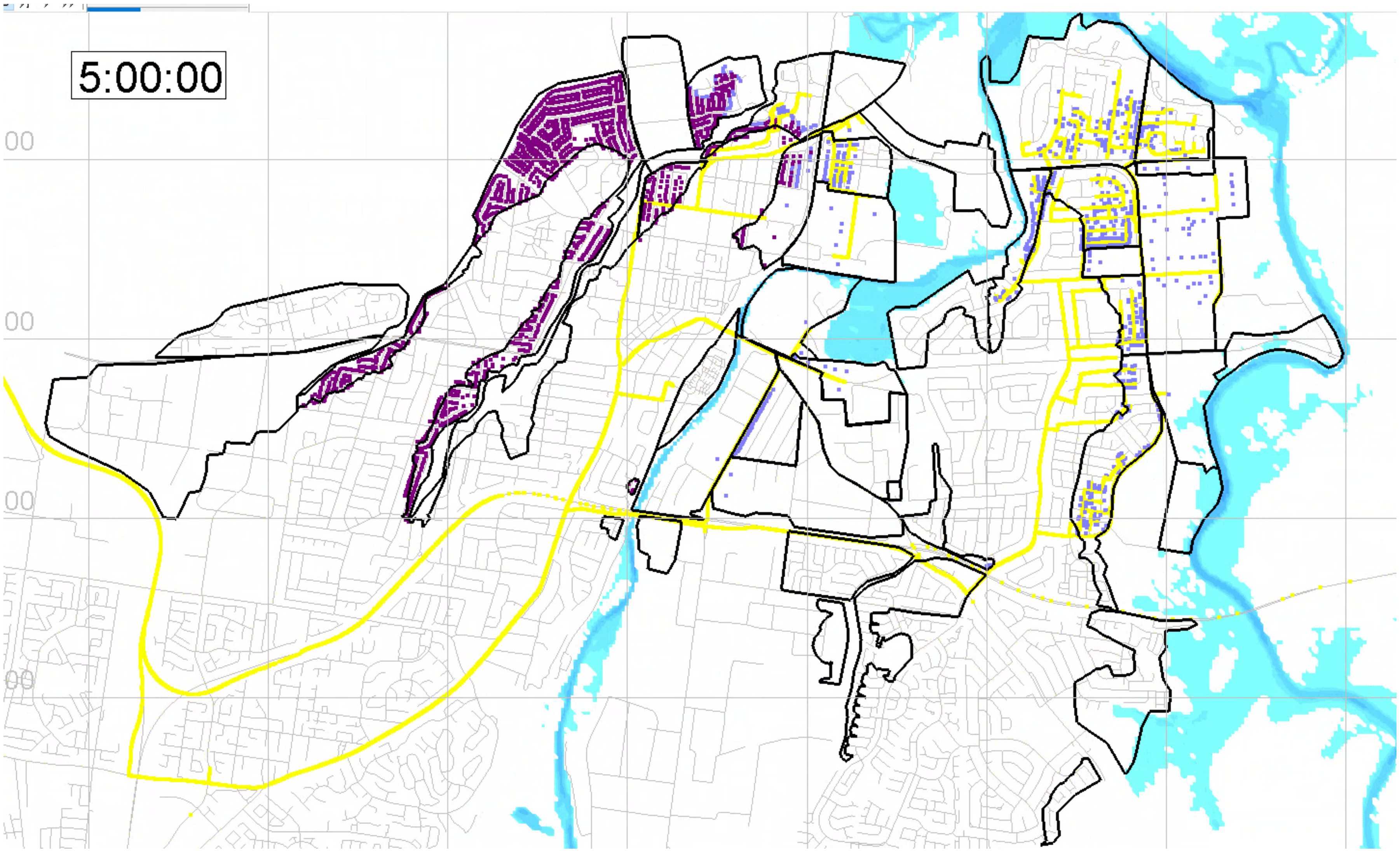

Figure B21. Georges River PMF timestep 5:00 (Scenario B)

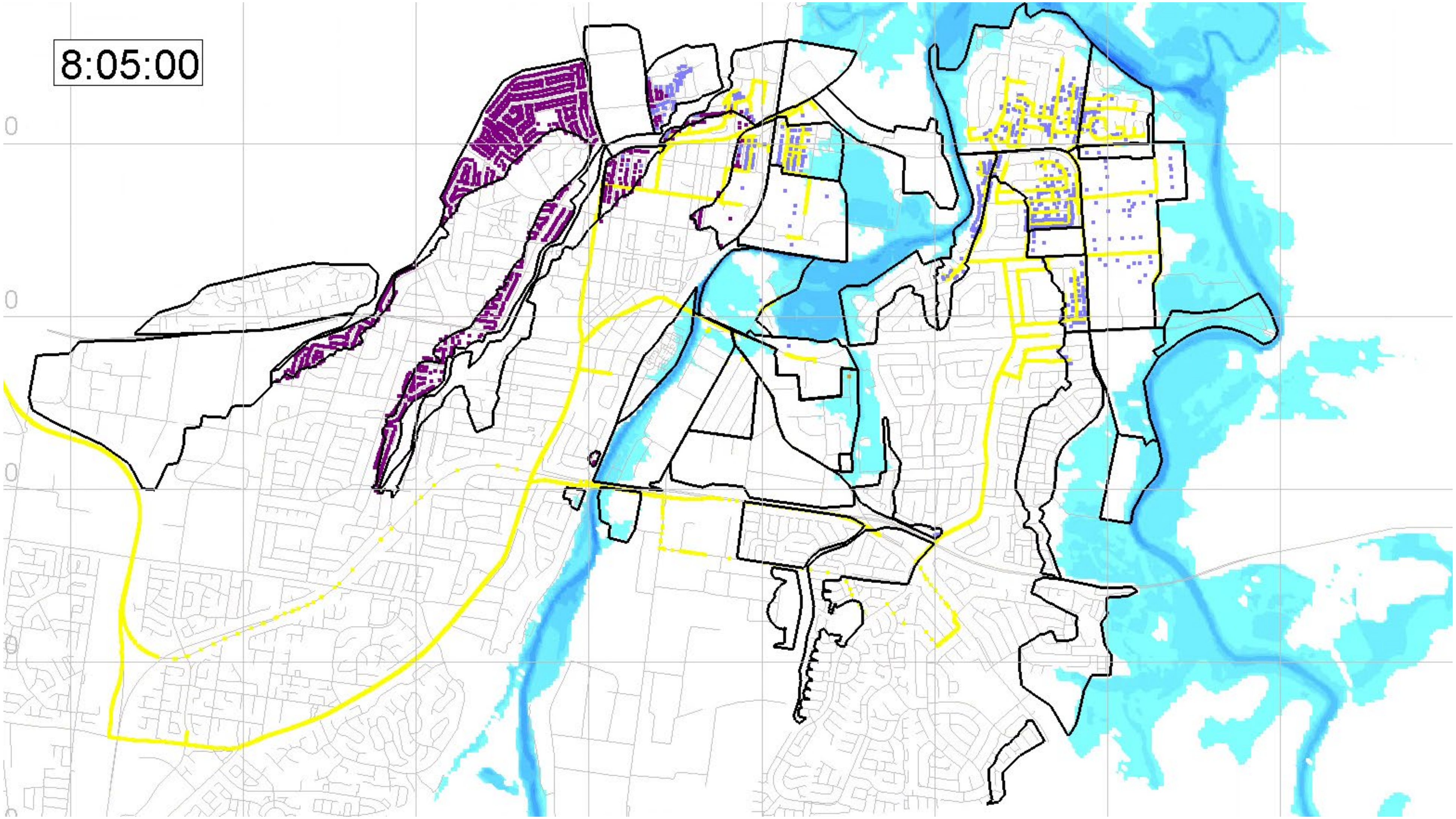

Figure B22. Georges River PMF timestep 8:05 (Scenario B)

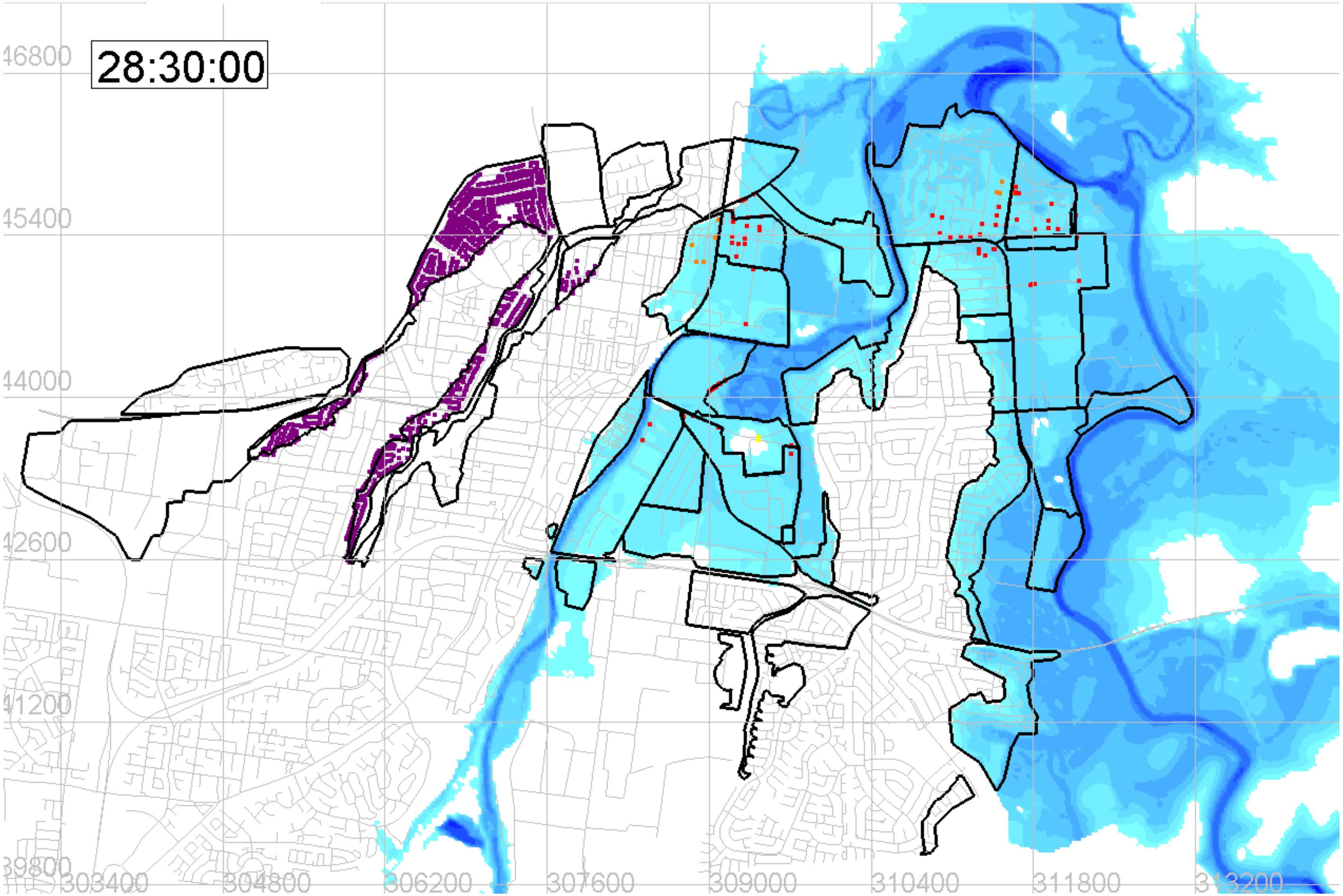

Figure B23. Georges River PMF timestep 28:30 (Scenario B)

Appendix C | Traffic Safety Factor Analysis for Scenario 1

Location	Time on Road (TOR)	Traffic Safety Factor (TSF)	Warning Acceptance Factor (WAF)	Warning Lag Factor (WLF)	Required Time (=TSF + WAF + WLF+TOR)	Available Time	Surplus Time	Time to Rise in Sector	Adjusted Surplus Time	Notes
R18 (Warwick Farm)		3.5	1	1	34	12	-22	19	-3	TRAPPED because there are no flood free public roads out
I9 (Warwick Farm)		3.5	1	1	33.5	12	-21.5	17.5	-4	TRAPPED because there are no flood free public roads out
R17 (Warwick Farm)		3.5	1	1	23.25	12	-11.25	20.5	9.25	Likely do have enough time to get out because there is not queueing the whole time, and there are several waves of cars leaving progressively
R27 (Liverpool)		3	1	1	20	12	-8	20	12	Actually do have enough time because low number of cars spread out over a long time (two waves with big gap in between)
R11 (Moorebank)		3	1	1	18.25	12	-6.25	20.5	14.25	Queueing (yellow) within subsector ends at +2 hrs, but last few cars aren't out until +11 hrs because Nuwarra Rd is backed up
I1 (Chipping Norton)		3	1	1	18	12	-6	4	-2	Queue extends into subsector because Nuwarra Rd is backed up
R1 (Chipping Norton)		2.5	1	1	16.5	12	-4.5	2	-2.5	Queue extends into subsector because Nuwarra Rd is backed up
R2 (Chipping Norton)		2.5	1	1	16	12	-4	2	-2	Queue extends into subsector because Nuwarra Rd is backed up
I2 (Chipping Norton)		2.5	1	1	15.5	12	-3.5	19	15.5	No queue within subsector, only because Nuwarra Rd is backed up
R16 (Liverpool)		2.5	1	1	15.5	12	-3.5	17	13.5	Likely do have enough time to get out because there is not queueing the whole time, and there are several waves of cars leaving progressively
R5 (Chipping Norton)		2.5	1	1	15.5	12	-3.5	19	15.5	Queue extends into subsector because Nuwarra Rd is backed up
R3 (Chipping Norton)		2	1	1	13.75	12	-1.75	20.5	18.75	Queue extends into subsector because Nuwarra Rd is backed up

Location	Time on Road (TOR)	Traffic Safety Factor (TSF)	Warning Acceptance Factor (WAF)	Warning Lag Factor (WLF)	Required Time (=TSF + WAF + WLF+TOR)	Available Time	Surplus Time	Time to Rise in Sector	Adjusted Surplus Time	Notes
I5 (Moorebank)		2	1	1	12	12	0			Queueing in subsector ends at -0.5 hr, but the last car isn't out until +5 hr because of queuing on Moorebank Ave
R6 (Chipping Norton)		2	1	1	12	12	0			Queue extents into subsector because Nuwarra Rd is backed up
I6 (Moorebank)		2	1	1	11.25	12	0.75			No queueing in subsector: some cars leave immediately at -2 hrs, and last car not out until +5.25 because of queueing to get onto the M5
R19 (Liverpool)		2	1	1	11.25	12	0.75			
I12 (Moorebank)		2	1	1	11	12	1			
I7 (Liverpool)		1.5	1	1	9.5	12	2.5			
R12 (Moorebank)		1.5	1	1	9.5	12	2.5			
R9 (Moorebank)		1.5	1	1	9.25	12	2.75			Queue extends into subsector because Nuwarra Rd is backed up
I3 (Moorebank)		1.5	1	1	9	12	3			
R26 (Liverpool)		1.5	1	1	8.5	12	3.5			
R10 (Hammondville)		1.5	1	1	8	12	4			
R4 (Chipping Norton)		1.5	1	1	7.5	12	4.5			
R21 (Warwick Farm)		1	1	1	6.5	12	5.5			
Hzone (Warwick Farm)		1	1	1	5	12	7			
I4 (Moorebank)		1	1	1	5	12	7			
I14 (Moorebank)		1	1	1	4.75	12	7.25			

Location	Time on Road (TOR)	Traffic Safety Factor (TSF)	Warning Acceptance Factor (WAF)	Warning Lag Factor (WLF)	Required Time (=TSF + WAF + WLF+TOR)	Available Time	Surplus Time	Time to Rise in Sector	Adjusted Surplus Time	Notes
R15 (Liverpool)		1	1	1	4.5	12	7.5			
I8 (Warwick Farm)		1	1	1	4	12	8			
IR1 (Chipping Norton)		1	1	1	4	12	8			No queue within subsector, only because Nuwarra Rd is backed up
I15 (Warwick Farm)		1	1	1	3.75	12	8.25			
R23 (Holsworthy)		1	1	1	3.5	12	8.5			
R25 (Chipping Norton)		1	1	1	3.25	12	8.75			
I13 (Moorebank)		1	1	1	3	12	9			
R7 (Moorebank)		1	1	1	3	12	9			