



Brookvale Structure Plan

WATER MANAGEMENT STRATEGY

Final Report

April 2026

alluvium



Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for Country and the waterways within.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for Northern Beaches Council under the contract titled 'Water Management Strategy Brookvale Structure plan'.

Authors: Prawi Woods, Alexandra Nero, Angelina Newton, Shaw Abrey
Review: Suresh Hettiarachchi
Approved: Suresh Hettiarachchi

Revision: 4 – Final Water Management Strategy Report
Date issued: 10 April 2026
Issued to: Felicity Shonk, Northern Beaches Council
Citation: Water Management Strategy Report

Cover image: Brookvale Creek, Alluvium Consulting

Contents

1	Introduction	1
1.1	<i>Project background</i>	<i>1</i>
1.2	<i>This report.....</i>	<i>1</i>
1.3	<i>Study area</i>	<i>2</i>
1.4	<i>Stakeholders</i>	<i>3</i>
1.5	<i>Project scope.....</i>	<i>3</i>
1.6	<i>Strategic context.....</i>	<i>3</i>
1.7	<i>Background information and previous studies</i>	<i>4</i>
1.8	<i>Data sources</i>	<i>8</i>
1.9	<i>Available flood models</i>	<i>9</i>
2	Standards and guidelines	11
2.1	<i>Warringah Development Control Plan 2011</i>	<i>11</i>
	Part C4.....	11
	Part E11.....	11
	Part G4	11
2.2	<i>Northern Beaches Council – Memo: Consideration of Climate Change in Flood Planning Levels</i>	<i>11</i>
2.3	<i>Ministerial Direction 4.1 – Flooding.....</i>	<i>11</i>
2.4	<i>NSW Government Flood Risk Management Manual</i>	<i>12</i>
2.5	<i>Shelter-in-Place Guidelines for Flash Flooding (2025)</i>	<i>12</i>
2.6	<i>NSW Government planning circulars.....</i>	<i>12</i>
2.7	<i>Warringah LEP 2011.....</i>	<i>12</i>
	Clause 5.21: Flood planning.....	13
	Clause 5.22: Special flood considerations.....	14
2.8	<i>Northern Beaches Council – Water Management for Development Policy (2021).....</i>	<i>14</i>
2.9	<i>Northern Beaches Council – Draft Integrated Water Management and Water Sensitive Urban Design Guideline (2025).....</i>	<i>14</i>
2.10	<i>NSW MUSIC Modelling Guidelines.....</i>	<i>15</i>
3	Existing conditions	16
3.1	<i>Catchments and context</i>	<i>16</i>
3.2	<i>Site visit</i>	<i>17</i>
3.3	<i>Land use</i>	<i>20</i>
3.4	<i>Topography.....</i>	<i>21</i>
3.5	<i>Flooding</i>	<i>21</i>
	Previously proposed mitigation options	22
	Warringah Mall.....	22
3.6	<i>Water quality.....</i>	<i>26</i>
4	Proposed Structure plan	28

5	Catchment delineation.....	30
5.1	<i>Catchment analysis</i>	30
5.2	<i>Sub-catchment analysis</i>	31
	Sub-catchment fraction impervious	31
6	Hydrological analysis.....	34
6.1	<i>Model parameters.....</i>	34
6.2	<i>Design rainfall.....</i>	36
6.3	<i>Climate change.....</i>	37
6.4	<i>WBNM modelling for design events</i>	37
6.5	<i>Critical temporal patterns and duration selection</i>	37
6.6	<i>Comparison between ARR2019 and ARR1987 results</i>	39
7	Hydraulic Modelling	42
7.1	<i>TUFLOW model updates</i>	42
	Manly Lagoon	42
	Greendale Creek.....	42
7.2	<i>TUFLOW Results</i>	43
	Manly Lagoon	43
	Greendale Creek.....	44
7.2.1	<i>Mapping.....</i>	45
	Flood Planning Area	45
	Flood Categories Mapping – Northern Beaches Council	46
	Flood Function	46
7.3	<i>Options identification.....</i>	47
	Scenario 1: Developed Conditions – Hydrology updates only	47
	Scenario 2: Developed Conditions – Proposed buildings' impacts	47
	Scenario 3: Clearview Place Levee.....	47
7.3.1	<i>Constraints.....</i>	49
7.3.2	<i>Opportunities.....</i>	52
	Urban renewal and increased pervious areas	52
	Stormwater infrastructure and WSUD integration.....	52
	Shelter-in-place considerations	52
	Property modification and planning controls	52
	Clearview Place Levee	53
	Other flood management options.....	53
7.4	<i>Ministerial Direction</i>	54
7.5	<i>Mitigation option modelling</i>	56
	Mitigation Scenario 3 (M03)	58
	Mitigation Scenario 4 (M04)	59
8	Water quality analysis	60
8.1	<i>Existing pollutant load generation.....</i>	61
8.2	<i>Post-developed pollutant load generation</i>	65
8.3	<i>WSUD options toolkit</i>	69
8.4	<i>Constraints and land ownership</i>	75

8.5	Water quality WMS.....	77
	WSUD asset location	77
	Public open space and integrated water reuse opportunities	88
	Private development integration, design flexibility and broader WSUD delivery	88
	Scentre Group site.....	88
	Asset ownership	88
9	Multi-criteria analysis.....	89
9.1	Water quality opportunities.....	95
9.2	Flood mitigation opportunities	95
	Potential influence of increased building height on flooding	96
10	Conclusion.....	97
	References	99
	Appendix A: Flood maps	101
	Appendix B: Subcatchment imperviousness values	103
	Appendix C: MUSIC modelling parameters	107

Figures

Figure 1.	Site locality map	2
Figure 2.	Existing flood model extents	10
Figure 3.	Study area catchments overview	16
Figure 4.	Existing stormwater management assets in the study area	17
Figure 5.	The interface between the piped and daylighted sections of Brookvale Creek at the eastern border of Allenby Reserve (ID 1 Figure 4). From left to right: a) Culvert: estimated dimensions 3.05m (W) x 3.0m (H). b) Well-vegetated area facing toward the upper reaches of Brookvale Creek from the same location as the culvert.	18
Figure 6.	Opening into the daylighted section of Brookvale Creek along Old Pittwater Road (ID 2 Figure 4). From left to right: a) Functioning culvert. b) Sedimented deposition in the culvert. c) Rock-lined transition into the stabilised channel immediately downstream of the culvert.	18
Figure 7.	Entry of Brookvale Creek into the existing constructed waterway of the Warringah Mall stormwater system (ID 3 Figure 4). From left to right: a) Brookvale Creek flows into the existing culvert looking towards the entrance to Palm Tree Carpark. b) Overflow weir crest; entry to new culvert occurs in cases of overflow from the existing culvert adjacent to the Woolworths dock.	19
Figure 8.	The interface between the piped and daylighted sections of Brookvale Creek along Condamine Street (ID 4 Figure 4). From left to right: a) Opening of culverts into Brookvale Creek. b) Trash rack downstream from culverts in Warringah Golf Club.	19
Figure 9.	Existing land zoning for Warringah	20
Figure 10.	Site topography	21
Figure 11.	Existing Flood Hazard Map (NBC, 2023)	22
Figure 12.	Proposed drainage augmentation works for Stage 1 redevelopment of Warringah Mall (Cardno 2008)	25
Figure 13.	Brookvale Creek Overflow Inlet works (Cardno 2008)	26
Figure 14.	The current state of the existing trash rack (photo taken 16/10/2024)	27
Figure 15.	Recommended future land zoning map showing Scenario 1 development in green (Northern Beaches Council, 2024)	28
Figure 16.	Proposed Structure plan for Warringah Mall (SJB, 2024)	29

Figure 17. Stormwater catchment plan	30
Figure 18. Proposed Structure plan and sub-catchment mapping	31
Figure 19. Design rainfall depths	36
Figure 20. Critical hydrographs of the design events at the downstream boundary of the Warringah Mall.	39
Figure 21. Critical hydrographs of the design events at the downstream boundary of the Warringah Mall for the 1% AEP with climate change.	39
Figure 22. Comparison between rainfall depths used in ARR2019 and ARR1987.	39
Figure 23. Comparison of flow at Manly lagoon outlet. Left – ARR87, right – ARR2019	40
Figure 24. Difference in peak flow at Warringah Mall comparing different IFD and loss models	41
Figure 25. Additional stormwater infrastructure modelled	43
Figure 26. Comparison of existing flood extents between the FRMSP study and this study (note that the current(updated) modelling results are shown in the lighter shade of blue)	44
Figure 27. Comparison of flood levels for the 1% AEP for the Greendale Creek Flood Model utilising SGS	45
Figure 28. Provisional Warringah Mall structure plan building footprints overlaying the existing 1% AEP flood extent.	49
Figure 29. Warringah Acid Sulfate Soils Map	51
Figure 30. Mitigation scenario testing	57
Figure 31. Site amalgamation into development parcels (Ethos Urban, 2025).	60
Figure 32. Layout of the MUSIC model developed to understand broader catchment pollutant loads into the Manly Lagoon	61
Figure 33. Existing TSS generation (kg/year) from Manly Lagoon sub-catchments across the study area	62
Figure 34. Existing TP generation (kg/year) from Manly Lagoon sub-catchments across the study area	62
Figure 35. Existing TN generation (kg/year) from Manly Lagoon sub-catchments across the study area	63
Figure 36. Existing TSS contributions (kg/ha/year) from Manly Lagoon sub-catchments across the study area	64
Figure 37. Existing TP contributions (kg/ha/year) from Manly Lagoon sub-catchments across the study area	64
Figure 38. Existing TN contributions (kg/ha/year) from Manly Lagoon sub-catchments across the study area	65
Figure 39. MUSIC model used to understand pollutant load generated for the proposed amalgamated 'rezoned scenario' of the structure plan only	65
Figure 40. Pollutant load contribution intensity from amalgamated lots.	66
Figure 41. Land ownership of amalgamated parcels.	66
Figure 42. Council-owned land within the study area	75
Figure 43. Map showing existing infrastructure/services (mapped from DBYD) and council-owned land	76
Figure 44. Plan showing suggested locations of WSUD assets for the Brookvale Structure plan	80
Figure 45. Adapted section A (Cross Street) from Ethos Urban	83
Figure 46. Adapted section B (High Street) from Ethos Urban	84
Figure 47. Adapted section C (Pittwater Road South and Town Square) from Ethos Urban	85
Figure 48. Adapted section D (Roger Street) from Ethos Urban	86
Figure 49. Adapted section E (Pittwater Road North) from Ethos Urban	86
Figure 50. Adapted section F (New Laneway East of Pittwater Road) from Ethos Urban	87
Figure 51. Adapted section G (New Pedestrian Through-Site Link) from Ethos Urban	87

Tables

Table 1. Summary of available previous studies, plans and reports	5
Table 2. Summary of available data	8
Table 3. Summary of existing flood models	9
Table 4. Type 1 (lots < 500 m ²) (catchment group 3) water quality performance requirements (NBC, 2025)	15
Table 5. Type 2 (lots ≥ 500 m ²) (catchment group 3) water quality performance requirements (NBC, 2025)	15
Table 6. Summary of development and drainage augmentation at Warringah Mall	23
Table 7. Brookvale Structure Plan (Northern Beaches Council, 2024)	29

Table 8. Adopted fraction impervious for the proposed land use type	32
Table 9. External catchment	33
Table 10. Flood modelling parameters	35
Table 11. Climate change parameters	37
Table 12. Long term climate change parameters (2081-2100)	37
Table 13. Critical duration, temporal pattern, and flow for the design events at two study locations	38
Table 14. Comparison of Design Rainfall Intensities, 1% AEP Event (mm/hr)	40
Table 15. Comparison of flood levels between this study and the 2018 FRMSP Model	44
Table 16. Summary of constraints	50
Table 17. Summary of opportunities	53
Table 18. Ministerial Direction requirements and response	55
Table 19. Mitigation option scenarios	56
Table 20. Mitigation option purposes and hydraulic reasoning	57
Table 21. Amalgamated lot IDs and ownership.	60
Table 22. Pollutant load generation of the proposed amalgamated 'rezoned scenario' of the structure plan only	67
Table 23. Minimum required water quality and flow reduction volume to meet water quality targets.	68
Table 24. WSUD options toolkit: Passively irrigated street tree	70
Table 25. WSUD options toolkit: Rain Garden	71
Table 26. WSUD options toolkit: Wicking lawn	72
Table 27. WSUD options toolkit: Swale	73
Table 28. WSUD options toolkit: Stormwater harvesting	74
Table 29. Street location of amalgamated lots	78
Table 30. Estimated required treatment areas for an individual type of asset across Pittwater Road, Roger Street, Cross Street, and Warringah Mall to ensure water quality targets are met for the proposed 'rezoned scenario' of the structure plan. This assumes that only one variation of the asset is recommended across the development	78
Table 31. Number of an individual typical type of asset required across Pittwater Road, Roger Street, Cross Street, and Warringah Mall to ensure water quality targets are met for the proposed 'rezoned scenario' of the structure plan	79
Table 32. Percentage of the total treatment required	79
Table 33. Summary of the number of typical WSUD assets proposed for each street, the estimated treatment performance and high level, indicative capital costs	81
Table 34. Summary of the pollution reduction performance compared to the required targets, excluding two GPTs (Humegard HG45 or similar)	82
Table 35. Summary of the pollution reduction performance compared to the required targets, including two GPTs (Humegard HG45 or similar)	82
Table 36. MCA Criteria – water quality	89
Table 37. MCA Criteria – flooding	90
Table 38. MCA scoring descriptions and weightings	91
Table 39. Multi-criteria analysis results – water quality	93
Table 40. Multi-criteria analysis results – flooding	93
Table 41. Summary of MCA Results	94
Table 42. Adopted fraction imperviousness area by sub-catchment	104
Table 43. Recommended Rainfall Data for MUSIC modelling	108
Table 44. Monthly Evapotranspiration for Sydney Region	108
Table 45. Soil properties for MUSIC Source Nodes	108
Table 46. Pollutant generation parameter for each land use	109
Table 47. Treatment node assumptions – Vegetated swale assets	110
Table 48. Treatment node assumptions – GPT (Humegard HG45 or similar)	111

Table 49. Treatment node assumptions – Biofiltration assets	112
Table 50. Treatment node assumptions – Wicking (water demand) and stormwater harvesting assets	113

1 Introduction

1.1 Project background

Brookvale has been identified as a key strategic centre since 2015. The Brookvale Structure plan (Structure plan) was adopted by Northern Beaches Council in 2023 to encourage revitalisation and guide future growth of housing and employment.

The Structure plan seeks to implement the outcomes of the 'Towards 2040 – Northern Beaches Local Strategic Planning Statement' (LSPS) and deliver the following principles for growth in Brookvale:

- Supporting Brookvale as an employment-based centre
- Preserving the integrity of industrial lands
- Establishing a core area for commercial, civic and recreational uses near the B-line stop, including a new 5,000 m² town square with open space and a multi-purpose community facility
- Integrating Warringah Mall with its surrounding urban structure
- Enhancing Brookvale's identity and sense of arrival
- Bringing life back to the streets, including the revitalisation of Pittwater Road and increasing the residential population that will support greater activity
- Ensuring appropriate land-use interfaces
- Increasing blue and green infrastructure, such as urban tree canopy and establishing green grid links to new and surrounding public open spaces and supporting the Brookvale and Curl Curl Creeks
- Supporting sustainability (net zero and low emissions), resilience to address flood and urban heat risks
- Improving public transport and regional cycle networks to the Sydney CBD, French's Forest, Mona Vale and Manly
- Supporting the night-time economy, creative and innovative industries and public art.

The Structure plan proposes the delivery of 1,350 new dwellings and 900 new jobs over the next 15 years. Council is now commencing work on implementing the Structure plan, which involves several technical studies to support the preparation of a Planning Proposal, Development Control Plan, and Section 7.11 Contributions Plan. As part of this work, the Council will publish a Water Management Strategy (this study) to support the implementation of the Structure plan. The key objective of the Water Management Strategy (WMS) is to provide a technical study that supports the preparation of a planning proposal to implement the Brookvale Structure plan and specifically addresses Ministerial Direction 4.1 Flooding (to be discussed later).

The Water Management Strategy will determine mitigation measures, infrastructure requirements, implementation strategies, statutory planning controls and DCP requirements to manage stormwater drainage, detention and water quality and flood impacts.

1.2 This report

The purpose of this draft report is to present a consolidated summary of relevant information and technical investigations that support a Water Management Strategy for the Brookvale Structure plan, including:

- Reviews of
 - Background data and reporting
 - Available hydrologic, hydraulic and water quality models
 - Relevant standards and guidelines
 - Existing conditions and the proposed structure plan
- Catchment delineation and analysis
- Flood modelling and optioneering
- Water quality modelling and optioneering
- Conclusions.

1.3 Study area

The study area for the project, as shown in Figure 1, is bounded by:

- Harbord Road to the east
- The border of general industrial land zoning near Old Pittwater Road and Pittwater Road to the north
- Wattle Road, William Street, Condamine Street and Old Pittwater Road to the south
- The bushland buffer of Allenby Park to the west.



Figure 1. Site locality map

1.4 Stakeholders

Northern Beaches Council (NBC) is the local authority responsible for the future planning of the Brookvale Precinct and the implementation of the Brookvale Structure plan. NBC also acts as the local drainage authority for the Northern Beaches LGA. Scentre Group owns and operates Westfield Warringah Mall and has engaged SJB, an architecture firm, to prepare a concept design of the Warringah Mall Structure plan. Transport NSW is also an important stakeholder due to plans to improve public transport connectivity along the B-line bus stop. Together, these are key stakeholder organisations to this project, in addition to the surrounding community and land and business owners.

1.5 Project scope

This project aims to provide a technical study that supports the preparation of a Planning Proposal to implement the Brookvale Structure plan and specifically address Ministerial Direction 4.1 Flooding. The overall package of work includes a Water Management Strategy (WMS) to guide stormwater drainage, detention, water quality and flood impact management.

Key objectives include:

- Consolidate and update existing hydrologic and hydraulic models to determine stormwater drainage needs, potential resulting flood impacts, and potential mitigation measures for the proposed development.
- Develop a MUSIC model to assess stormwater quality impacts associated with the proposed development and to identify appropriate Water Sensitive Urban Design (WSUD) measures to meet current water quality objectives, consistent with Northern Beaches Council's adopted Development Control Plan (DCP) and associated WSUD and MUSIC modelling requirements.

This report details work up to a draft water management strategy stage, which includes assessing the impacts of the proposed development and investigating mitigation strategies to meet future stormwater quantity and quality requirements and comply with statutory planning controls and the DCP.

1.6 Strategic context

Planning for growth in Brookvale has been driven by the Brookvale Structure plan (NBC, 2023), including the development of 1,350 new dwellings and a new 5,000 sqm town square in the next 15 years. Water management-centred objectives of the Structure plan include increasing blue and green infrastructure, protecting both Brookvale and Curl Curl Creeks and supporting sustainability through managing flood and urban heat risks. The proposed development is located within the 1% AEP flood extent; as such, potential flood impacts of the development and mitigation options need to be assessed.

Overall, this report will provide a Water Management Strategy, as part of the several technical studies required to support the planning proposal and implementation of the Structure plan.

The following are summaries of key strategic documents that are directly relevant to, will influence, and/or align with key outcomes of this project and the vision for the Brookvale Structure plan. Other relevant documents are outlined in Section 2.



Brookvale Structure plan (2023)

NBC developed the Brookvale Structure plan to set the vision for Brookvale over the next 15 years and provide a strategic land use planning framework.

Brookvale Structure Plan
November 2023



Warringah Mall Structure plan (2024)

The concept design for Warringah Mall prepared by SJB (architectural firm) for Scentre Group detailing the preferred concept for a new town centre for Brookvale located on residual land.

Council Policy

Water Management for Development Policy

Policy Statement

This policy supports Council's commitment to protecting and enhancing the aquatic and terrestrial natural environment while ensuring protection of public and property across the Northern Beaches. The application of these principles, and corresponding planning controls, will deliver effective integrated management of stormwater, rainwater, groundwater and wastewater.

Principles

- Improve the quality of water discharged to our natural areas to protect the ecological and recreational condition of our beaches, waterways, riparian areas and bushland.
- Minimise the risk to public health and safety.
- Reduce the risk to life and property from any flooding and groundwater damage.
- A sustainable and holistic catchment wide approach is taken to development, of both private land uses and public facilities, on flood prone land.
- Climate change will inform decisions for future water infrastructure.
- Water sensitive urban design measures will be integrated into the built form to maximise liveability and reduce the impacts of climate change e.g. urban heat island effect and intensified rainfall events.
- Wherever possible, water courses are to be conserved or restored to their natural state.
- Reduce the consumption of potable water by encouraging water efficiency, the reuse of water and use of alternative water sources.
- Protect Council stormwater drainage assets during development works and to ensure Council's drainage rights are not compromised by development activities.

Scope and application

This policy applies to all development in the Northern Beaches Local Government Area (LGA) subject to Part 4 and Part 5 of the Environmental Planning & Assessment Act 1979 including development applications, exempt and complying development, except development within the Warriewood Valley Release Area, which is required to comply with Pthwater 21 Development Control Plan Section C6.

This policy also applies to all employees, agents, officers, councillors and committee members of Northern Beaches Council.

Inability to comply with the requirements of this policy may result in Development Consent not being granted.

Responsible Officer

Executive Manager of Environment and Climate Change

Version 2 | 26 February 2021 | Water Management for Development Policy | 2021/154368 | Page 1 of 100

Water Management for Development Policy (2021)

NBC manual outlining policies to ensure the effective integrated management of stormwater, rainwater, groundwater, and wastewater. This applies to all development in the Northern Beaches LGA, and includes WSUD, climate change and water quality requirements.

1.7 Background information and previous studies

Several studies and reports from previous projects within the study area have been reviewed, given their relevance to water management in the Brookvale Structure plan. A summary of the documents is provided in Table 1 and the following sections of the report incorporate the information that is relevant to this project.

Table 1. Summary of available previous studies, plans and reports

Document Name	Author	Date	Description
Flood Study Reports - Northern Beaches Council (online)	Varies	Varies	Online portal of flood studies and appendices for Northern Beaches Council, including Manly Lagoon and Greendale Creek.
Brookvale Structure plan - Indigenous and Non-Indigenous Heritage Report	GML Heritage	2024	The heritage advice for the Brookvale Structure plan includes an analysis of existing and potential heritage items, conservation areas, and planning constraints, along with draft recommendations and controls to protect these assets. It also provides descriptions of existing land uses and soil landscapes.
DRAFT DCP Flood Clause - Flood Prone Land	Northern Beaches Council	2024	Control applies to all flood-labile land in Northern Beaches Council LGA. Provides a matrix relating flood risk controls to each flood risk zone and land use combination.
DRAFT Memo - Consideration of Climate Change in Flood Planning Levels	Northern Beaches Council	2024	Provides background methodology for incorporating climate change and sea level rise into Flood Planning Levels for different types of development. Includes application of ARR guidelines, FRM manual, and sea level projections for Northern Beaches Council from CSIRO.
Presentation - Inception meeting - Brookvale Structure plan - Water Management Strategy	Northern Beaches Council	2024	Brief presentation of Brookvale Structure plan including flood risk zones, future development maps and before and after images of proposed development.
Warringah Mall Structure plan - Concept Design	SJB	2024	Maps of the site including site coverage, stormwater, flood risk zones, Structure plan and precinct plan. Imagery of proposed development for the civic plaza and local park.
Warringah Mall Structure plan - Concept Design Presentation SJB	SJB	2024	Presentation of the proposed development Scenario 1 and 2 for Warringah Mall and Pittwater Road. Objectives for the Brookvale Structure plan.

Document Name	Author	Date	Description
Greendale Creek Flood Study	WMA Water	2023	Flood study using WBNM hydrologic model calibrated with historic flood level data and TUFLOW hydraulic model for Greendale Creek catchment, including Curl Curl Lagoon. Includes climate change assessment and information for emergency response planning.
Brookvale WSUD Investigation and Concept Design	Royal Haskoning DHV	2023	Stage 1: Investigation of how well the existing Gross Pollutant Trap (GPT) at Warringah Golf Club treats water quality in the Brookvale Creek catchment. Stage 2: Concept design of potential adjustments to existing GPT and identification of alternative upstream water quality treatment devices.
Water Management for Development Policy - Council Policy	Northern Beaches Council	2021	Northern Beaches Council manual outlining policies to ensure effective integrated management of stormwater, rainwater, groundwater and wastewater. Includes elements of stormwater management and flood risk management including WSUD, impacts of climate change and water quality requirements. Applies to all development in Northern Beaches LGA.
Warringah Mall - Stage 2B Redevelopment Flood Impact Assessment	Cardno	2021	Flood impact assessment for Westfield Warringah Mall Stage 2B redevelopment involving the Mini Major Loading Dock. Update of the previous flood model to include overall augmentation scheme for Warringah Mall and regrading of the loading dock area.
Warringah Mall - DA 2018/1514 Warringah Mall— Stage 2 Redevelopment - Response to Northern Beaches Council Natural Environment Referral Response – Flood Deferred Commencement Condition	Cardno	2019	Updated flood impact assessment for Westfield Warringah Mall Stage 2 redevelopment, with added blockage assessment in line with ARR 2019 to ensure no adverse impact to neighbouring properties from development.
Warringah Mall - Updated Flood Impact Assessment of Westfield Warringah Mall Project – Stage 2 Redevelopment	Cardno	2018	Updated flood impact assessment for Westfield Warringah Mall Stage 2 redevelopment. Utilised XPRAFTS hydrologic model and existing XPSWMM2D hydraulic model, amended to include upgraded stormwater network specified in 2018 Stormwater Management Report. Drawings of stormwater amendments and flood maps were provided.

Document Name	Author	Date	Description
Warringah Mall - Stormwater Management Report - Westfield Shopping Centre Warringah Stage 2 Ver 7	Cardno	2018	Assessment of proposed stormwater network for second-stage redevelopment of the eastern side of the existing Westfield Mall, including assessment of on-grade car park, loading dock, water quality controls, and erosion and sediment control. Utilised the DRAINS model and ARR 2016 IFD data in the initial loss-continuing loss hydrological model.
Warringah Mall - Stormwater Management Report - Westfield Shopping Centre Warringah Stage 2 Ver 7A	Cardno	2018	Latest version of Warringah Mall - Stormwater Management Report - Westfield Shopping Centre Warringah Stage 2 Ver 7, with updated drawings.
SWS00003 - WQD - Within Golf Course - Brookvale Creek - Data Sheet	Unknown	2016	Images of GPT, trash rack and dewatering area at the north end of Warringah Golf Club, including maintenance report.
Warringah Mall - Concept Drainage Augmentation Works	Cardno	2013	General arrangement plan and detailed arrangement plans of drainage augmentation work along Cross Street, Brookvale Creek, Cross Street roundabout, Green Street, Target entry, David Jones Loading dock, Dale Street roundabout, Woolworth's loading dock and Starfish Carpark.
Final Scan - Stamped Plans, including Landscape stormwater (dem), Warringah Mall - Concept Drainage Augmentation Works (Cardno) and Brookvale Creek Bank Stabilisation (Cardno)	Cardno and dem	varies	Drawings of landscape and stormwater plan for Warringah Mall (2010), concept drainage augmentation works at Warringah Mall (2009), layout plan and sediment and erosion control plan for Brookvale Creek bank stabilisation works (2011).
Concept Drainage Augmentation Works - Warringah Mall, Brookvale	Cardno	2008	General arrangement plans and detailed arrangement plans for concept drainage augmentation works at Warringah Mall, Brookvale.
Concept Drainage Augmentation Works - Stage 1 Expansion Works - Warringah Mall, Brookvale	Cardno	2008	General arrangement plans and detailed arrangement plans for concept drainage augmentation works – <i>Stage 1 Expansion Works</i> at Warringah Mall, Brookvale.
Warringah Mall - Statement of Environmental Effects - Stormwater Augmentation Works	Urbis	2008	Environmental assessment for concept drainage augmentation works at Warringah Mall, Brookvale.

Document Name	Author	Date	Description
Warringah Mall Flood Impact Assessment	Cardno Willing	2008	Flood impact assessment of proposed augmentation scheme for Warringah Mall to reduce overland flooding, following from mitigation options mentioned in the 2007 Cardno Willing report. Proposal to undertake a subset of augmentation works in conjunction with the first-stage retail development. The study area was the Brookvale Creek catchment to Condamine Street using an XPSWMM2D hydraulic model.
Peninsula Industrial Estate Floodplain Management Study Summary Report	Cardno Willing	2006	The original Floodplain Management Study was completed in 2006, based on 2004 modelling. The study aims to assess different structural management options for the Peninsula Industrial Estate to reduce flood hazards and damages in the Brookvale Creek floodplain. First mention of retarding basins and drainage augmentation works.

1.8 Data sources

Table 2 presents the available data that will be used to inform and complete the hydrologic, hydraulic and water quality modelling and assessments for the Structure plan. The currency and accuracy of this data are important for developing a robust water management strategy that addresses the stormwater requirements and issues for the area.

Table 2. Summary of available data

Data	Source	Date	Description
Council geospatial data	Northern Beaches Council	2024	Catchment boundaries, study area, bridges, contours, and central ALS ground data
Pit and pipe network data	Northern Beaches Council	2024	Pipe data including IDs, type and diameter. Pit data, including IDs and current operational status
Existing development	Northern Beaches Council	2024	Land zoning, height of buildings and additional permitted uses for existing development
Proposed development	Northern Beaches Council	2024	Recommended future land zoning, additional permitted uses, future floor space ratio and height of building data
Water quality data	Northern Beaches Council	2024	Shapefile of acid sulphate soils with classes for Warringah, and a shapefile for the location of water quality devices with description

Digital Elevation Model	Northern Beaches Council	2023	1m LiDAR data
Flood Hazard (2023)	Northern Beaches Council	2023	Flood hazard map from 22 August 2023 specifying high flood risk, medium flood risk and low flood risk zones
Geotechnical data	Northern Beaches Council	2023	Information on soil conditions in parts of the study area
NSW hydrolines	NSW Government - SEED	2017	Hydrolines delineating NSW waterways

1.9 Available flood models

The following existing models were available to the study:

- Warringah Mall Flood Model
- Greendale Creek Flood Study
- Manly Lagoon 2018 TUFLOW Base Model.

The model details are summarised in Table 3 and the model extents are shown in Figure 2.

Table 3. Summary of existing flood models

Project	Software	Originator	Date	Description	Proposed use in the project
Warringah Mall Flood Model	XPSWWM	Cardno	2018 to 2021	<i>The most recent hydraulic model was developed for the Manly-Lagoon Catchment. Developed to inform Warringah Mall infrastructure changes.</i>	Extraction of details of the hydraulic infrastructure relevant to Warringah Mall.
Greendale Creek Flood Study	WBNM and TUFLOW	WMAwater	2023	<i>This study assesses flood behaviour and risks within the Greendale Creek catchment area, developed in line with ARR 2019 requirements, with consideration of potential climate change impacts.</i>	Will form the base model for the Greendale Catchment
Manly Lagoon Flood Study	XP-RAFTS and TUFLOW	BMT WBM	2013	<i>Developed to define existing flood behaviour in the Manly Lagoon Catchment.</i>	For information only - superseded by Manly Lagoon FRSMP model.
Manly Lagoon FRSMP	XP-RAFTS and TUFLOW	WMAwater	2018	<i>Part of the Manly Lagoon FRMS, developed using Australian Rainfall and Runoff (ARR) 1987 hydrology.</i>	Forms the base model for the Manly Lagoon catchment.

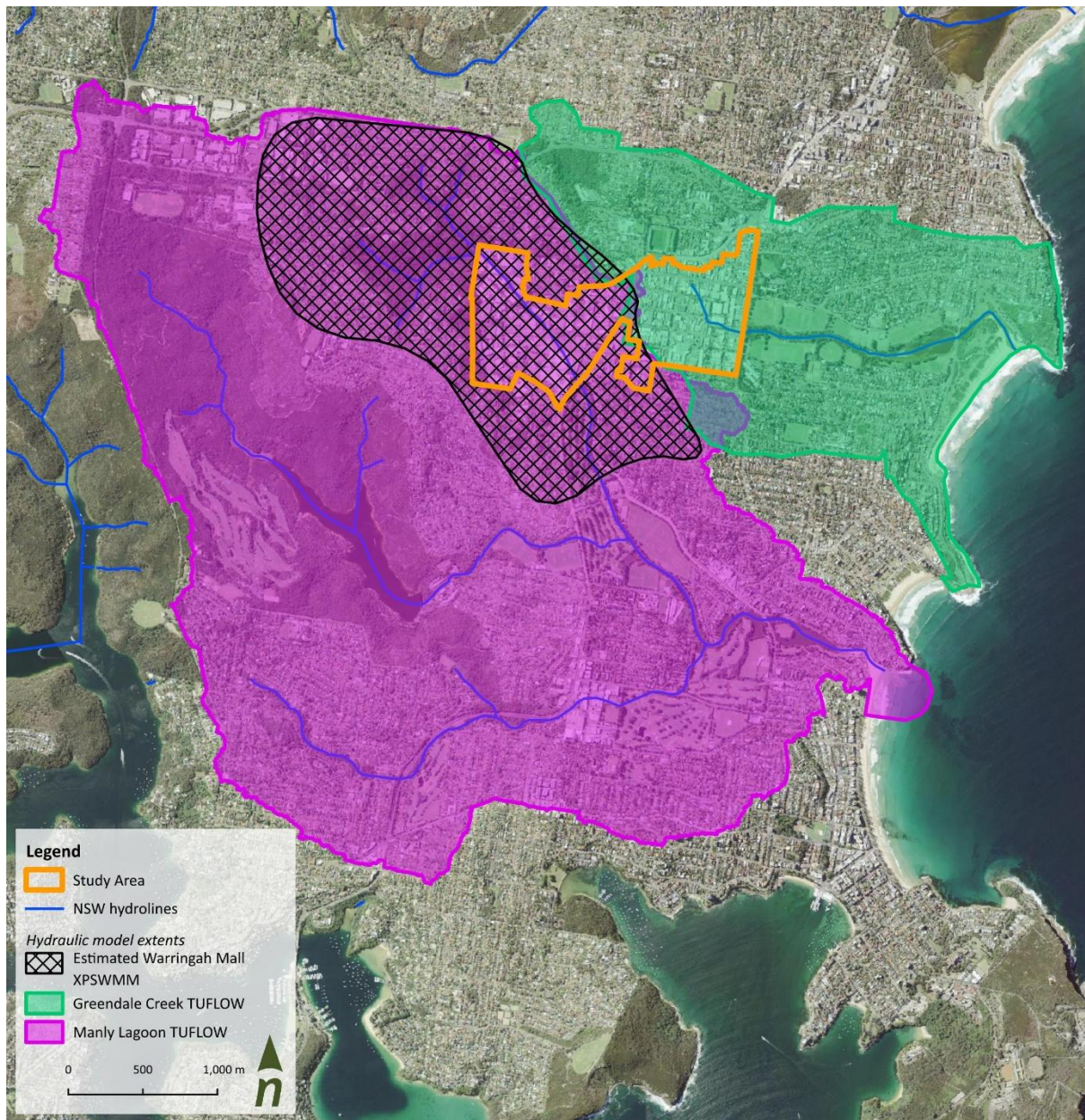


Figure 2. Existing flood model extents

2 Standards and guidelines

2.1 Warringah Development Control Plan 2011

The Warringah Development Control Plan 2011 (DCP) is a comprehensive planning document that guides development within the Warringah area, now part of the Northern Beaches Council in New South Wales. It was adopted by the council on June 8, 2010, and came into effect on December 9, 2011. The DCP provides detailed guidelines and controls for various aspects of development and is in the process of being updated. There are two specific environmental planning and development control plan clauses relating to water management, which are outlined below.

Part C4

Section C4 of the Warringah Development Control Plan 2011 focuses on Stormwater. This section requires that stormwater runoff must not cause downstream flooding and must have minimal impact on any receiving stormwater infrastructure, watercourse, stream, lagoon, lake and waterway or the like. Stormwater drainage systems are to comply with Council's Water Management for Development Policy (see Section 2.8 below).

Part E11

Section E11 of the Warringah Development Control Plan 2011 focuses on Flood Prone Land. This section provides guidelines and controls for development on land identified as being at risk of flooding. The main objectives are to ensure that development is safe, does not increase flood risk to other properties, and is designed to minimise damage during flood events. Council is preparing a new comprehensive Northern Beaches DCP, which will include revised controls relating to flood prone land. A draft version of the revised Flood Prone Land Clause was provided by the Northern Beaches Council on October 10, 2024.

Part G4

Section G4 of the Warringah Development Control Plan 2011 focuses on Warringah Mall. This section provides specific guidelines and controls for development within the Warringah Mall area, aiming to ensure that any development is consistent with the desired character and functionality of the mall. A new set of development controls specific to Brookvale Centre are being prepared and will ultimately replace Part G4. Stormwater and flood risk aspects will be covered by the new LGA-wide Flood Prone Land and Integrated Stormwater Management and Water Sensitive Urban Design DCP clauses.

2.2 Northern Beaches Council – Memo: Consideration of Climate Change in Flood Planning Levels

A draft version of the Memo, which outlines the background methodology and reasoning behind the incorporation of climate change in Flood Planning Levels for various kinds of development, was provided by Northern Beaches Council on October 10, 2024. The Memo is based on the most up-to-date scientific data and guidance to promote sustainable use of floodplain environments and ensure that new development is compatible with flood hazard information, which accounts for climate change.

2.3 Ministerial Direction 4.1 – Flooding

The Ministerial Direction 4.1 is part of the Local Planning Directions issued by the Minister for Planning under the *Environmental Planning and Assessment Act 1979*. The directions apply to planning proposals lodged with the Department of Planning and Environment (now the Department of Planning, Housing and Infrastructure). Focus area 4 of the Planning Directions focuses on resilience and hazards, with the objectives of Direction 4.1 being:

- a) *Ensure that the development of flood-prone land is consistent with the NSW Government's Flood Prone Land Policy and the principles of the Floodplain Development Manual 2005. (Note: now Flood Risk Management Manual (2023))*
- b) *Ensure that the provisions of the Local Environmental Plan that apply to flood-prone land are commensurate with flood behaviour and include consideration of the potential flood impacts both on and off the subject land.*

This direction applies to all planning proposals that create, remove or alter a zone or a provision that affects flood-prone land.

2.4 NSW Government Flood Risk Management Manual

The Flood Risk Management Manual (2023) by the NSW Government provides guidance for managing flood risks through a risk-based approach. It emphasises assessing flood risks using updated models and climate change projections, focusing on sustainable land use planning and development. The manual also details a step-by-step floodplain management process, which includes conducting flood studies, risk assessments, and community engagement to ensure that flood management plans are robust and responsive to community needs.

For Northern Beaches Council, the manual is essential in guiding the design of the future Structure plan. The Structure plan will be developed in line with the recommendations of the manual. The manual's emphasis on adaptive planning also ensures that the stormwater system will be designed to withstand future climate-related flood risks, making it a key resource for the Council's long-term flood management strategy.

2.5 Shelter-in-Place Guidelines for Flash Flooding (2025)

The recently released Shelter-in-Place Guidelines for Flash Flooding (DPHI 2025) provides a framework for assessing when sheltering in place is a suitable emergency response during flash flood events. These guidelines are particularly relevant for areas subject to rapid-onset flooding where evacuation may not be feasible due to short warning times.

Key considerations outlined in the guidelines include:

- **Building Suitability:** Shelter locations should be structurally sound, multi-storey where possible, and have safe refuge areas above expected flood levels.
- **Access to Essential Services:** Buildings designated for sheltering should have access to food, water, power, and communication systems to support occupants during the event.
- **Decision-Making Frameworks:** Authorities and property owners should establish clear criteria for when sheltering in place is the safest option versus when evacuation should be prioritised.
- **Emergency Planning and Communication:** Signage, pre-event planning, and coordination with emergency services are essential to ensure that occupants understand shelter-in-place procedures.

The guidelines also emphasise the importance of integrating shelter-in-place strategies with broader flood risk management measures, including flood planning levels and emergency response planning. Further consultation with relevant authorities is recommended to tailor shelter-in-place protocols to specific site conditions and community needs.

2.6 NSW Government planning circulars

The current NSW planning system circulars provide several non-statutory advice documents on government principles, procedures and practices to assist in implementing relevant planning laws and policies. Relevant advice is provided for, but not limited to, addressing flood risk in planning decisions (PS 24-001) and development assessment under the Environmental Planning and Assessment Act 1979 (EP&A Act).

2.7 Warringah LEP 2011

The Warringah Local Environmental Plan (LEP) 2011 is a regulatory framework that guides land use and development within the Warringah area, now part of the Northern Beaches Council. It sets out zoning regulations, development standards, and environmental protections to ensure sustainable growth and maintain the area's character. The LEP includes provisions for residential, commercial, and industrial zones, as well as measures to protect heritage sites and natural resources.

Clause 5.21: Flood planning

This clause of the LEP focuses on flood planning. The objectives of this clause are:

- a) to minimise the flood risk to life and property associated with the use of land*
- b) to allow development on land that is compatible with the flood function and behaviour on the land, taking into account projected changes as a result of climate change*
- c) to avoid adverse or cumulative impacts on flood behaviour and the environment*
- d) to enable the safe occupation and efficient evacuation of people in the event of a flood.*

Clause 5.22: Special flood considerations

This clause of the LEP focuses on special flood considerations. The objectives of this clause are:

- a) *to enable the safe occupation and evacuation of people subject to flooding*
- b) *to ensure development on land is compatible with the land's flood behaviour in the event of a flood*
- c) *to avoid adverse or cumulative impacts on flood behaviour*
- d) *to protect the operational capacity of emergency response facilities and critical infrastructure during flood events*
- e) *to avoid adverse effects of hazardous development on the environment during flood events.*

2.8 Northern Beaches Council – Water Management for Development Policy (2021)

This policy from Northern Beaches Council supports their commitment to protecting and enhancing the natural environment by ensuring sustainable and effective management of water resources during development projects. It focuses on improving water quality, managing flood and groundwater risks, promoting water efficiency, and protecting natural watercourses. The policy advocates for water-sensitive urban design and compliance with development standards to safeguard public health, safety, and the environment within the Northern Beaches area.

The key principles of the policy are:

- *Improve the quality of water discharged to our natural areas to protect the ecological and recreational condition of our beaches, waterways, riparian areas and bushland*
- *Minimise the risk to public health and safety*
- *Reduce the risk to life and property from any flooding and groundwater damage*
- *A sustainable and holistic catchment-wide approach is taken to the development of both private land uses and public facilities, on flood-prone land*
- *Climate change will inform decisions for future water infrastructure*
- *Water Sensitive Urban Design measures will be integrated into the built form to maximise liveability and reduce the impacts of climate change e.g. urban heat island effect and intensified rainfall events*
- *Wherever possible, watercourses are to be conserved or restored to their natural state*
- *Reduce the consumption of potable water by encouraging water efficiency, the reuse of water and the use of alternative water sources*
- *Protect Council stormwater drainage assets during development works and ensure Council's drainage rights are not compromised by development activities.*

2.9 Northern Beaches Council – Draft Integrated Water Management and Water Sensitive Urban Design Guideline (2025)

The Northern Beaches Council's draft Integrated Water Management (IWM) and Water Sensitive Urban Design (WSUD) Guideline outlines methods for integrating sustainable water management practices into urban development. This includes the specification of WSUD assets and reference to MUSIC modelling parameters to simulate the effectiveness of proposed stormwater management measures. These guidelines, updated by Alluvium, aim to enhance urban water management and enable proposed developments to meet the stormwater quality targets from the Integrated Stormwater Management and Water Sensitive Urban Design DCP (2025). Here, the controls are applied to two types of development:

- **Type 1:** all development sites with a total impervious area of less than 500 m². Small subdivisions result in two or three residential lots with the individual lots' post-development impervious area of less than 500 m².
- **Type 2:** all development sites with an impervious area of more than 500 m².

Stormwater quality and volume requirements, as outlined in the Draft IWM and WSUD Guideline (2025), are presented in Table 4 and Table 5.

Table 4. Type 1 (lots < 500 m²) (catchment group 3) water quality performance requirements (NBC, 2025)

Pollutant	Performance Requirements
Stormwater runoff (Flow)	Rainwater tank implemented as per BASIX requirements
Stormwater pollutants	Implementation of a sediment filter

Table 5. Type 2 (lots ≥ 500 m²) (catchment group 3) water quality performance requirements (NBC, 2025)

Pollutant	Performance Requirements
Stormwater runoff (Flow)	20% reduction in the post-development mean annual load
Gross pollutants (GP)	90% reduction in the post-development mean annual load
Total suspended solids (TSS)	85% reduction in the post-development mean annual load
Total phosphorus (TP)	65% reduction in the post-development mean annual load
Total nitrogen (TP)	45% reduction in the post-development mean annual load

2.10 NSW MUSIC Modelling Guidelines

The NSW MUSIC Modelling Guidelines provide a framework for using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) software to simulate and manage urban stormwater quality (BMT WBM, 2015). These guidelines, developed by BMT WBM Pty Ltd for Greater Sydney Local Land Services, outline the application of MUSIC in both urban and rural catchments, detailing how to develop models for different site conditions and scenarios. This guideline will be used to supplement the Northern Beaches Council MUSIC modelling guidelines in the development of the MUSIC models for this project.

3 Existing conditions

3.1 Catchments and context

The study area is situated in the Brookvale Creek and Greendale Creek sub-catchments, shown in Figure 3. The Brookvale Creek sub-catchment covers an area of 4.5 square kilometres, representing 31 percent of the wider Manly catchment (which is made up of the Brookvale Creek, Manly Creek and Burnt Bridge Creek sub-catchments shown on Figure 3). The headwaters of Brookvale Creek are located northwest of the study area at Allenby Park. The creek flows southeast through Brookvale and Warringah Mall, continuing towards Warringah Golf Club and converging with Manly Creek to the south.

The Greendale Creek sub-catchment covers 4.8 square kilometres and accounts for 81 percent of the wider Curl Curl catchment (which is made up of the Greendale Creek and Freshwater Creek sub-catchments, shown on Figure 3). Greendale Creek flows from Brookvale Beach Park to the northeast of the study area, through industrial land and towards open space land to the east, eventually discharging to Curl Curl Lagoon.

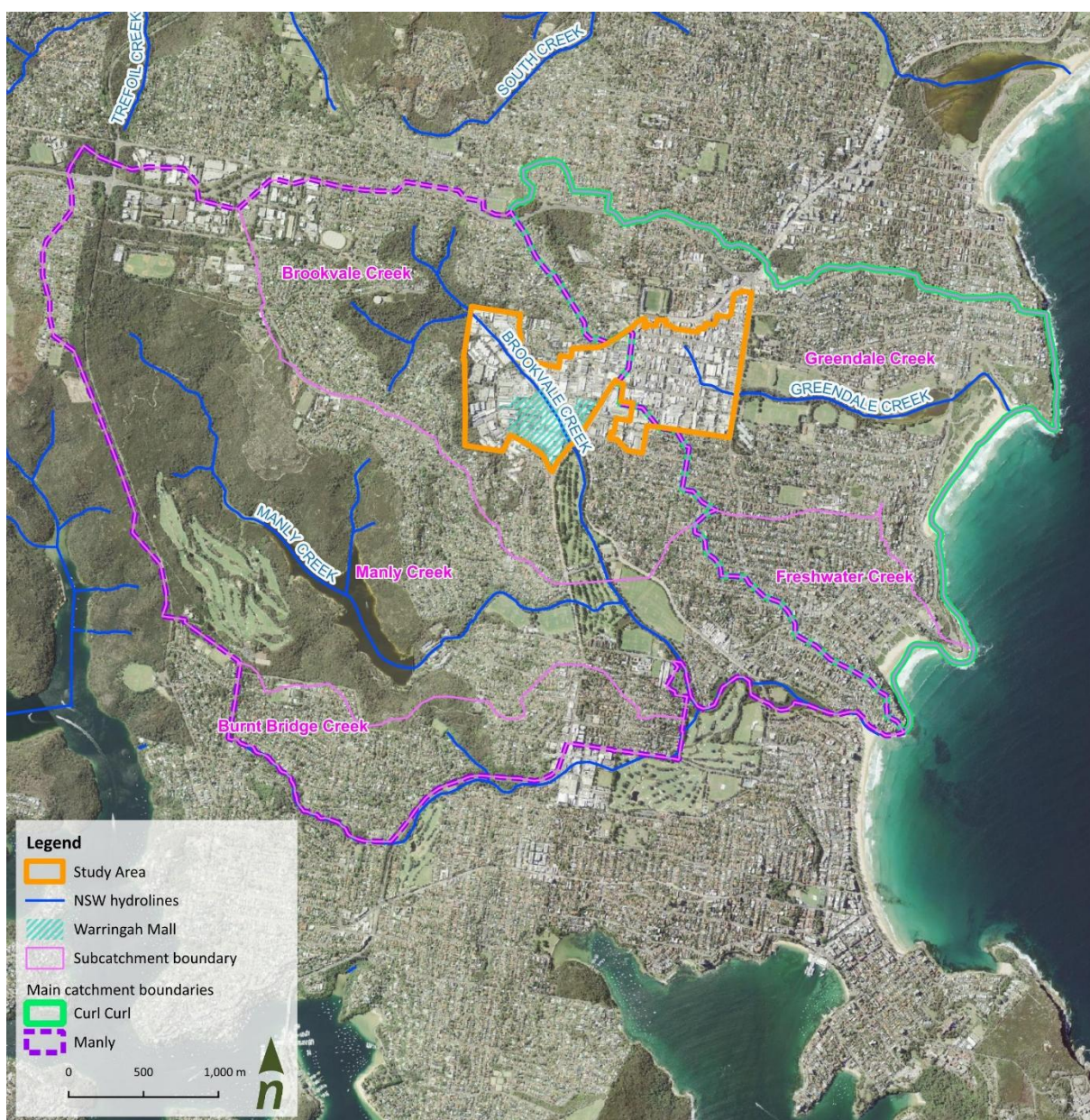


Figure 3. Study area catchments overview

Both Brookvale Creek and Greendale Creek flow through heavily industrialised and developed areas with built stormwater networks. The natural creek lines are integrated with pipe networks, which convey flows through the system from one open space area to the next. The piped sections and daylighted sections of the creeks are shown in Figure 4.

3.2 Site visit

A site visit was undertaken on Wednesday, 16 October 2024, attended by Shaw Abrey, Prawi Woods, Alexandra Nero and Angelina Newton from Alluvium. The site visit provided an opportunity to gain an appreciation of the study area, key site values and constraints, identification of infrastructure and features not captured in the desktop assessment, and opportunities for stormwater management. Features visited included:

- The interface between the piped and daylighted sections of Brookvale Creek at the eastern border of Allenby Reserve (Figure 5).
- Opening into the daylighted section of Brookvale Creek along Old Pittwater Road (Figure 6).
- Entry of Brookvale Creek into the existing constructed waterway of the Warringah Mall stormwater system (Figure 7).
- The interface between the piped and daylighted sections of Brookvale Creek along Condamine Street (Figure 8).

Images from the site visit of the intersections between piped and daylighted sections of the creek are shown in Figure 5 to Figure 8. The IDs of the locations of these intersections are provided in Figure 4.

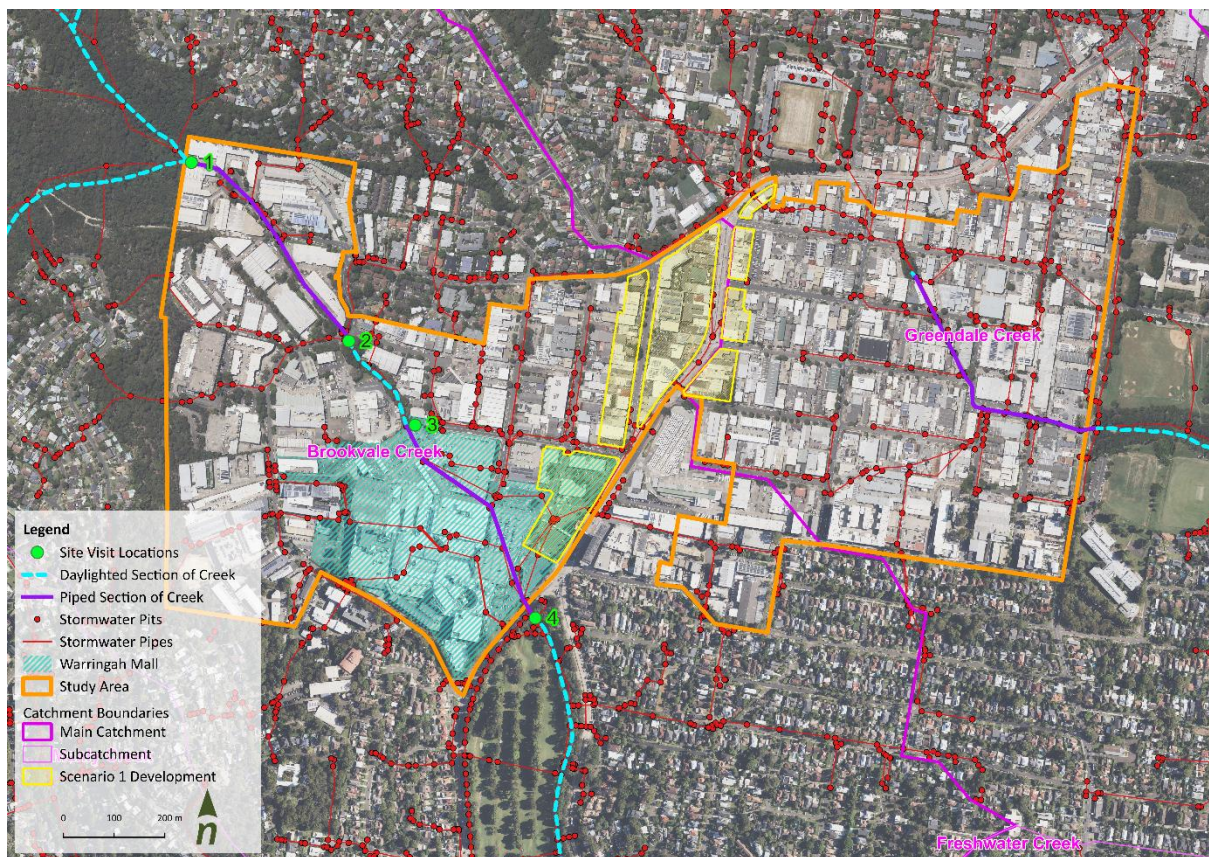


Figure 4. Existing stormwater management assets in the study area



Figure 5. The interface between the piped and daylighted sections of Brookvale Creek at the eastern border of Allenby Reserve (ID 1 **Figure 4**). From left to right: a) Culvert: estimated dimensions 3.05m (W) x 3.0m (H). b) Well-vegetated area facing toward the upper reaches of Brookvale Creek from the same location as the culvert.



Figure 6. Opening into the daylighted section of Brookvale Creek along Old Pittwater Road (ID 2 **Figure 4**). From left to right: a) Functioning culvert. b) Sedimented deposition in the culvert. c) Rock-lined transition into the stabilised channel immediately downstream of the culvert.



Figure 7. Entry of Brookvale Creek into the existing constructed waterway of the Warringah Mall stormwater system (ID 3 Figure 4). From left to right: a) Brookvale Creek flows into the existing culvert looking towards the entrance to Palm Tree Carpark. b) Overflow weir crest; entry to new culvert occurs in cases of overflow from the existing culvert adjacent to the Woolworths dock.



Figure 8. The interface between the piped and daylighted sections of Brookvale Creek along Condamine Street (ID 4 Figure 4). From left to right: a) Opening of culverts into Brookvale Creek. b) Trash rack downstream from culverts in Warringah Golf Club.

3.3 Land use

The study area predominantly comprises industrial and commercial land uses, including the retail precinct of Warringah Mall to the south. Heavy industrial sites are located west of Warringah Mall, and light industrial sites are south and east of Pittwater Road. A commercial buffer lines Pittwater Road and serves as the Brookvale town centre. Residential development is the primary land use surrounding the study area. Open space land use also borders the study area, with Allenby Park to the west, Greendale Creek to the east and Warringah Golf Club to the south. The land zoning of the area is shown in Figure 9.

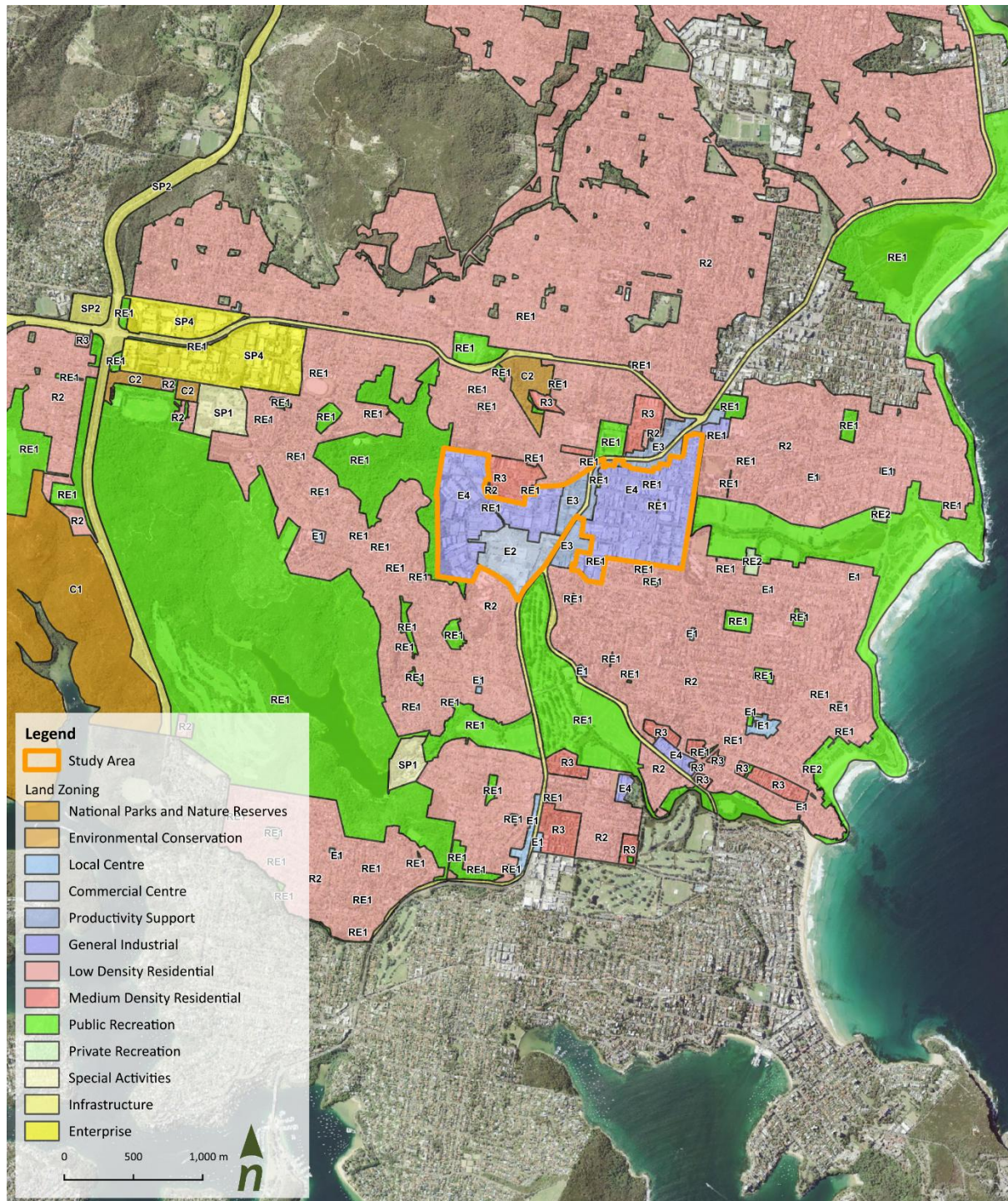


Figure 9. Existing land zoning for Warringah

3.4 Topography

The study area sits within the low-lying floodplain of the Brookvale Creek and Greendale Creek sub-catchments. The upper reaches of Brookvale Creek (85 - 87 m AHD) flow from the northwest of the site down towards Warringah Mall (10 m AHD) and exit to the south of the study area (9 m AHD) at Warringah Golf Club. In the northeast of the study area, the upper reaches of Greendale Creek (12 m AHD) flow to the east of the study area towards Harbord Road (5 m AHD).

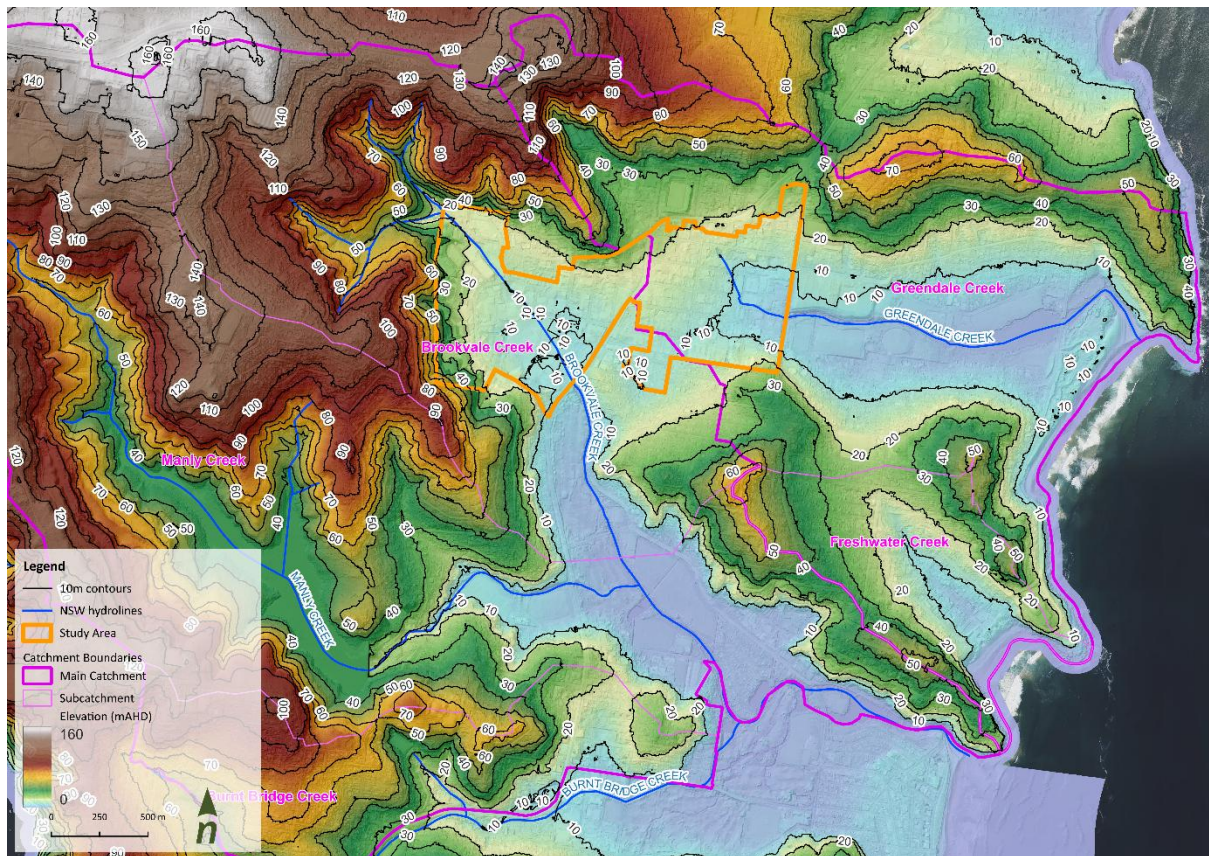


Figure 10. Site topography

3.5 Flooding

The parts of the study area that are flood-affected are shown in Figure 11, which shows the high flood risk, medium flood risk and low flood risk precincts. The study area is divided into two main catchments, Curl Curl and Manly. The Greendale Creek catchment is part of the Curl Curl catchment and covers the eastern side of the study area. The Brookvale Creek catchment is part of the Manly catchment and covers the western side of the study area, including Warringah Mall. Under existing conditions, major storms cause flooding of Warringah Mall by way of both overland flows and out-of-bank flows from Brookvale Creek.

There are records of flooding at the following locations in the study area:

- Peninsula Industrial Estate along Clearview Place
- Starfish carpark
- Cross Street carpark
- Entry to Woolworths from Palm Tree carpark
- Cross Street roundabout.

The importance of appropriate flood management as part of the Structure plan is paramount, as not only are there safety implications of flooding within the precincts, but the site also drains to Manly Creek which is surrounded by flood-prone land and assets. The flood investigation, in collaboration with the Water Sensitive

Urban Design plan, will seek to provide an environment that safely passes floods while not making conditions worse downstream.

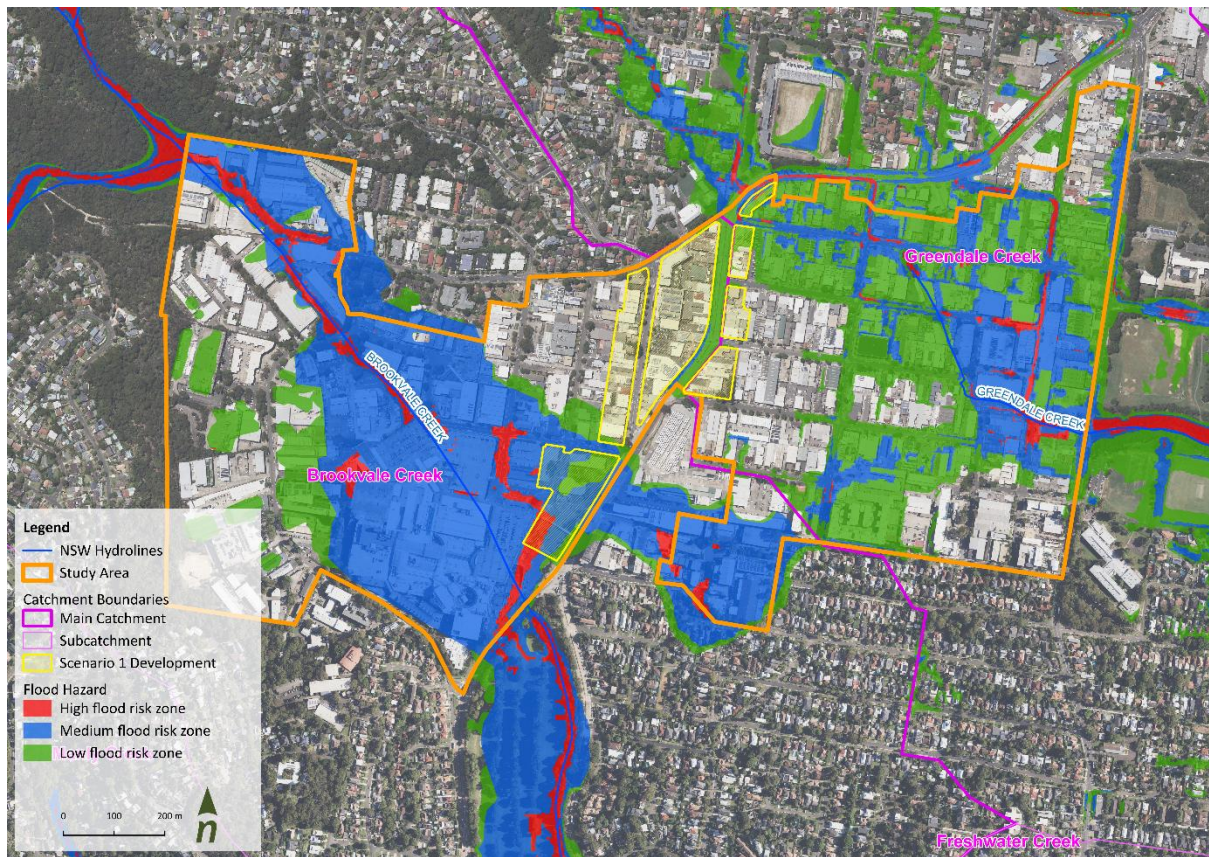


Figure 11. Existing Flood Hazard Map (NBC, 2023)

Previously proposed mitigation options

Various flood mitigation options have been suggested in studies since 2006 to reduce flood hazard and the risk of damages for the Peninsula Industrial Estate, Warringah Mall and surrounding properties.

The 2006 Peninsula Industrial Estate Floodplain Management Study proposed retarding basins in Allenby Reserve at two separate locations, along with drainage augmentation works at the end of Clearview Place for Peninsula Industrial Estate. These options were further assessed alongside potential drainage augmentation works at Warringah Mall in the 2007 report titled *Managing Flooding of Warringah Mall*. Scheme 3, which included a retarding basin in Allenby Reserve, and drainage augmentation works at both Peninsula Industrial Estate and Warringah Mall was found to achieve the greatest reduction in population at risk and flood damages. However, Council chose not to undertake Scheme 3 due to concerns over the potential environmental impacts of constructing a retarding basin in a bushland reserve.

Subsequently, the mitigation approach selected was to augment the drainage within Warringah Mall to increase culvert capacity and to reduce overland flooding along the primary overland flow path through Warringah Mall during a 100-year ARI (1% AEP) event to a Low-hazard rating without the need for upstream works.

Warringah Mall

Warringah Mall, a key regional shopping centre for Sydney's northern beaches, is located within the Brookvale Creek catchment (see Figure 3). The Mall originally opened in 1963 and has since undergone several expansions and renovations to enhance its facilities and services. Before 2004, it was identified that the mall experienced flooding during major storms due to overland flows and out-of-bank flows from Brookvale Creek (Cardno, 2018).

Since 2004, several studies and projects have been completed to manage and mitigate the stormwater behaviour through the Warringah Mall site. The purpose of each has been summarised in Table 1. Based on the

results and recommendations of the studies, as well as the continued development of the site, the stormwater infrastructure has been significantly augmented to achieve the following (Cardno, 2021):

- *Exclude overland flows from the retail areas within Warringah Mall*
- *Reduce flood levels in Brookvale Creek from Warringah Mall upstream to Old Pittwater Road*
- *Lower the 1% AEP flood level in Green Street by up to 57 cm*
- *Reduce overland flooding along the primary overland flow path through the external car parks of Warringah Mall and its associated internal roads, and reduce the overland flows to low-hazard throughout Warringah Mall except for a small section of the access road connected to Pittwater Road (north of the Castle Street carpark)*
- *Provide at least 300 mm freeboard to the entries to Warringah Mall from the Palm Tree carpark and at least 500 mm freeboard to entries to Warringah Mall from the Star Fish carpark per Council requirements*
- *Increase flood levels by no greater than 30 mm only in the Warringah Golf Course immediately downstream of Condamine Street.*

The redevelopment of Warringah Mall has mainly occurred in two stages. The first stage of the development included the construction of a new retail centre along the western side of the mall, including 8,000 m² of additional floor space and associated parking. The Stage 2 redevelopment of Warringah Mall covers the eastern side of the existing Warringah Mall, next to the intersection of Condamine Street and Pittwater Road. These stages have been summarised further in Table 6.

Table 6. Summary of development and drainage augmentation at Warringah Mall

Phase of development	Summary
Stage 1	The 2008 Warringah Mall Flood Impact Assessment documents the proposed stormwater augmentation works for Warringah Mall to be implemented with this first stage of retail development. The proposed augmentation works included (see Figure 12): Brookvale Creek overflow inlet works (see Figure 13) • Lowering the existing overflow weir crest (see Figure 7) to the existing ground level and removing soil from below the access road to improve storage • Cutting a 5m wide slot into the existing parapet wall and installing a bar screen over the slot for public safety • Installing a flood barrier across the access road to prevent overflows from the slot, which discharges to the access road, from flowing into the Woolworths loading dock. These works reduced the 1% AEP flood level by up to 480mm immediately upstream of the mall. Cross Street roundabout • Local regrading of Cross Street roundabout to improve flow diversion into a long, grated inlet at the southwest kerb-line of the intersection, which connects to the existing open section of the constructed waterway. Major culvert augmentation • Two new 3.6 (W) x 1.5m (H) culverts were constructed along the Cross Street boundary which deviates along the Green Street boundary • Major grated inlet along Green Street to capture overland flows ponded in an existing trapped low point on Green Street • The two new 3.6 (W) x 1.5m (H) culverts join the existing 3.3 (W) x 1.5m (H) culvert at the southern side of the Palm Tree carpark

Phase of development	Summary
	• Major chamber at Green Street to redistribute flows between existing and new culverts • Major grated inlet structure at the elongated Dale Street roundabout, including local regrading of roads to direct overland flows towards the grated inlet structure • Two new 3.3 (W) x 1.8m (H) culverts exiting the grated inlet structure headings towards a new chamber below Condamine Street. Four existing 2.8 (W) x 1.8m (H) culverts also meet at this new chamber • Local regrading and protection work for the new outfall at Condamine Street • Existing 1350mm diameter RCP conveying stormwater from Pittwater Road deviated south along the Pittwater Road boundary and is connected to a new line of culverts. The existing RCP is capped south of the proposed augmentation works. Drainage augmentation in the vicinity of Starfish carpark • Stage 1: Connect existing drainage line to existing 2.0 (W) x 2.0m (H) culvert running between Woolworth's loading dock and David Jones's loading dock. The deviation includes three 600mm RCPs connecting the new section of the 1.8 (W) x 0.9m (H) culvert that replaces the 1.2 (W) x 0.9m (H) existing culvert • Stage 2: Disuse the existing 900mm RCP downstream of deviation. Construct a new graded inlet opposite the southern entry of the carpark. Local regrading of existing roads to direct overland flows towards the grated inlet. The drainage augmentation scheme for Warringah Mall Stage 1 was subject to peer review in 2009, client amendments in 2010 and further amendments by Council in 2015. It was assumed that following Council approval, construction was commenced. The drainage augmentation scheme for Stage 1 also accounted for footprints of future development identified in the 2007 masterplan for Warringah Mall. This masterplan represents the vision of Warringah Mall up to 2021 and identified that most future development was likely to occur along the eastern side of the site facing Pittwater Road and Condamine Street.
2011 Brookvale Creek Bank Stabilisation Plan	The 2011 Brookvale Creek Bank Stabilisation Plan Bank proposes bank stabilisation works for Brookvale Creek. The study area was the 90m of creek section immediately downstream of Warringah Mall, including a 10m transition to natural surfaces. The plan aimed to reduce bank erosion due to the increases in flow velocity resulting from the proposed drainage augmentation scheme at Warringah Mall. Stabilisation measures include: • Rock groynes and baffles • Rock boulders laid on a gravel bed surface with a geotextile liner and rip rap for scour protection. It is assumed these works were constructed in conjunction with the Stage 1 redevelopment of Warringah Mall.
Stage 2	The Stage 2 redevelopment of Warringah Mall covers the eastern side of the existing Warringah Mall, next to the intersection of Condamine Street and Pittwater Road. The 2018 Warringah Mall Flood Impact Assessment assessed the flood impacts resulting from the Stage 2 redevelopment combined with the constructed Stage 1 drainage augmentation scheme and found minimal changes to flood impacts. The 2018 Warringah Mall Stormwater Management Report mentions two new jellyfish GPTs and a sedimentation basin within their concept design for water quality treatment. In the plans, these are located upstream of the existing trash rack GPT along Condamine Street

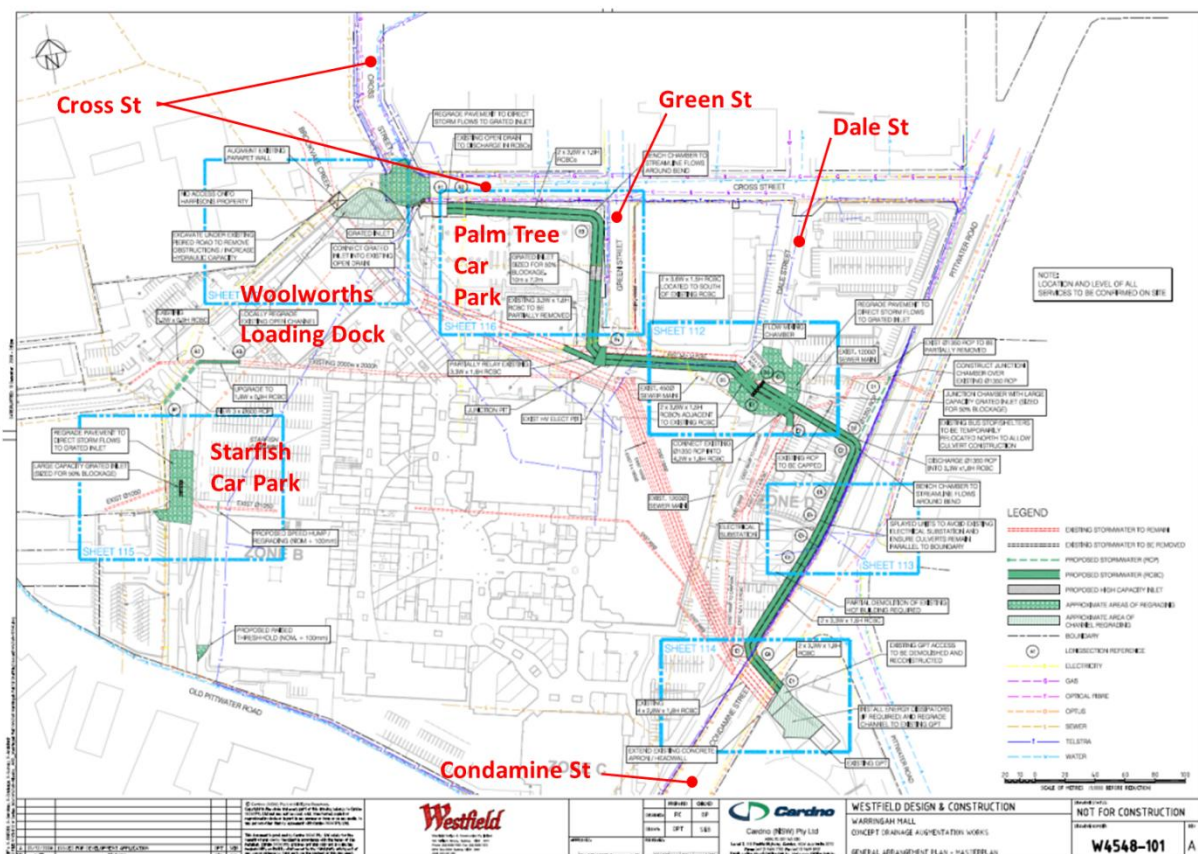
Phase of development

Summary

and Pittwater Road. It is assumed that these assets were constructed as per the design plans.

Stage 2B

The 2021 Warringah Mall Flood Impact Assessment was conducted for the Stage 2B redevelopment of Warringah Mall. This involved local regrading works for the Mini Major loading dock which interface with existing pavement levels and have negligible impacts on the flood extent.



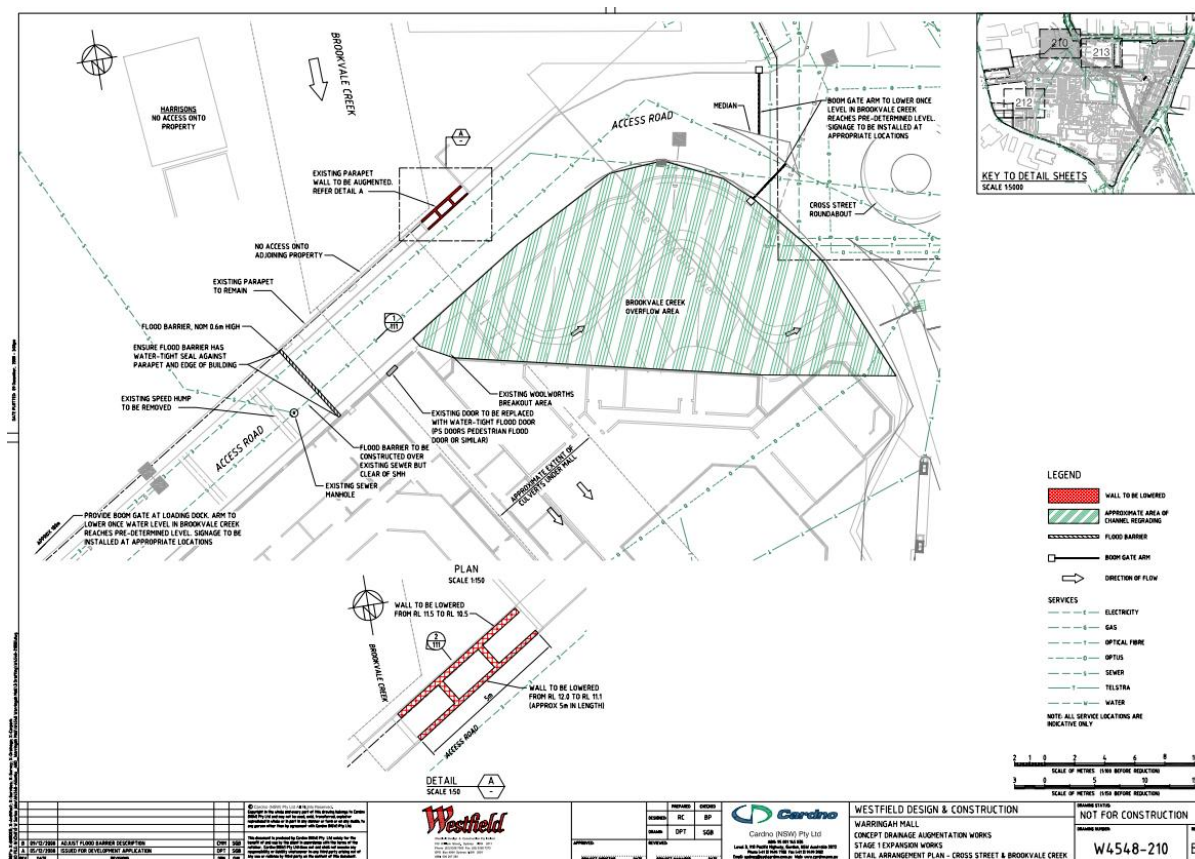


Figure 13. Brookvale Creek Overflow Inlet works (Cardno 2008)

3.6 Water quality

The *Brookvale WSUD Investigation and Concept Design – Stage 1 Report (RHDHV 2023)* provides an in-depth review of the existing water quality conditions in Brookvale Creek. The report investigates the condition and performance of the existing large Gross Pollutant Trap (GPT) on Brookvale Creek at the northern boundary of the Warringah Golf Club. A recent image of the GPT is shown in Figure 14.

The report included a historical pollutant source modelling and assessment, which concluded that previous land uses within the catchment are unlikely to introduce long-lasting sources of pollutants.

The stormwater pollution parameters for each source node in the MUSIC Model developed for the project were adopted per the Northern Beaches Council MUSIC Modelling Guidelines (Alluvium, 2016). Through the modelling, some smaller areas of higher pollutant-producing potential were identified throughout the Brookvale Creek catchment (i.e. dog parks, construction sites and mechanics). Dog parks and construction sites accounted for less than 0.1 % of the catchment; therefore, their influence was deemed to be negligible. Although MUSIC cannot model oil and grease, it was noted that the high number of motor mechanics in the catchment should be accounted for when identifying treatment opportunities throughout the catchment.

There are also several Sydney Water sewer overflows within the Brookvale Creek catchment, which are expected to result in elevated nutrient pollutant loads in the creek during and after larger rainfall events. These overflows should also be considered when identifying future water quality treatment opportunities.

Water quality testing was also conducted as part of this investigation by RHDHV. Results were compared to industry guideline values, and the results were discussed at length in the report. Key findings included:

- *Total Phosphorus concentrations upstream and within the GPT were higher than the ANZECC 2000 guideline value*

- *Total Nitrogen (TN) concentrations exceeded ANZECC 2000 concentrations upstream, within and downstream of the GPT*
- *Approximately 60% of the TN was in the form of inorganic nitrogen, which is more harmful to ecological systems than organic nitrogen*
- *Nitrate concentration was lower than the trigger value recommended by the Australia and New Zealand Guidelines (ANZG) 2018, which is the current accepted value*
- *Ammonia concentrations upstream, within and downstream of the GPT were below the 2018 default guideline values*
- *Faecal coliform concentrations upstream, within and downstream of the GPT are significantly above the ANZECC 2000 guideline values for primary contact (150 cfu/100mL).*

It was concluded that the GPT provides some form of pollutant reduction for most pollutants and toxicants. However, additional sampling at more locations and times of day was recommended. The potential sources of the elevated faecal coliform levels were also recommended for further investigation.



Figure 14. *The current state of the existing trash rack (photo taken 16/10/2024)*

4 Proposed Structure plan

The study area for this project is identified in the recommended future land use zoning map (Figure 15), and includes:

- Existing shop-top housing development along Pittwater Road and Roger Street (MU1 zone)
- Winbourne Road carpark (SP2 zone)
- Northeast corner of the Warringah Mall site (MU1 zone)
- Existing Aldi site (E2 zone)
- Industrial lands east and west of Pittwater Road (E4 zones).

Character sub-precincts identified in the Brookvale Structure plan include:

- Precinct 1 (The Core) – Includes the E2 zone and the MU1 zone at the northeast corner of Warringah Mall (which contains the Town Square)
- Precinct 2 (Roger Street) – Includes the MU1 zones along Roger Street
- Precinct 3 (Pittwater Road) – Includes the MU1 zones along Pittwater Road and the SP2 zone
- Precinct 4 (Industrial East) – Includes the E4 zones east of Pittwater Road
- Precinct 5 (Industrial West) – Includes the E4 zones west of Pittwater Road.

An overview of the Warringah Mall Structure plan is provided in Figure 16, although it should be noted that Scentre Group site will ultimately be progressed through separate State Significant Development processes. A comparison of the two proposed scenarios outlined in Table 7.

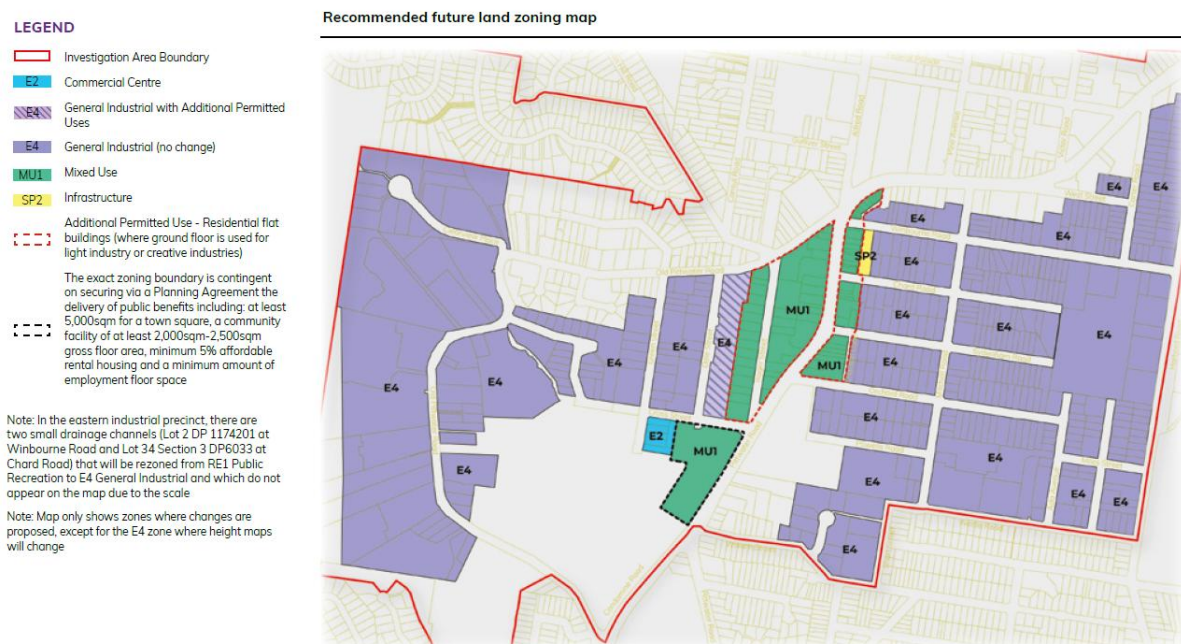


Figure 15. Recommended future land zoning map showing Scenario 1 development in green (Northern Beaches Council, 2024)

Structure Plan

1. New plaza adjacent to the B-Line stop
2. Local park at the entry of Cross and Duke Street
3. Green edge along Condamine Street and Pittwater Road
4. Steepling of Kmart/ orange car parks with active development
5. New north south street to provide vehicle movement north/ south through the site
6. New bus interchange along east west street
7. Reconfigured entries + exits
8. Relocated exit north
9. Relocated entry and exists to orange car park to allow for sleeving
10. New porte-cochère
11. Access to loading docks retained



Figure 16. Proposed Structure plan for Warringah Mall (SJB, 2024)

Table 7. Comparison of Scenario 1 and Scenario 2 development (Northern Beaches Council, 2024)

	Scenario 1 Brookvale Structure plan	Scenario 2 Possible additional density
Dwellings	1,350 dwellings* *Assumed 90sqm unit size	+952 dwellings* *Scentre Group: +547 *30% bonus on 1,350 dwellings: +405 Total (Scenario 1 & 2): 2,302 dwellings
Residential floor space	122,072sqm* *Core: 26,051 sqm *Roger St: 47,454 sqm *Pittwater Rd: 48,567 sqm	Scentre Group: + 49,230sqm* *547 dwellings x 90 sqm unit size 30% bonus on 122,072 sqm: +36,622 sqm** **122,072 sqm x 0.3 Total (Scenario 1 & 2): 207,924 sqm*** *** 122,072 sqm + 49,230 sqm + 36,622 sqm
Jobs	900 jobs	No change
Employment floor space	44,890sqm* *Core: 11,000 sqm *Roger St: 16,748 sqm *Pittwater Rd: 17,142 sqm	No change

5 Catchment delineation

The sub-catchments draining to the study area were delineated using the CatchmentSIM software, relying on the 2023 1 m resolution Digital Elevation Model (DEM). The resolution of sub-catchments generally followed the previous sub-catchments in the 2013 Manly Lagoon Flood Study (BMT WBM, 2013), with a refinement focusing on the Warringah Mall. The open watercourses and stormwater pipe networks were used to guide the sub-catchment delineation. Ultimately, the catchment draining to Manly Lagoon has a total area of 18,300 ha, including 138 sub-catchments with areas ranging from 0.11 to 53.3 ha, averaging 13 ha. The catchment overview is shown in Figure 3.

Figure 17 shows the Manly Lagoon sub-catchments which contribute to flows in the study area and converge at the outlet downstream of the existing trash rack GPT. There are 16 sub-catchments highlighted in green that intersect with the study area, and 17 sub-catchments entirely upstream.

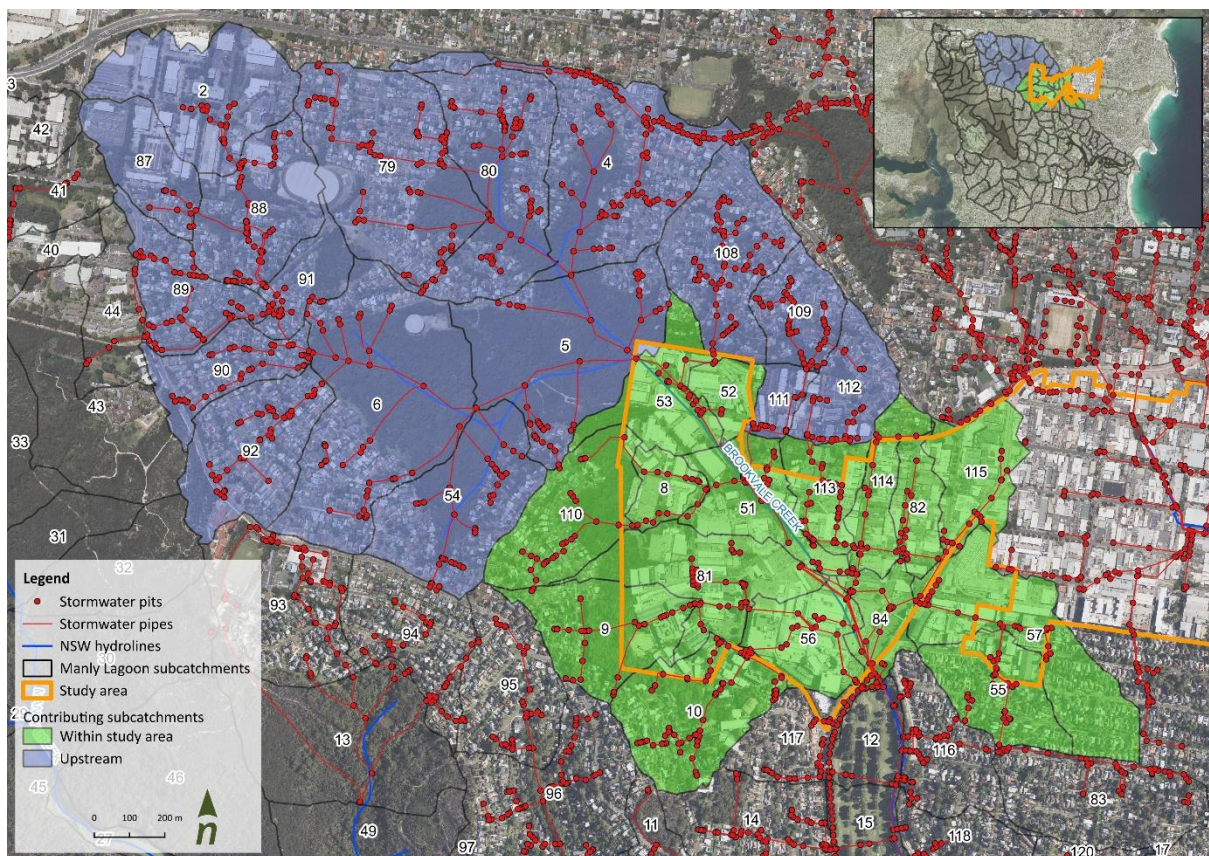


Figure 17. Stormwater catchment plan

5.1 Catchment analysis

The catchment was categorised into seven land uses, including natural, urban residential, recreation, industrial/commercial, public services, open water, and roads. This categorisation was based on the latest NSW Land Use 2017 dataset from SEED, with some adjustments made based on recent satellite imagery to update the current condition.

5.2 Sub-catchment analysis

Figure 18 shows the proposed Structure plan in the context of the post-development land uses and Manly Lagoon sub-catchments. The Structure plan was delineated into the mixed-use land use category, based on the Council-provided 'Recommended Future Land Zoning Map' (NBC, 2024) and Warringah Mall Structure plan Concept Design (SJB, 2024), which shows the E2 – Commercial Centre zone as a mix of residential, commercial and open space land use. The SP2 – Infrastructure zone was assumed to remain in the industrial/commercial land use category.

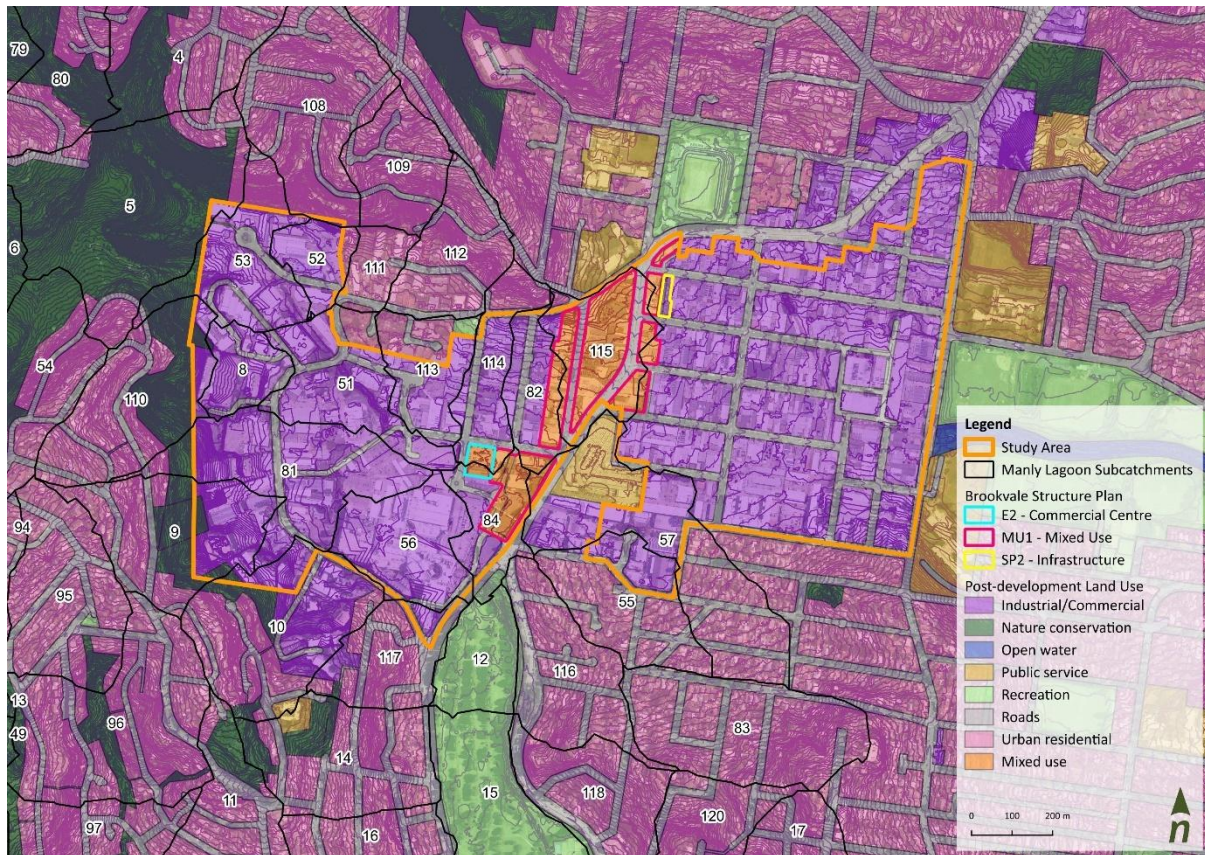


Figure 18. *Proposed Structure plan and sub-catchment mapping*

Sub-catchment fraction impervious

The total impervious area (TIA) fraction was estimated against the satellite imagery for some sample blocks and applied to similar land uses. The effective impervious area (EIA) is based on relationships from ARR:

- Residential, public service, recreation: $EIA = 60\% * TIA$
- Industrial/commercial, roads: $EIA = 80\% * TIA$
- Open water: $EIA = 100\% * TIA$

The Structure plan, land use categories, and impervious fractions are shown in Table 8.

Table 8. Adopted fraction impervious for the proposed land use type

Structure Plan Land Use	Description	Fraction Impervious (TIA)	Effective Impervious Area (EIA)
Industrial/commercial	Services, commercial services and research facilities	95	76
Nature conservation	National parks, surface water supply, residual native cover and other conserved areas	0	0
Open water	Estuaries and coastal waters, water extraction and transmission, reservoirs, rivers, lakes, marshes and wetlands	90	90
Public service	Public services, such as schools, hospitals, Council	40	24
Recreation	Recreation and culture, rural residential without agriculture	20	12
Roads	Roads	50	40
Urban residential	Urban residential	65	39

The land use categorisation, fraction impervious and proposed effective impervious area for the 16-study area sub-catchments are provided in Table 42 (Appendix B). The seventeen sub-catchments upstream of the study area were grouped into three larger sub-catchments denoted 'Upstream 1', 'Upstream 2', and 'Upstream 3' based on their outlets. The land use categorisation, fraction impervious and proposed effective impervious area for these three larger upstream sub-catchments are provided in Table 9.

Table 9. External catchment

External catchment	Structure plan land use	Existing area (ha)	Proposed area (ha)	Fraction impervious (FI)	Proposed effective impervious area (ha) – Area x FI
Upstream 1 (SC 2, 4, 5, 6, 54, 79, 80, 87, 88, 89, 90, 91, 92, 108)	Industrial/commercial	22.79	22.79	76	17.32
	Nature conservation	53.74	53.74	0	0
	Open water	2.14	2.14	90	1.93
	Public service	4.11	4.11	24	0.99
	Recreation	0.6	0.6	12	0.07
	Roads	34.6	34.6	40	13.84
	Urban residential	93.25	93.25	39	36.37
	Sub-total	211.23	211.23		70.52
Upstream 2 (SC 109, 111)	Industrial/commercial	0.01	0.01	76	0.01
	Roads	1.39	1.39	40	0.56
	Urban residential	7.76	7.76	39	3.03
	Sub-total	9.16	9.16		3.6
Upstream 3 (SC 112)	Roads	1.64	1.64	40	0.66
	Urban residential	5.65	5.65	39	2.2
	Sub-total	7.29	7.29		2.86

6 Hydrological analysis

The updated hydrological model for Manly Lagoon, developed as part of this study, was used to support this assessment. The catchment and land use delineation described in Chapter 6 formed the basis of the updated hydrological model.

The hydrological model was developed to:

- Update the previous RAFTS model, which followed ARR1987, to a WBNM model following ARR2019
- Provide hydrological inputs for updating the TUFLOW model in this area.

The following chapter describes the parameters adopted, hydrological model development, and climate change considerations.

For this study, the Watershed Bounded Network Model (WBNM) was selected as the preferred hydrological modelling approach. This decision was based on several factors, including compliance with contemporary industry standards, compatibility with the latest Australian Rainfall and Runoff (ARR2019) guidelines, and the suitability of WBNM for modelling urban catchments such as Manly Lagoon.

WBNM offers a semi-distributed approach that effectively represents runoff processes across complex urban catchments, providing more accurate hydrological inputs for flood modelling. Compared to XP-RAFTS, which is no longer a supported software, WBNM integrates with ARR2019's updated rainfall temporal patterns, losses, and spatial distribution methods. Additionally, WBNM's flexible structure allows for direct input into hydraulic models such as TUFLOW, facilitating a seamless transition between hydrological and hydraulic modelling components.

The adoption of WBNM ensures that the updated hydrological model aligns with current best practices, improves consistency with other contemporary flood studies, and enhances the accuracy of flood predictions for Manly Lagoon.

6.1 Model parameters

This model provides an update of the previous hydrological model from the Manly Lagoon Flood Study (BMT WBM, 2013) to align with ARR2019. Calibration was not undertaken following agreement with Council due to the additional effort required to do so. While gauge and flood level data are available, it is recommended that calibration be considered in a future flood study update to improve confidence in model results. The primary objective of this update was to provide a like-for-like assessment using ARR2019 methodologies rather than a recalibrated model. The updated model serves as a platform that can be refined and further developed by future practitioners should funding become available for a full flood study.

Losses and catchment parameters were adopted from the previous model, with modifications to align with the latest guidance from ARR2019. Nonlinear routing was applied to sub-catchments, using a nonlinearity exponent of $m=0.77$ and a lag parameter of $C=1.6$ across all sub-catchments to determine lag time in flood routing. An impervious lag factor of 0.1 was used to convert rainfall to runoff for impervious areas, while a stream lag factor of 1 was applied to represent natural reaches.

The Probability Neutral Burst Initial Loss for NSW was applied for the pervious area following the NSW Office of Environment and Heritage guide (OEH, 2019). The continuous loss (CL) was considered following these studies:

- ARR data hub (Geoscience Australia, 2019): CL = 1.6 mm/h. The values from the ARR data hub are suggested to be adjusted by 0.4 to avoid overestimation (OEH, 2019), i.e., CL = $1.6 \times 0.4 = 0.64$ mm/h.
- FFA-reconcile loss for Parramatta hospital area: CL = 0 mm/h. This area is mostly impervious.
- Manly Lagoon Flood Study: CL = 2.5 mm/h.

Compared to the 2016 ARR Data Hub values, the Manly Lagoon Flood Study's CL is relatively high, likely influenced by the presence of Manly Dam. To adopt a more conservative approach, a CL of 0.64 mm/h, based on the ARR Data Hub with the OEH adjustment, was applied in this study.

For Effective Impervious Area (EIA), an Initial Loss (IL) of 1.5 mm and CL of 0 mm/h were used. For the Impervious Connected Area (ICA), IL was set to 0.7 times the pervious IL, with a CL of 0.64 mm/h applied per ARR2019 recommendations.

Details of parameterisation and comparisons to the Manly Lagoon Flood Study are provided in Table 10.

Table 10. Flood modelling parameters

Flood modelling parameters	This study (following ARR2019)	Manly Lagoon Flood Study (following ARR1987)
IL for Effective Impervious Area (EIA)	1.5 mm	2 mm
IL for pervious areas	Probability Neutral Burst Initial Loss for NSW	10 mm
IL for Indirectly Connected Area (ICA)	0.7*IL for Pervious Area	
CL for EIA	0 mm	0 mm
CL for pervious area and ICA	0.64 mm (=0.4*ARR Data Hub IL)	2.5 mm

6.2 Design rainfall

Design rainfall depths were obtained from the Intensity-Frequency-Duration (IFD) data at the catchment centroid for all design events up to the 0.1% AEP (BoM, 2016). Durations ranged from 30 minutes to 168 hours to capture short- and long-duration events relevant to flood modelling.

Areal Reduction Factors (ARF) were applied in accordance with ARR2019 for catchments up to 30,000 km², covering durations up to 168 hours and AEPs more frequent than 0.05% AEP. These adjustments account for the spatial variability of rainfall across the catchment. The design rainfall depths for the selected events are presented in Figure 19. Point temporal patterns for catchments smaller than 75 km² were obtained from the ARR Data Hub for the East Coast South region. Spatial patterns were assumed to be uniform across the catchment.

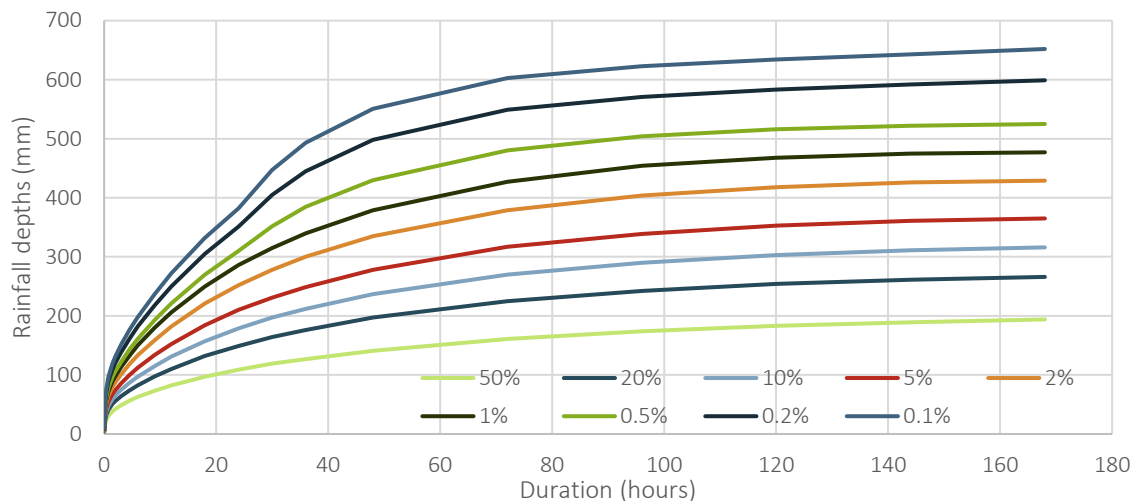


Figure 19. Design rainfall depths

The Probable Maximum Precipitation (PMP) for the catchment was estimated using the Generalised Short Duration Method (GSDM), which is widely used for deriving extreme rainfall estimates for durations up to six hours. This method follows guidelines from the Bureau of Meteorology (BoM) and is appropriate for small to medium-sized catchments. It provides an upper-bound estimate of possible precipitation based on meteorological conditions, moisture availability, and storm efficiency.

Rainfall depths were determined using the GSDM approach, incorporating BoM's recommended adjustments for local topography and climatic conditions. These estimates were refined using catchment characteristics to ensure they aligned with hydrological conditions specific to the study area. The temporal distribution of PMP rainfall was derived from standard GSDM temporal patterns, ensuring that peak intensities were appropriately represented. A time-weighted distribution was applied to capture the most intense periods of rainfall within the storm event.

The spatial distribution of PMP rainfall was determined using CatchmentSIM, applying areal reduction factors (ARF) to adjust for catchment size. Catchment delineation information was used to ensure a consistent application of PMP depths across sub-catchments. For this study, a uniform spatial distribution was assumed, in line with BoM methodologies for small to medium catchments.

6.3 Climate change

The proposed climate change parameters for the hydrologic analysis are provided in Table 11. To align with Council's Draft Climate Policy and Draft DCP Flood Clause, the climate change scenario applied in this assessment has been updated to adopt the SSP3-7.0 scenario.

Table 11. Climate change parameters

	This study (following ARR2019)
Climate change scenario	SSP 3-7.0
IL rate of change	1.1% (East Coast)
CL rate of change	3.8% (East Coast)
Study event for climate change	1% AEP

The selection of climate change parameters for this study follows the updated climate change guidance in ARR 4.2, Book 1, Chapter 6. Recent literature suggests that initial loss (IL) is likely to increase with rising temperatures due to drier soil conditions. The updated guidelines provide estimates for these adjustments. For this study, the climate change scenarios were applied to the 1% AEP event, and adjustments to rainfall intensity and loss parameters were calculated based on the relevant SSP pathways.

The values for the long-term climate change parameters (2081–2100) under SSP2-4.5 and SSP3-7.0 are summarised in Table 12.

Table 12. Long term climate change parameters (2081-2100)

	SSP 2-4.5	SSP 3-7.0
α (%/°C)	14.7 for critical duration 2h, 14.85 for critical duration 1.5h, 15 for critical duration $\leq$ 1h	
ΔT (°C)	2.4 (1.8-3.2)	3.3 (2.5-4.3)
IL (%/°C)	2.0 (0.6-4.3)	
CL (%/°C)	3.8 (1.1-8.0)	

Note that α , IL and CL values apply to both SSP 2-4.5 and SSP 3-7.0 values.

These climate change parameters were incorporated into the hydrological modelling to assess potential impacts on design flood estimates and inform adaptation strategies.

6.4 WBNM modelling for design events

Rainfall-runoff modelling in this study was developed using WBNM software version 2017 with Storm-Injector 1.4.0 HL for interface and output processing. Sub-catchment details, including area, imperviousness, and connections, were imported into Storm-Injector from CatchmentSIM results. The model was run for the infrequent to rare events, i.e., 50%, 20%, 10%, 5%, 2% and 1% AEP, very rare to extreme events, i.e., 0.5%, 0.2% and 0.1% AEP, and the PMF event.

6.5 Critical temporal patterns and duration selection

Each model was run with an ensemble of various durations and temporal patterns. For each rainfall duration, the adopted temporal pattern was the temporal pattern that resulted in the 60th percentile peak flow rate. The

critical duration for each design event is the duration with the highest mean flow rate of all adopted temporal patterns of all durations. The adopted temporal pattern of the critical duration becomes the critical temporal pattern. Warringah Mall and the outlet of the Manly Lagoon catchment were selected as focus locations for the purposes of selecting critical duration and temporal patterns for this study.

The critical temporal pattern and duration at these locations are presented in Table 13. The hydrographs of design events and the climate change hydrographs at downstream of the Warringah Mall are presented in Figure 20 and Figure 21, respectively.

Table 13. Critical duration, temporal pattern, and flow for the design events at two study locations

Event	Downstream Warringah Mall			Manly Lagoon Outlet		
	Critical duration	Critical Temporal Pattern	Critical flow (m ³ /s)	Critical duration	Critical Temporal Pattern	Critical flow (m ³ /s)
50% AEP	2 hours	4640	16.82	3 hours	4608	9.08
20% AEP	1.50 hour	4605	25.03	2 hours	4602	14.08
10% AEP	1 hour	4568	30.12	3 hours	4572	16.22
5% AEP	1 hour	4568	35.97	3 hours	4572	19.43
2% AEP	1 hour	4558	42.46	2 hours	4405	23.71
1% AEP	1 hour	4558	49.31	2 hours	4405	27.59
0.2% AEP	1 hour	4558	62.4	1.50 hour	4405	34.99
0.1% AEP	1 hour	4558	68.71	1.50 hour	4405	38.54
PMF GSDM	1 hour	4	303.34	1.50 hour	4	173.2

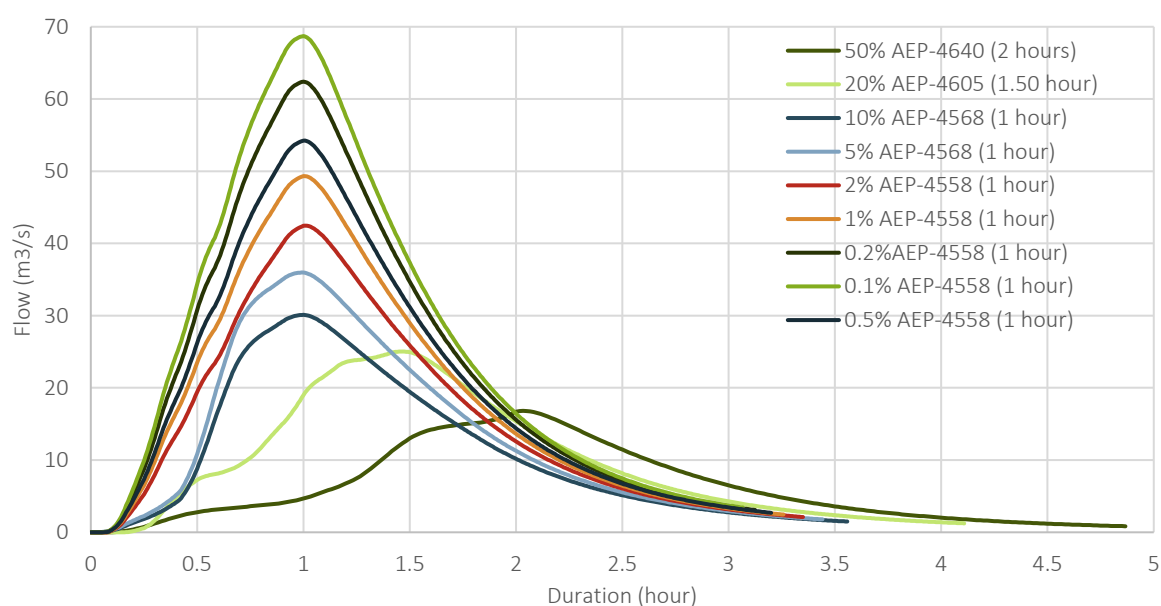


Figure 20. Critical hydrographs of the design events at the downstream boundary of the Warringah Mall.

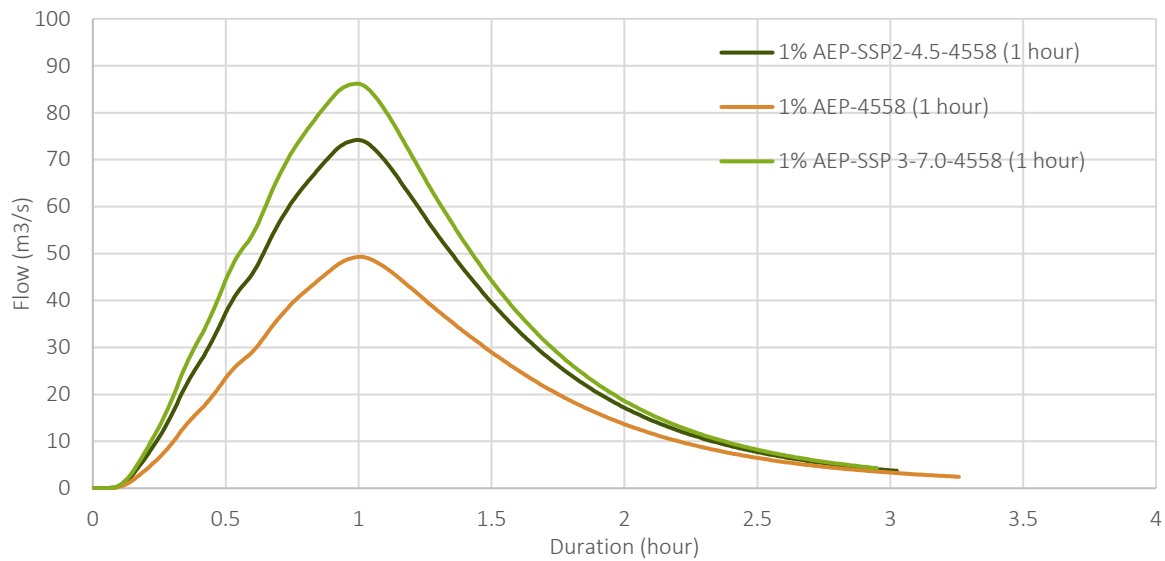


Figure 21. Critical hydrographs of the design events at the downstream boundary of the Warringah Mall for the 1% AEP with climate change.

6.6 Comparison between ARR2019 and ARR1987 results

The rainfall depths data used in ARR2019 versus the ones used in the Manly Lagoon Flood Study following ARR1987 are shown in Figure 22. ARR2019 data has a lower rainfall depth for a corresponding event and duration.

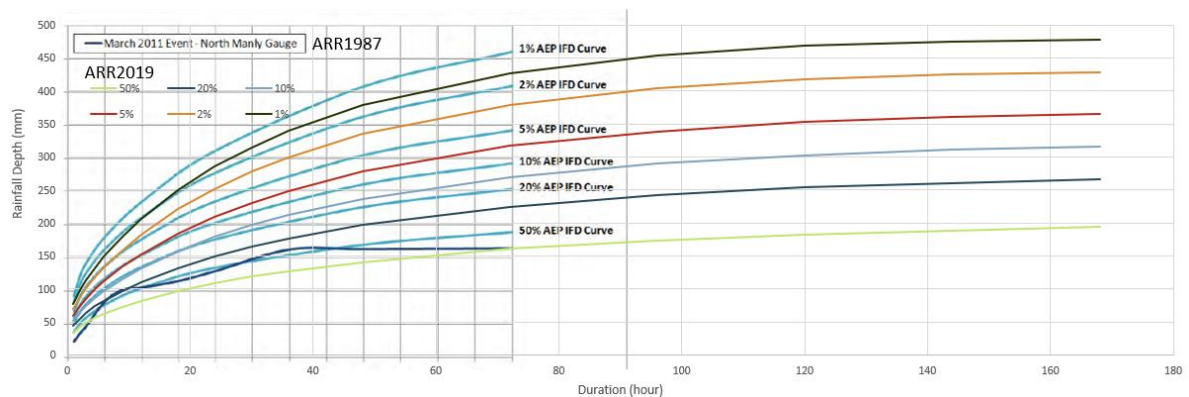


Figure 22. Comparison between rainfall depths used in ARR2019 and ARR1987.

Table 14. Comparison of Design Rainfall Intensities, 1% AEP Event (mm/hr)

Hours (h)	ARR87 Rainfall Intensity (mm/h)	ARR19 Rainfall Intensity (mm/h)	Diff (%)
0.5	133	123	-8%
1	93	78	-16%
1.5	74.5	59	-21%
2	62	49	-21%
3	47.6	38	-21%
6	30.3	25	-17%
9	24	20	-17%
12	19.6	17	-12%
24	13	11.9	-8%

Although the model in this study followed the ARR2019 with lower rainfall depths, lower losses were applied, and thus, the general critical flows resulting from the new model were not significantly different from the previous model. However, the critical durations from the new model are considerably shorter than those of the previous model, i.e., mostly 5.5 hours previously and 1.5 to 3 hours in this model.

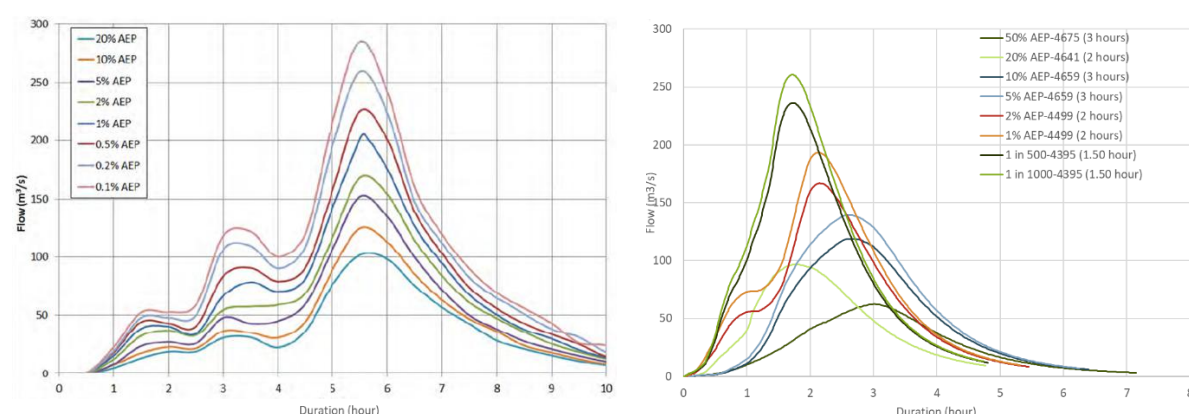


Figure 23. Comparison of flow at Manly lagoon outlet. Left – ARR87, right – ARR2019

A sensitivity analysis was undertaken to compare flow results between ARR1987 and ARR2019 design methodologies to better understand the influence of updated intensity-frequency-duration (IFD) data and loss parameters on the hydrological response.

Three scenarios were tested:

1. ARR1987 losses were applied, using an initial loss (IL) of 10 mm and a continuing loss (CL) of 2.5 mm/hr. Indirectly Connected Areas (ICA) were included.
2. ARR2019 Probability Neutral Losses were applied with ICA included (this was used for the design modelling scenario).
3. ARR2019 Probability Neutral Losses were applied without ICA.

The results shown in Figure 24 showed that the ARR1987 losses produced the lowest peak flows, due to the higher overall loss rates applied in that methodology. When comparing the two ARR2019 scenarios, flows without ICA were slightly higher than those with ICA, though the difference was marginal. This suggests that for this catchment, the inclusion of ICA has a relatively minor influence on peak flow estimates under ARR2019 conditions, but the choice of loss methodology has a more significant effect.

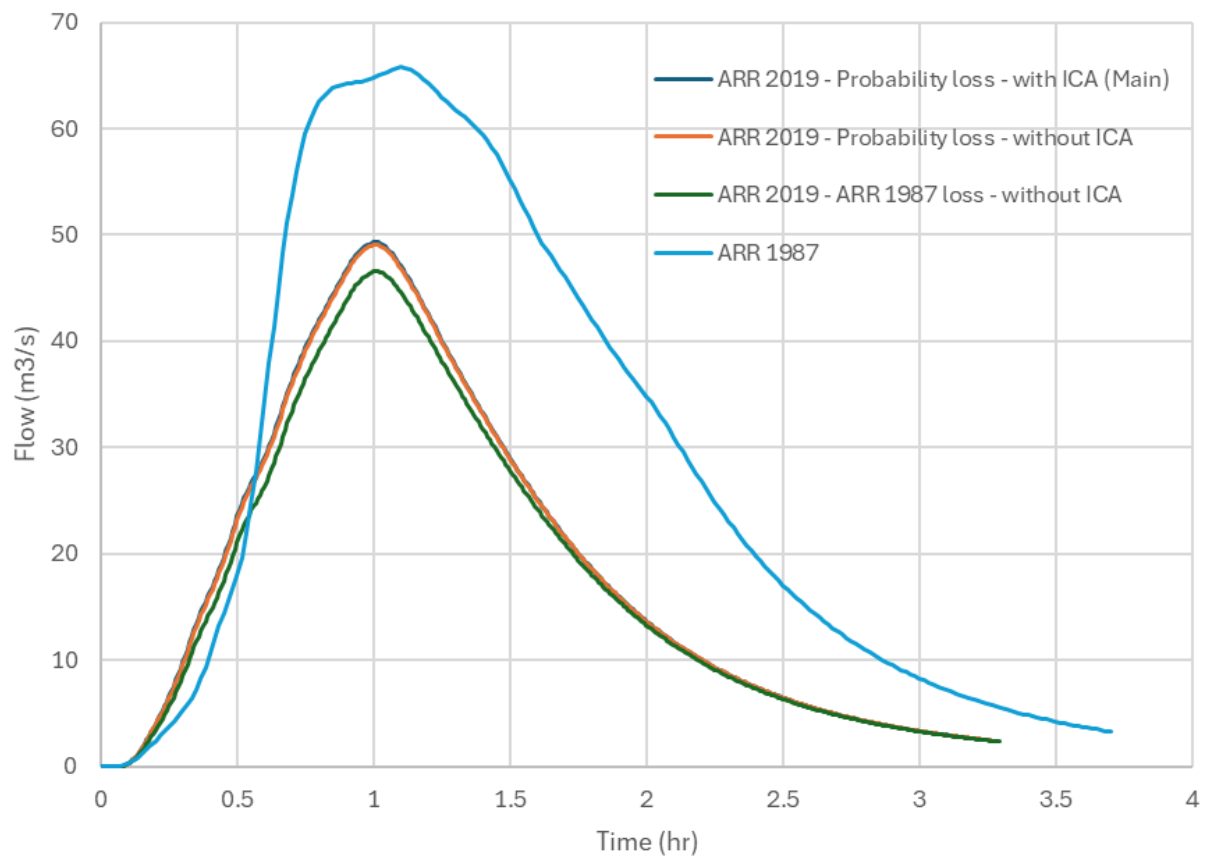


Figure 24. Difference in peak flow at Warringah Mall comparing different IFD and loss models

7 Hydraulic Modelling

7.1 TUFLOW model updates

Manly Lagoon

The existing TUFLOW model for Manly Lagoon, initially developed for the 2013 Manly Lagoon Flood Study (BMT 2013) and updated for the Manly Lagoon FRMSP (WMAwater 2018), was used as the foundation for this assessment. The model employed the 2013 TUFLOW solver with a five-metre grid resolution. For this study, updates to the model were made to enhance the solver, refine the grid resolution, and incorporate more recent datasets.

The model was updated to the 2023 TUFLOW solver with a refined two-metre grid size. The sub-grid sampling solver was also adopted, allowing the model to achieve results comparable to those using finer grid resolutions while significantly reducing computational effort. Additionally, the 2023 LiDAR dataset replaced the 2007 dataset, ensuring the model reflects the most current terrain information.

The hydrologic component of the model was also updated with the flows derived in the previous chapter applied directly to the 2D domain, where runoff initially propagates as sheet flow. As runoff accumulates, defined overland flow paths emerge. In areas with stormwater infrastructure, flow is automatically transferred to the 1D domain where sufficient pipe capacity exists to convey the runoff effectively.

In addition to updates to the solver, LiDAR, and hydrology, changes to the stormwater network since 2013 were also incorporated into the model. The XP-SWMM model developed for the Warringah Mall Flood Study was reviewed to extract the stormwater upgrades documented in Table 6, which are illustrated in Figure 25. These updates primarily involve major culvert augmentations and associated works. Furthermore, additional stormwater pipes that were not previously included in the 2013 model have now been incorporated to enhance the accuracy and completeness of the updated model.

The model development encountered several challenges. Ideally, a stepped transition would have been undertaken for the solver update; however, the old hydrology was incompatible with the new solver due to changes in the way source-area boundaries are applied. This required modifications to ensure the hydrological inputs were appropriately represented. Additionally, the adoption of the 2023 LiDAR dataset introduced complexities, particularly with stormwater pipes featuring daylighted inverts, which required extensive troubleshooting to ensure correct connectivity within the model. The new dataset also contained triangulations that required manual refinement, adding further complexity to the terrain processing.

While these updates represent improvements to the model, the development process remains ongoing, and results are subject to further refinement. The updated model was used to support the forthcoming options analysis and mitigation testing as presented in the following sections. As noted, further verification and refinement should be undertaken as part of future flood study updates and Flood Risk Management Study and Plan (FRMSP) processes to ensure the model's ongoing accuracy and robustness for informing final design and mitigation strategies.

Greendale Creek

The Greendale Creek flood model was more recently completed and is considered up to date (WMAwater 2023), requiring fewer adjustments compared to other models. The model adopted a two-metre grid size and utilised the 2018 HPC solver, which aligns with contemporary modelling practices. As a sensitivity test, the model was updated to the 2023 solver, incorporating the sub-grid sampling module to assess any potential differences in results. The updated results are presented in Section 7.2



Figure 25. *Additional stormwater infrastructure modelled*

7.2 TUFLOW Results

Manly Lagoon

The updated Manly Lagoon TUFLOW model results focus on flooding in the Warringah Mall area, presenting flood depths, velocities and hazard mapping for a range of design events. Simulations were undertaken for the 50%, 20%, 10%, 5%, 2%, and 1% AEP events, as well as for the very rare to extreme events (0.5% and 0.2% AEP), climate change scenarios and the Probable Maximum Flood (PMF) event. The results for these events are presented in Figures A01 to A21.

A comparison of the updated 1% AEP results against the previous flood study indicates reductions in both flood level (around 0.7 m to 1.7 m) and extent globally. Refer to Table 15 and Figure 26 comparing flood level and extent differences. These reductions are primarily attributed to the change in design rainfall intensities derived from ARR2019 implementation, as well as the updated stormwater infrastructure, which has increased pipe conveyance and improved drainage efficiency, contributing to the observed reductions.

The Brookvale Creek downstream of Warringah Mall exhibited smaller reductions in flood levels (-0.1m) with the model updates. This is due to the enhanced piped conveyance from the stormwater upgrades that were added to the model, which have increased the efficiency of upstream drainage and redirected more flow downstream. As a result, reductions in water levels here were less than those compared to other locations within the catchment.

Table 15. Comparison of flood levels between this study and the 2018 FRMSP Model

Location	Existing Flood Level (m AHD) (1% AEP 60min duration)		
	2018 FRMSP model	This study	Difference (m)
Brookvale Creek at Warringah Mall	12.5	10.8	-1.7
Green Street Roundabout	10.3	9.7	-0.7
Green Street and Cross Street Intersection	10.4	9.4	-1.0
Warringah Mall Carpark	9.9	9.1	-0.8
Brookvale Creek Downstream	6.3	6.2	-0.1

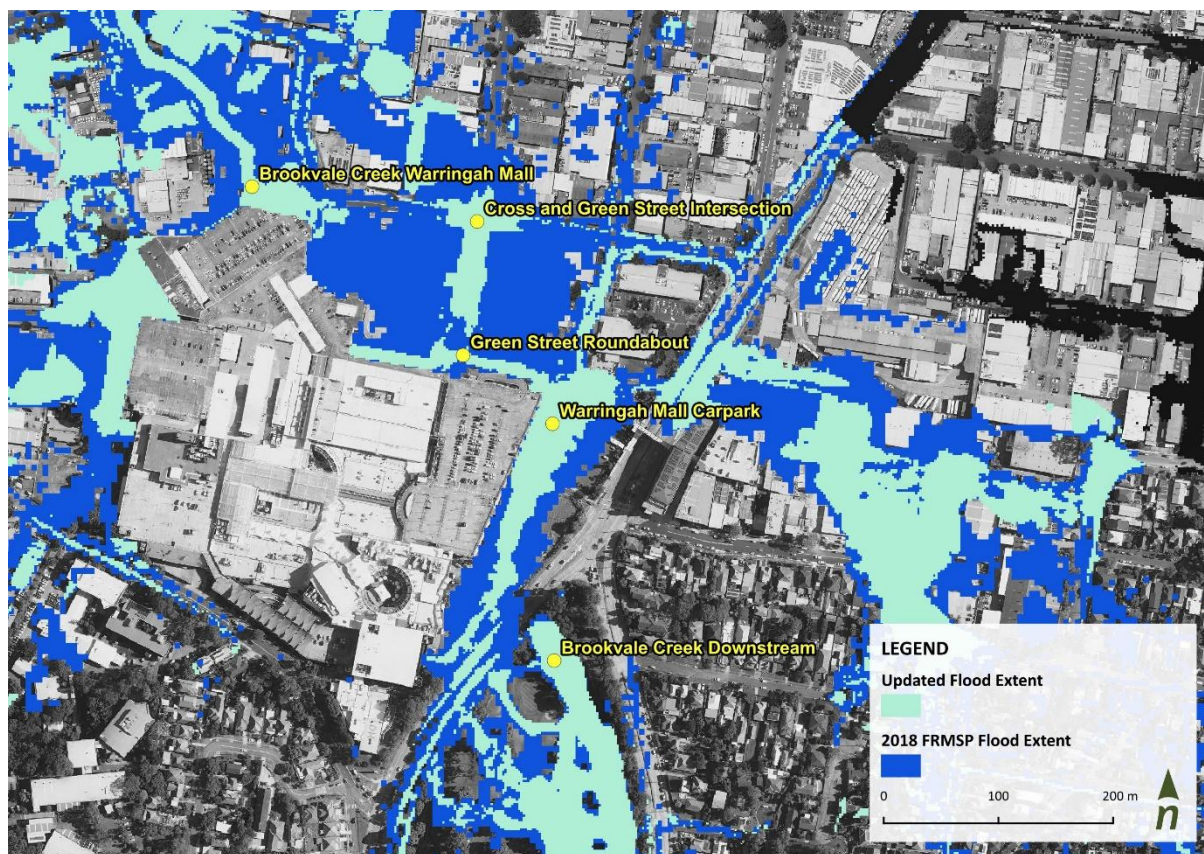


Figure 26. Comparison of existing flood extents between the FRMSP study and this study (note that the current(updated) modelling results are shown in the lighter shade of blue)

Greendale Creek

The results of the SGS solver change for the 1% AEP event are presented in Figure 27, where the updated model results are compared against the original study by subtracting the previous water levels from the updated outputs. A positive value indicates that water levels in the updated model are higher, whereas a negative value represents a decrease.

The comparison shows a mix of increases and decreases across the study area, with most differences being within ± 5 cm. Some slightly larger increases are observed along Greendale Creek, which are attributed to subtle differences in the model solver since 2018. These changes are primarily due to refinements in the shallow water

equation solver, particularly in the change to the application of turbulence, which affects how energy losses and eddies are resolved. Additionally, the SGS solver allows for slight increases in conveyance, but given that the underlying topography is based on a 1 m resolution, the impact remains minor.

Considering that the differences are small and within an acceptable tolerance for flood modelling, retaining the original results and model configuration is more practical and has been retained for this study. This approach avoids the need for recalibration or validation while still providing sufficient two-metre resolution detail for optioneering analysis. The modelling and map outputs are presented in Appendix A.

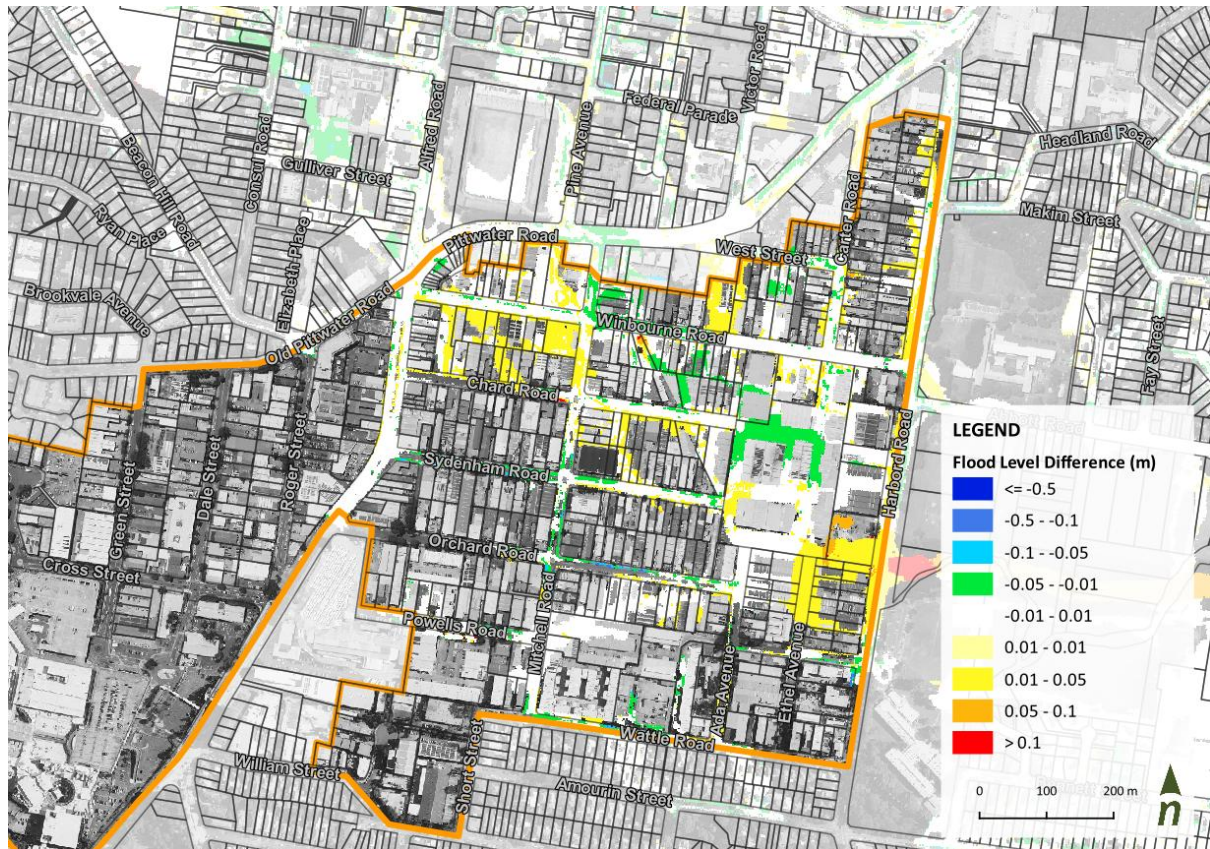


Figure 27. Comparison of flood levels for the 1% AEP for the Greendale Creek Flood Model utilising SGS

7.2.1 Mapping

Flood Planning Area

The Flood Planning Area (FPA) has been delineated in accordance with the NSW Flood Risk Management Manual, based on the application of Flood Planning Levels (FPLs) used by Council to guide development on flood-prone land. The FPL is defined as the combination of the flood level from the Defined Flood Event (DFE) and an appropriate freeboard allowance. The DFE is based on the climate change scenario relevant for the expected design life of the proposed development.

Council's Draft DCP Flood Clause requires developments with long term design life to derive the FPL from the 1% AEP event under long-term climate change conditions. This includes developments involving intensification, consistent with those proposed within the structure plan. The application of this scenario is consistent with Council's most current strategic planning guidance.

To avoid the clutter of identifying minor, low-risk flood-affected areas, a minimum depth threshold of 150 mm was applied, and isolated inundation areas smaller than 100 m² were excluded from the mapped FPA. This is consistent with mapping undertaken by Council in other catchment areas.

The provisional mapped Flood Planning Area for developed conditions is presented in Figure C01.

Flood Categories Mapping – Northern Beaches Council

Flood Category 1 mapping for this project was undertaken in alignment with the methodology adopted by Northern Beaches Council (NBC), as described in the 'Draft FPCC Mapping Memo – M250814' produced by WMAwater in August 2025. NBC's approach is derived from best practice guidance from the Australian Disaster Resilience Handbook Collection (Handbook 7: Managing the Floodplain, AIDR 2017) and the NSW Flood Risk Management Manual 2023. Flood Category 2 is equivalent to the Flood Planning Area and Flood Category 3 is equivalent to the area within the PMF extent.

Key steps in the NBC Flood Category 1 mapping process:

- **Flood category definition:** NBC defines Flood Category 1 as areas of high flood risk where development is heavily restricted. This category draws on the Flood Planning Constraint Category (FPCC) framework, focusing on areas critical for flood conveyance and those subject to high flood hazard
- **Data sources:** Mapping was based on the developed (unmitigated) scenario. Category 1 mapping has been provided for both the 1% AEP and 1% AEP + climate change (CC) events, which were used as the Defined Flood Event (DFE), respectively.

Flood Category 1 subcategories:

- **Category 1a:** Areas of flow conveyance during the Defined Flood Event (DFE), where floodwaters move through the floodplain and development could alter flood behaviour
- **Category 1b:** Areas of high-hazard (H6) during the DFE, where flood conditions are unsafe for people and vehicles and pose structural risks to buildings
- **Category 2a:** Areas of flow conveyance during events larger than the DFE (e.g., 0.2% AEP), where rare floodwaters may affect people and buildings
- **Category 2b:** Areas of high-hazard (H5) during the DFE, where flood conditions are unsafe for people and vehicles and buildings are vulnerable to damage
- **Category 2c:** Areas subject to high-hazard (H6) during the Probable Maximum Flood (PMF), where extreme flood conditions may cause failure of buildings and pose evacuation challenges.

Flood Category 1 areas represent significant constraints to development. Changes to topography or development in these areas can alter flood behaviour and increase risk elsewhere. The mapping supports land use planning by identifying zones where development should be avoided or strictly managed due to their importance in maintaining flood function or the presence of unsafe conditions.

Flood Category 1 mapping is presented in Figures D01 and D02.

Flood Function

Flood function mapping was undertaken using a modified version of the indicator method, consistent with the approach outlined in Howells et al. (2003). This classification supports land use planning and flood risk management by identifying the hydraulic role of land within the floodplain. The classification was based on model outputs from the 1% AEP + Climate Change scenario.

The criteria applied are as follows:

- **Floodway:** Areas where the velocity–depth product ($V \times D$) exceeds $0.3 \text{ m}^2/\text{s}$, indicating locations that convey significant flow and are critical to the functioning of the floodplain.
- **Flood storage:** Areas where $V \times D \leq 0.3 \text{ m}^2/\text{s}$ and depth $> 0.3 \text{ m}$, indicating areas that primarily store floodwaters and assist in attenuating peak flows.
- **Flood fringe:** Remaining areas within the flood extent that fall outside the above categories.

An iterative process was used to refine these thresholds, aiming to achieve meaningful delineation and improved continuity of floodway features across the catchment. The $0.3 \text{ m}^2/\text{s}$ value for the $V \times D$ threshold was applied to better capture the extent and connectivity of primary conveyance paths. This ensures that the

mapped flood function areas reflect the dominant hydraulic processes and are appropriate for informing planning and management responses.

Flood function mapping is presented in Figures E01 to E03.

7.3 Options identification

With the base model updated, an assessment of potential flood management and mitigation options was undertaken. The hydraulic model was modified to represent three key scenarios that reflect the staged evolution of development and associated flood management strategies:

Scenario 1: Developed Conditions – Hydrology updates only

The model was updated to reflect anticipated urban renewal, incorporating reduced imperviousness and widespread application of WSUD principles in line with the draft structure plan (see Chapter 5.2).

Flood mapping has not been provided for this scenario, as afflux results were found to be insignificant. The updated hydrologic assessment indicates minor reductions in peak flood levels and velocities across the precinct, primarily due to the increased pervious area. However, the catchment's flood response continues to be dominated by larger upstream inflows, meaning local changes have only a limited effect on overall flood behaviour.

This scenario demonstrates that while WSUD and reduced imperviousness provide local drainage benefits, their influence on major flood behaviour remains modest in this context.

Scenario 2: Developed Conditions – Proposed buildings' impacts

This scenario includes the introduction of a preliminary structure plan, building footprints, representing the draft-built form layout within the Warringah Mall precinct.

Figures B01 to B06 present the changes in flood level and velocity resulting from the proposed structure plan infrastructure when compared with existing conditions, under the 1% AEP, 1% AEP + climate change (CC), and PMF events. Increases in flood depth of up to approximately 0.5 m occur where proposed buildings intersect existing flow paths or shallow floodplain corridors, which is an unacceptable level of impact and would contravene flood-related policy and controls. These impacts are more pronounced under the more extreme events.

The intersection of proposed buildings with existing flow paths is a key driver of these changes, as shown in the 1% AEP and 1% AEP + CC flood maps. Notably, changes in flood depth at Warringah Mall are smaller in the climate change scenario (Figure B01 compared with Figure B02), as a greater proportion of flow becomes trapped upstream due to flow paths being constricted by the proposed buildings. Overall, the extent of impacts is greater under the climate change condition, as illustrated in Figure B02.

The modelling confirms the importance of avoiding development in flow corridors. Future iterations of development planning should focus on preserving any overland flow paths so as to not risk increasing local flood levels and residual risk.

Figure 28 illustrates the proposed building layout against the 1% AEP flood extent, showing several areas of potential conflict between development and flood conveyance zones. Figures E04 to E06 also present the resulting peak hazard conditions for this scenario. This has been explored further in Section 7.5 as part of the mitigation scenario testing.

Scenario 3: Clearview Place Levee

The Clearview Place Levee was previously identified in the FRMSP as a potential mitigation option for downstream areas, including Warringah Mall. In this assessment, the levee was re-evaluated using updated rainfall intensities based on ARR2019 and refined hydraulic modelling.

The levee consisted of raising the headwall across the entire span of the valley, blocking gaps between buildings and raising it to a level of 23.1 m AHD.

Under current 1% AEP design conditions, the revised rainfall inputs result in reduced flow rates, meaning overland flow from upstream no longer overtops and routes down Clearview Place. As a result, the levee provides little to no flood mitigation benefit in these scenarios. Minor reductions in flood levels may be realised in more extreme flood events; however, the overall benefit remains limited under typical conditions.

However, given the forested, steep headwater catchment, blockage susceptibility is assessed as moderate to high for the 3 m × 3 m box culvert under ARR guidance. To test the levee's performance under blockage conditions, the model was subsequently updated to apply a 50% blockage of the upstream

drainage system as a sensitivity assessment, simulating the potential effects of debris accumulation or vehicular obstruction. Under this scenario, the levee provides a more substantial benefit by containing overland flows and reducing flood levels across the Warringah Mall precinct. The resulting flood level and velocity changes are shown in Figures B07 and B14, illustrating the potential for flood mitigation in the event of system inlet blockage upstream of Clearview Place.

These findings suggest that while the levee has limited benefit under typical operating conditions, it may serve an important contingency function under blockage or failure scenarios.

Summary

The updated results from all three scenarios (summarised in Figure 28) provide insight into how development and targeted interventions influence flood behaviour. The following key findings emerged:

- Hydrologic improvements alone yield only minor flood reductions due to upstream dominance.
- Proposed building footprints must avoid floodways to prevent adverse flood impacts and buildings will not be allowed in Flood Category 1 areas.
- The Clearview Place levee offers resilience benefits under blockage scenarios but limited value under normal conditions.

These outcomes have informed the identification and refinement of mitigation opportunities to be progressed through the multi-criteria analysis process and mitigation option testing, detailed in the following sections.

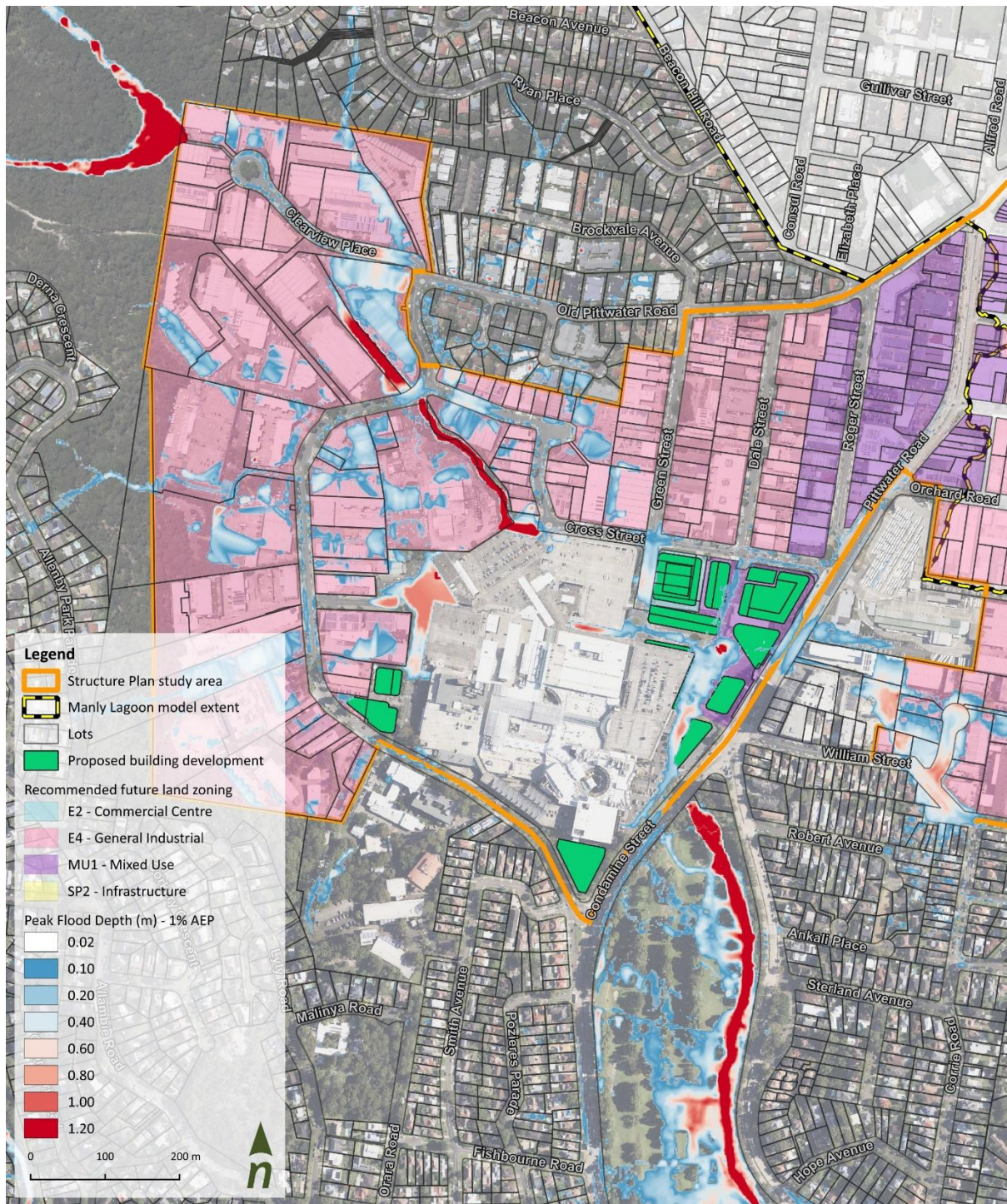


Figure 28. Provisional Warringah Mall structure plan building footprints overlaying the existing 1% AEP flood extent.

7.3.1 Constraints

The study area presents several constraints that limit the feasibility of certain flood mitigation measures. These constraints primarily relate to site conditions, existing infrastructure, and environmental considerations, which restrict opportunities for large-scale structural interventions. The summary in Table 16 below outlines the key constraints identified in this study, along with potential actions to take into consideration. The rest of this chapter provides further detail on each constraint, discussing its implications and how it affects potential flood mitigation strategies.

Table 16. Summary of constraints

Name	Description	Action
Presence of Acid Sulfate Soils	Difficulties with excavation, increasing costs and delaying construction. ASS could limit the feasibility of below-ground on-site detention (OSD).	Limit excavation where practicable
Land fully developed	Limited opportunities for large-scale retention and detention solutions.	None
Existing below-ground infrastructure	The presence of stormwater pipes, electrical utilities, and water mains limits opportunities for below-ground storage.	Limit the below-ground works
Environmental impacts upstream of the Clearview Place levee	Potential detention benefits are identified in FRMS, but environmental considerations remain a constraint.	Benefits are substantially lower than identified in the FRMS, where the levee is not considered viable as a primary measure, with limited effectiveness under typical conditions.
Downstream capacity limits stormwater upgrades	The existing stormwater network, including recently upgraded trunk drainage, has limited remaining capacity. This constrains the feasibility of adding new infrastructure or increasing pipe sizes.	Focus on surface flow management and integrate overland flow paths into design. Avoid reliance on major pipe upgrades.
Limited Developable Land outside of Floodways in extreme events	Under extreme conditions such as Flood Category 1, floodways expand across a significant portion of the study area, leaving limited space for safe development. This constrains future land use planning and increases the challenge of locating new development outside high-hazard areas.	Refine structure plan layouts to avoid Flood Category 1 where possible, prioritise development in lower-hazard fringe areas, and implement planning controls to restrict intensification within mapped floodways. Consider further scenario testing to optimise building placement.

During the site visit, it was noted that significant difficulties were encountered during the construction of the Warringah Mall major culvert augmentation due to the presence of acid sulfate soils, shown in Figure 29. These conditions led to increased costs and construction delays. As a result, below-ground on-site detention (OSD) is to be avoided if possible, due to the challenges associated with excavation and soil management in these areas.

In addition to geotechnical constraints, existing underground infrastructure, including stormwater pipes, electrical utilities, and water mains, further limits the potential for below-ground storage solutions. These constraints must be considered when assessing the feasibility of detention or retention systems within the catchment. Further updates to stormwater infrastructure should also consider this if any updates or additional local stormwater infrastructure are required.

Another significant constraint is that the land within the study area is already fully developed, limiting opportunities for large-scale retention and detention solutions. While localised changes can be implemented, they are unlikely to be on a scale that would meaningfully impact rare or extreme flood events.



Figure 29. *Warringah Acid Sulfate Soils Map*

The previously completed FRMSP identified the potential for detaining water at Clearview Place, upstream of Warringah Mall, to provide downstream flood mitigation benefits. This measure was found in the FRMSP to have a positive benefit-to-cost ratio; however, it is constrained by environmental considerations. While detention at this location may be a viable option, it requires further assessment to balance flood mitigation benefits with ecological and land-use impacts.

The existing stormwater network, including recently upgraded trunk drainage systems, has limited residual capacity to accommodate further augmentation. This constrains opportunities to install additional underground infrastructure or substantially upsize existing assets. As a result, the strategy should focus on preserving and enhancing overland flow paths and integrating surface-based stormwater management measures into the urban design, rather than relying on significant new underground drainage works.

A key constraint identified through the flood assessment is the limited availability of developable land outside mapped floodways under extreme flood events, such as the Probable Maximum Flood (PMF). The extent of floodways under these conditions covers a substantial portion of the study area, reducing the flexibility to accommodate new development without encroaching on high-hazard zones. This presents a challenge for strategic planning, particularly where intensification is proposed. It reinforces the need for a cautious approach to site layout, building placement, and the application of planning controls that avoid floodways and minimise exposure to high-hazard areas. Further refinement of the structure plan and consideration of alternative layouts may be required to ensure development remains consistent with floodplain risk management objectives. See Section 7.5 for mitigation option testing, which investigates this further.

The identified constraints indicate that options for structural flood mitigation measures, such as detention and underground storage, are significantly limited due to site conditions, existing infrastructure, and environmental

considerations. As a result, the focus of flood management strategies will need to shift towards policy-oriented approaches. This includes planning controls, floodproofing measures, and setting appropriate flood planning levels to mitigate flood risk through adaptive urban planning rather than large-scale structural modifications. These policy-driven approaches will be discussed in detail in the following opportunities section.

7.3.2 Opportunities

The constraints outlined in the previous section limit the feasibility of large-scale structural flood mitigation measures. However, they also help narrow down the available flood risk and management opportunities. These opportunities focus on leveraging existing infrastructure, exploring non-traditional flood management solutions that can be integrated with any redevelopment activity, and integrating planning and policy measures to mitigate flood risk while supporting sustainable development.

Urban renewal and increased pervious areas

The transition of parts of the study area to mixed-use residential development is expected to result in an increase in pervious and indirectly connected areas, which could lead to reduced runoff. While this change is unlikely to significantly alter large or extreme flood events, it may provide benefits for more frequent flood events by reducing minor nuisance flooding. This change in land cover can also decrease the duration of flooding, which will help with management options to increase public safety during a flood event.

Stormwater infrastructure and WSUD integration

The Warringah Mall culvert augmentation upgrades have been designed to accommodate future development within the Warringah Mall area (Cardno, 2018). These upgrades have opened infill developable land, allowing for development with reduced flood impact and risk to residents and businesses. Figure 28 presents some of the urban renewal areas (in green). This presents an opportunity to support urban renewal while maintaining flood resilience and creates potential for integrating WSUD options and enhancing integrated stormwater management, which is further discussed in [Chapter 9](#).

Shelter-in-place considerations

The Brookvale area is subject to flash flooding, with critical flood durations of under two hours. Given the short warning times and rapid onset of flooding, the updated Shelter-in-place Guideline for Flash Flooding (DPHI 2025) provides important considerations for managing flood risk in this location.

The Guideline outlines key criteria for determining the suitability of sheltering in place as an emergency response measure. For Brookvale, several factors such as building suitability, access to essential services, and emergency planning and communication need to be considered.

Implementation considerations, such as decision-making frameworks, should be developed in consultation with emergency services to determine when sheltering in place is the safest option. These should be paired with the integration of flood planning levels to ensure that key shelter locations remain above PMF. The Warringah Mall area has a mix of retail, commercial, and public spaces. Businesses and property owners should be informed of shelter-in-place protocols, and emergency kits or designated safe areas should be established where appropriate.

While the Guideline offers a structured approach to managing flash flood risks, shelter-in-place requirements are already addressed through the Development Control Plan (DCP). As such, this measure is not considered further in the options assessment and has not been included in the MCA. Future updates to the DCP or emergency response frameworks should continue to be guided by the Guideline and ensure shelter-in-place procedures remain current and site-appropriate.

Property modification and planning controls

While property modification measures, such as floodproofing for commercial properties, can reduce flood damages in isolated cases, the FRMSP found that these measures are not suitable in the Manly Lagoon catchment. Specifically, voluntary house raising was deemed inappropriate due to the prevalence of slab-on-ground construction, and voluntary purchase was not recommended due to the limited number of eligible properties and the prohibitive cost of acquisition.

As a result, property modification is not considered further in the options assessment. The focus instead is on planning controls, which provide a more strategic and preventative approach to managing flood risk. Setting appropriate flood planning levels (FPL) remains a key consideration in the next stage of the assessment. Council is currently reviewing how climate change is incorporated into FPLs, and as part of this stage of modelling and assessment, we will engage with Council to discuss and implement their updated approach.

Clearview Place Levee

The potential construction of a levee at Clearview Place, originally identified in the FRMSP, has been revisited as part of this assessment. While initial modelling under standard drainage conditions showed minimal benefit under standard conditions, a 50% blockage scenario revealed the levee's role in mitigating downstream flood impacts during failure scenarios.

Figures B07 and B14 demonstrate that, under partial blockage of the upstream trunk drainage system, the levee effectively prevents spill into the Warringah Mall precinct and contributes to notable reductions in flood levels across the downstream area. This suggests the levee may not serve as a primary mitigation measure under typical conditions but could play a key role in enhancing system resilience under failure or obstruction scenarios.

Other flood management options

There is also an opportunity to consider non-traditional options such as elevated buildings or above-ground on-site detention (OSD) solutions, subject to further investigation. Additional options could include designing elevated pedestrian pathways or bridges to maintain accessibility during flood events. These approaches can complement existing flood management strategies while enhancing urban resilience. A summary of potential opportunities is outlined in Table 17 below.

Table 17. Summary of opportunities

Opportunity Name	Description	Potential Actions	Progressed to MCA
Urban renewal and increased pervious areas	Mixed-use residential development is expected to increase pervious areas, potentially reducing runoff in frequent flood events.	Encourage planning controls to maintain pervious areas and promote green infrastructure.	Yes
Stormwater infrastructure and WSUD integration	Stormwater upgrades at Warringah Mall enable low-risk development and provide opportunities for integrating WSUD and enhanced stormwater management.	Integrate WSUD measures into new developments and improve stormwater system resilience.	Yes
Clearview Place Levee and Detention	A levee upstream of Clearview Place has been identified as a viable option in the FRMSP to temporarily store runoff and reduce downstream peak flows, subject to further investigation and environmental assessment.	Undertake further feasibility analysis to assess environmental and planning constraints. Consider floodgates installed at top end of trunk drainage as an alternative to levee.	Yes
Planning Controls	Planning controls support flood resilience by guiding appropriate development, managing exposure to flood risk, and incorporating	Set flood planning levels for Brookvale and embed controls into relevant planning instruments.	Yes

Opportunity Name	Description	Potential Actions	Progressed to MCA
Non-Traditional Flood Management Options	climate change in flood planning levels. These measures are now the primary non-structural focus.		
	Options such as elevated buildings, above-ground OSD, and pedestrian pathways offer additional ways to manage flooding and improve urban resilience, subject to feasibility testing.	Investigate the feasibility and effectiveness of alternative, non-traditional design solutions for inclusion in future flood planning.	No
	Shelter-in-place is already addressed in the Development Control Plan (DCP) and has not been progressed for further options assessment.	Continue to be guided by updated emergency response guidance and maintain consistency with DCP provisions.	No
	Property-level modifications, such as floodproofing, were discussed but house raising and voluntary purchase are not supported by the FRMS and have not been considered in the options assessment.	Not progressed. Planning controls are instead the primary non-structural tool being considered.	No

7.4 Ministerial Direction

To support the assessment of consistency with the Ministerial Direction, key flood planning layers have been developed as part of this study. These include the Flood Planning Area (FPA), Flood Function Classification, and Flood Planning Category 1 mapping. These layers provide the spatial context needed to evaluate the suitability of future development within flood-affected land and to ensure that proposed planning changes appropriately consider flood risk.

The proposed planning outcomes must be demonstrably consistent with these layers to satisfy the requirements of the Ministerial Direction. Future land use and built form must avoid intensification within areas of high flood constraint (e.g., floodways or Flood Category 1 areas), and any development within the FPA must be subject to appropriate controls that consider evacuation, structural resilience, and potential off-site impacts. The accompanying summary in Table 18 addresses each assessment requirement of the Ministerial Direction, informed by the modelling and mapping outputs of this study.

Table 18. Ministerial Direction requirements and response

Assessment Requirement	Summary Response
Is the proposal located in a high-risk catchment?	The catchment is considered high-risk due to the presence of high-hazard and floodway areas, rapid rise characteristics, and the potential for significant overland flow paths through the development area.
Location in relation to flood constraints (floodway, storage, fringe; hazard class; frequency)	Figures E01 and E06 show the floodway, storage, and fringe mapping as well as flood hazard classifications. Several parts of the site are within floodway or high-hazard areas. Future planning layouts should consider this and avoid areas of high-hazard.
Does the proposal increase risk to life elsewhere under PMF conditions?	Modelling of the unmitigated layout shows increased flood levels exceeding 0.2 m, and over 0.5m in some locations during the PMF (Figure B03), which would elevate risk to life. These impacts are primarily associated with buildings placed within key flow paths. It is expected that these risks can be reduced by adjusting building locations to avoid floodways. Within the design flood event, impacts on neighbouring properties are also noted. Revisions to building orientation and layout are recommended to minimise these effects and so as to not cause adverse impacts, with new development in Flood Category 1 to not be permitted as per Council's Draft DCP clause. The Brookvale catchment is subject to short-duration flash flooding, with critical durations under two hours and limited available warning time. Access constraints have been identified, particularly for properties near Cross and Green Streets, which can become isolated during flood events. Given these conditions, shelter-in-place may be a necessary flood response strategy for some developments.
Evacuation constraints/rate of rise/access	Council's guidance outlines specific criteria for shelter-in-place refuges, including minimum floor levels above the PMF, structural integrity, and self-sufficiency requirements. While not all proposed developments will require formal shelter-in-place design, any development unable to achieve safe and timely evacuation must demonstrate compliance with these requirements. This includes ensuring access to the refuge for all occupants, sufficient space, natural lighting, and essential emergency supplies. These considerations should inform planning and building design for development proposed in areas subject to access and evacuation constraints.
Sensitive or hazardous land uses proposed?	No sensitive or hazardous land uses (e.g. caravan parks, childcare centres, aged care, etc.) are currently proposed. Land use controls should limit these types of developments in the future in high-hazard areas.

Adverse flooding impacts on surrounding properties?	Proposed land use changes lead to minor reductions in overall flood levels due to increased pervious areas. However, the current building layout causes unacceptable impacts on neighbouring properties and would be non-compliant. These impacts should be addressed at the DA stage by ensuring development is located outside floodways and/or relocating the buildings, having open foyers at ground level, or through some other mitigation option.
Cut and fill / other works impacting flood behaviour?	Minor regrading is expected with limited fill. Preliminary modelling of proposed building footprints indicates some localised impacts, which can be reduced through elevation or revised siting. No retaining walls or embankments are proposed.
Development resilience to flooding	Floor levels should be set at or above the FPL (1% AEP + CC with freeboard), with planning controls expected to prohibit basements in high-risk areas.
Flood scenarios assessed and alignment with FPL	Events modelled include 20%, 5%, 1%, 1%+CC, 0.5%, 0.2%, 0.1% and PMF. The FPL is based on the 1% AEP with SSP3-7.0 climate change factors, consistent with Council policy.

7.5 Mitigation option modelling

Following the initial evaluation of constraints and scenarios, flood modelling, completion of the MCA, and subsequent discussions with NBC, four mitigation scenarios were identified for further assessment to address potential development impacts. These scenarios are summarised in Table 19 and Figure 30, with further rationale provided in Table 20.

Table 19. Mitigation option scenarios

Mitigation option/s tested	Mitigation Scenario 1 (M01)	Mitigation Scenario 2 (M02)	Mitigation Scenario 3 (M03)	Mitigation Scenario 4 (M04)
Adjusted building footprint - to avoid Category 1 Flood Area (refer to Figure D01)	Yes	Yes	Yes	Yes
Swale - to improve flow conveyance		Yes	Yes	
Upgraded trunk drainage - to increase the capacity of the existing drainage network			Yes	
Flood gates - to retain surface water upstream of Clearview Place				Yes

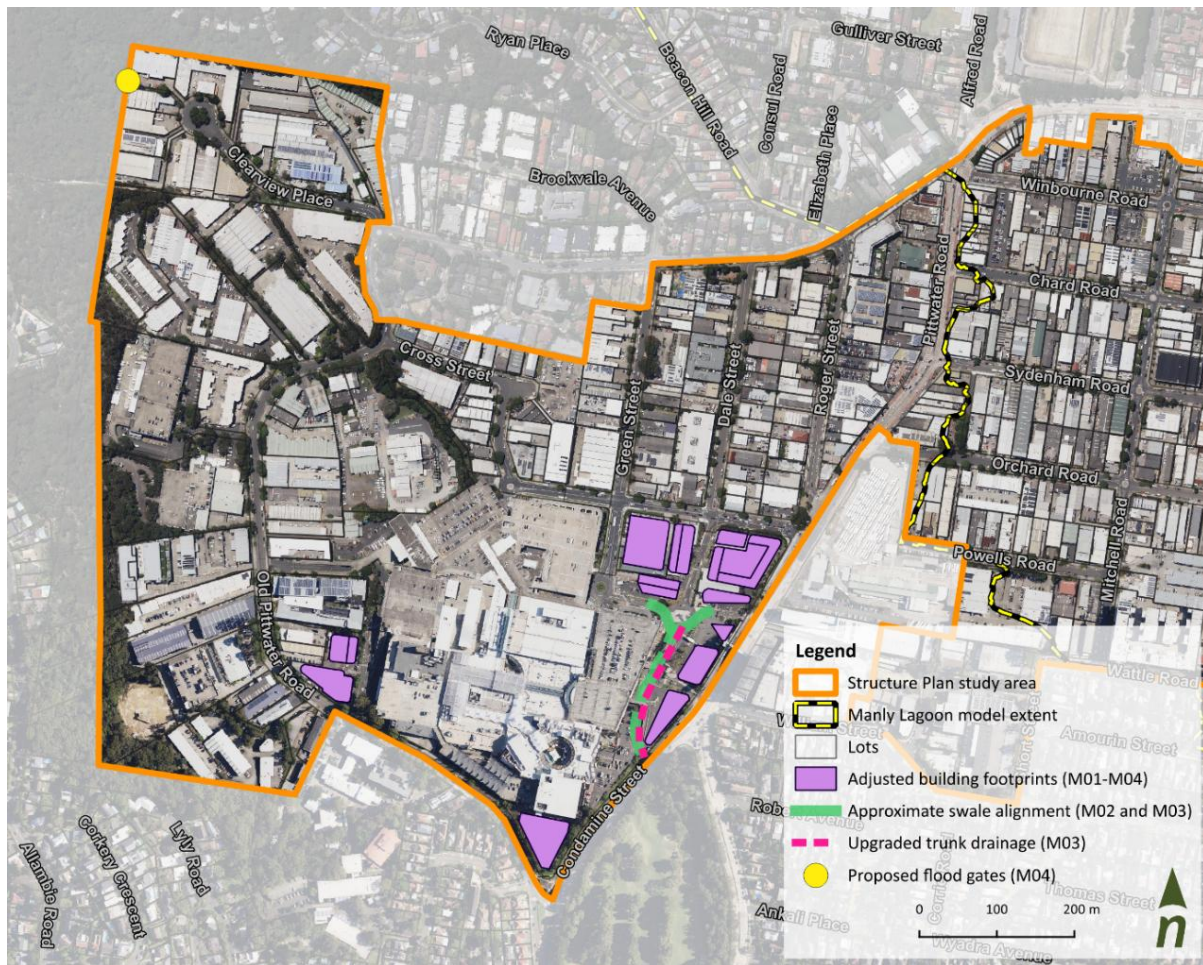


Figure 30. Mitigation scenario testing

Table 20. Mitigation option purposes and hydraulic reasoning

Mitigation	Purpose and Rationale	Hydraulic Reasoning
Adjusted Building Footprints (common to all scenarios)	Avoids placing new development within Flood Category 1 areas, where proposed building footprints intersect key overland flow corridors. This measure directly addresses the primary cause of increased depths in Scenario 2 and aligns with flood-safe land-use planning principles. It also reduces reliance on downstream structural solutions by preventing new obstructions to conveyance.	Existing overland flow paths through Warringah Mall and surrounding precincts are shallow, narrow, and highly sensitive to obstruction. Adding built form in these corridors generates backwater effects and increases upstream depths by up to ~0.5 m under major events. While avoidance of Flood Category 1 areas reduces risk, maintaining overall conveyance capacity requires minimising development across all flood-affected areas
Swale to Improve Overland Flow Conveyance (M02 & M03)	Introduces a dedicated surface conveyance corridor to maintain a continuous, predictable overland flow path through the precinct. The swale complements footprint adjustments by managing flows during surcharge or blockage	The swale consolidates and guides surface flows, limiting uncontrolled sheet flow and reducing localised ponding. By maintaining flow concentration, the swale prevents the spreading of floodwaters and lowers the depths observed under Scenario 2. It provides an

Mitigation	Purpose and Rationale	Hydraulic Reasoning
Trunk Drainage Upgrade (M03)	conditions and reducing dependency on constrained pipe networks.	alternative pathway when piped systems approach capacity or become partially blocked.
	Mitigates limitations of the existing piped network, which operates close to capacity and is constrained by utility congestion, acid sulfate soils, and downstream culvert capacity. Upgrades focus on sections where additional conveyance can provide meaningful relief to the local drainage system.	Enlarged or duplicated pipes reduce overland flow by capturing and conveying more runoff, especially in locations where roads currently act as informal channels. Benefits are most pronounced near upgraded segments but diminish downstream where Condamine Street culverts restrict overall system performance, particularly under climate change.
Flood Gates Upstream of Clearview Place (M04)	The flood gates are proposed to provide peak-flow management and resilience upstream of Clearview Place, reducing the peak volume and velocity of floodwaters reaching downstream areas during flood events.	Flood gates function as temporary detention, slowing the release of upstream flows to reduce downstream depth and velocity peaks. While effective at managing downstream hazards, upstream levels rise during operation and require consideration of ecological impacts, maintenance, and coordination with emergency procedures (e.g., shelter-in-place protocols).

Initial hydraulic modelling for all four scenarios was completed to investigate the level of mitigation impacts of each scenario. The results showed that M03 and M04 had the potential to have some effect on mitigating flood impacts. Therefore, full hydraulic modelling runs were completed for those two scenarios, and the results are provided in Figures F01 to F10 for M03 and G01 to G10 for M04. Each scenario is evaluated across a range of flood events (20% AEP, 5% AEP, 1% AEP, PMF, and 1% AEP+CC), with results shown as differences in flood level and velocity compared to the existing scenario.

Mitigation Scenario 3 (M03)

This scenario increases drainage capacity within the existing network to improve the conveyance of floodwaters through the precinct. The flood maps (F01 to F05: flood level, F06 to F10: flood velocity) show that M03 delivers broad, distributed reductions in flood levels, particularly along key overland flow paths and adjacent to upgraded drainage alignments. The most significant decreases (up to 0.2 m or more) are concentrated in the central and southern portions of the study area.

Flood velocity maps reveal that most of the precinct experiences reduced or unchanged velocities, especially downstream of the trunk upgrades, which lowers hazard and risk to property and people. Some targeted increases in velocity are observed adjacent to the upgraded pipes and within the swale, reflecting more efficient conveyance and concentration of flows, but these are generally contained within engineered corridors.

M03 effectively mitigates potential increases in flood level up to the 1% AEP within acceptable limits, particularly in areas where the upgraded drainage can intercept and redirect overland flows. However, the benefit is limited by the downstream capacity of the existing stormwater network. If downstream pipes or channels are already at or near capacity, further upgrades upstream may have diminishing returns.

The 1% AEP + CC flood results show that the trunk drainage upgrade continues to mitigate flood levels across much of the study area. However, the effectiveness is less compared to the standard 1% AEP event, as the increased rainfall and runoff associated with climate change push the downstream network closer to capacity. Some localised areas, particularly along the alignment of the proposed swale, may experience minor increases in flood level as more runoff accumulates, but these remain within generally acceptable limits.

As noted in the constraints discussed previously, large-scale underground works can be challenged by the presence of underground utilities, acid sulfate soils, and the fully developed nature of the site.

Mitigation Scenario 4 (M04)

This scenario simulates the installation of flood gates, with modelling assuming a 20% blockage of the existing pipe to represent operational conditions. The flood gates act to temporarily retain water upstream of Clearview Place, reducing the volume and velocity of floodwaters reaching downstream areas during peak events. Previous modelling completed for blockage assessment also suggests that holding back flow upstream can have an impact on downstream flooding. Here, the modelling focused on simulating installed flood gates that would operate during storm events.

The flood maps (G01 to G05: flood level, G06 to G10: flood velocity) demonstrate significant improvements in downstream flood behaviour for events up to the 1% AEP, with lower flood velocities and depths in critical areas. The benefits are spatially focused, with the greatest improvements seen in the direct path of overland flow. Upstream of the flood gates, the modelling shows increased flood levels and velocities due to temporary detention and redirected flows. These increases are generally modest and occur within areas already subject to flooding for events up to the 1% AEP. In the 1% AEP + CC scenario, these upstream increases in flood levels when the flood gates are deployed begin to extend into the developments along Clearview Place, causing increases over 0.05 m within the study area. This highlights the need for careful management of upstream impacts as climate change increases flood severity. Nevertheless, the scenario demonstrates that flood gates are highly effective at shielding key precincts from fast-moving floodwaters, provided upstream impacts are managed.

Further investigation is required to develop operational rules for the flood gates under normal conditions to ensure both feasibility and safety in day-to-day operations. Additionally, consideration of the environmental impacts of extended detention in the forested area should be considered for this option.

8 Water quality analysis

The Brookvale study area is transforming a predominantly commercial/industrial land use to a developed mixed-use land use, including commercial, industrial, residential and open space. The focus area is in catchment group 3 of the Northern Beaches water management target catchment groups. Originally, individual lots within each development parcel varied between being greater and less than 500 m². These lots will undergo a site amalgamation into developable parcels. All amalgamated parcels are greater than 500 m² and therefore are required to meet stormwater quality targets.

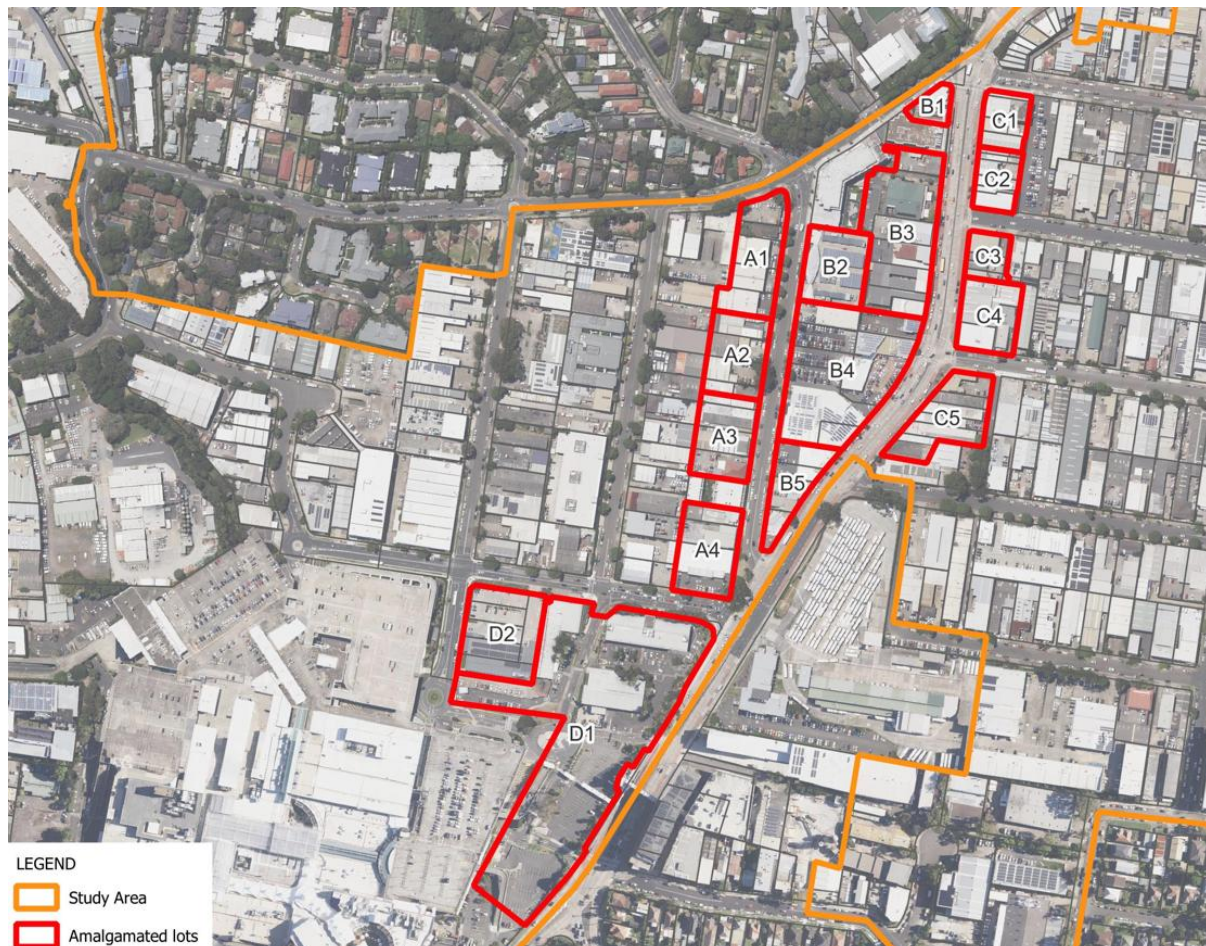


Figure 31. Site amalgamation into development parcels (Ethos Urban, 2025).

Table 21. Amalgamated lot IDs and ownership.

Updated lot name:	A1	A2	A3	A4	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2
Private	✓	✓	✓				✓			✓	✓	✓	✓	✓		
Col Crawford				✓		✓		✓	✓							
NBC (public) + private					✓											
Warringah Mall															✓	
Aldi																✓

Alluvium developed a model for stormwater improvement conceptualisation (MUSIC) at two scales to better understand the Brookvale Structure plan's pollutant load contribution within the broader Manly Lagoon catchment, and what the expected load generation from each amalgamated development parcel would be.

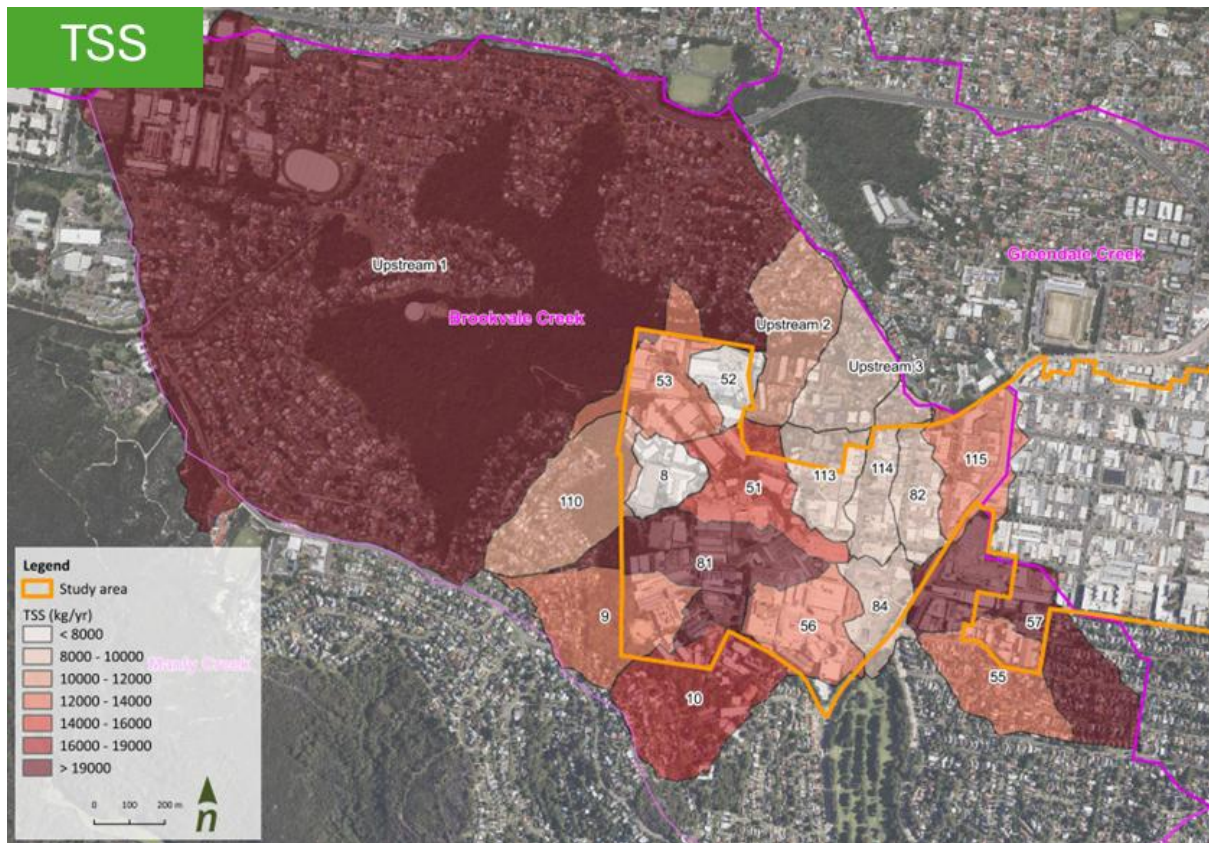


Figure 33. Existing TSS generation (kg/year) from Manly Lagoon sub-catchments across the study area

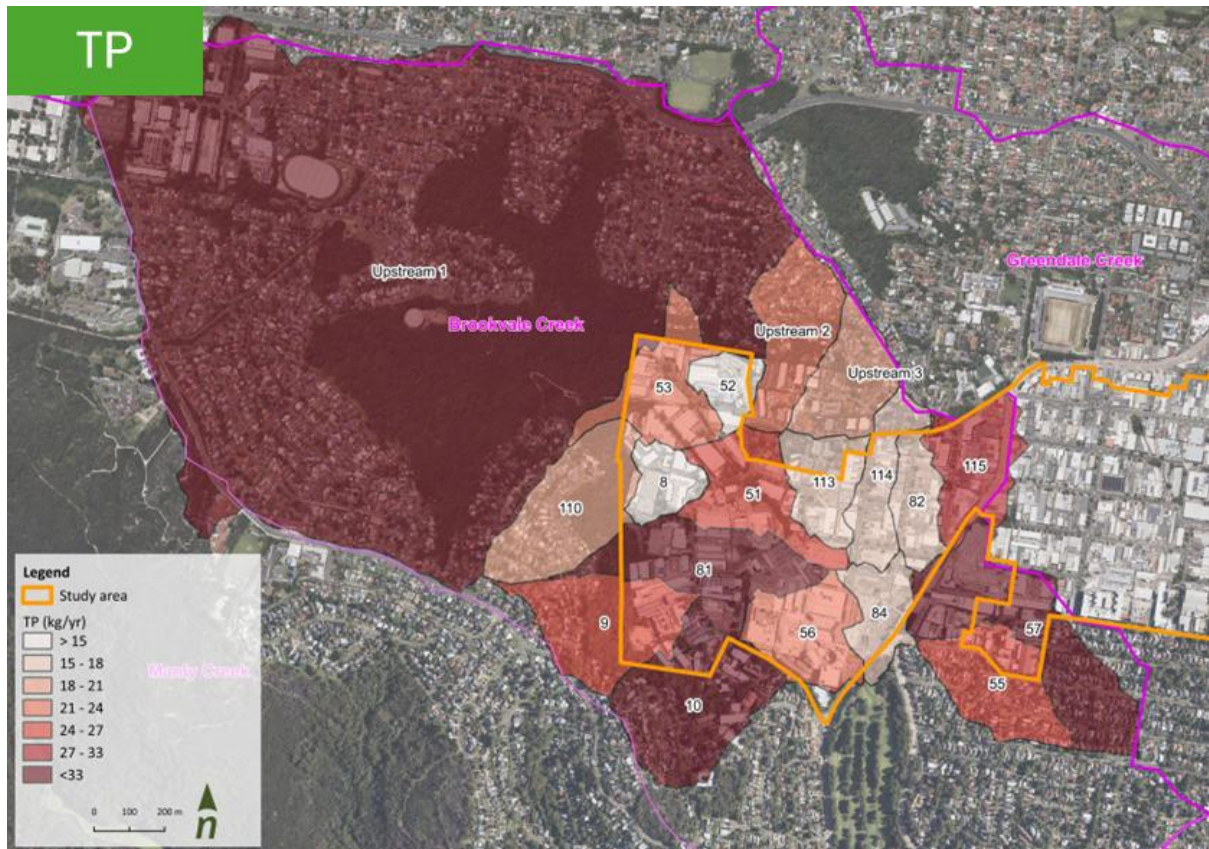


Figure 34. Existing TP generation (kg/year) from Manly Lagoon sub-catchments across the study area

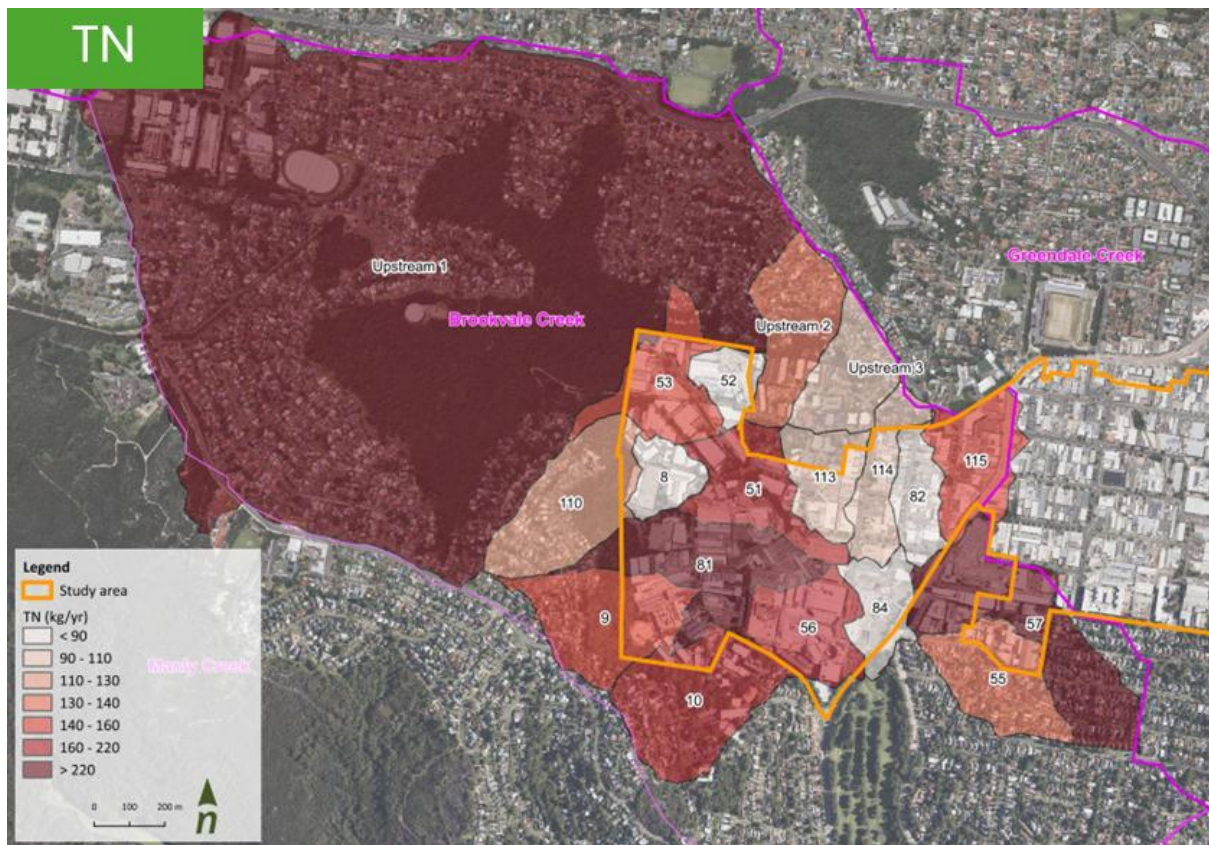


Figure 35. Existing TN generation (kg/year) from Manly Lagoon sub-catchments across the study area

Although the development parcels do not generate most of the total pollutant load into Manly Lagoon, they will contribute some of the highest pollutant concentrations into the receiving environment. Figure 36 through to Figure 38 presents the existing pollutant load concentration contribution (kg/ha/year) for TSS, TP and TN from each sub-catchment that drains through the focus area into Manly Lagoon. These figures highlight the importance of managing stormwater quality across the amalgamated development parcels, which have land uses that are intensive stormwater pollutant contributors.

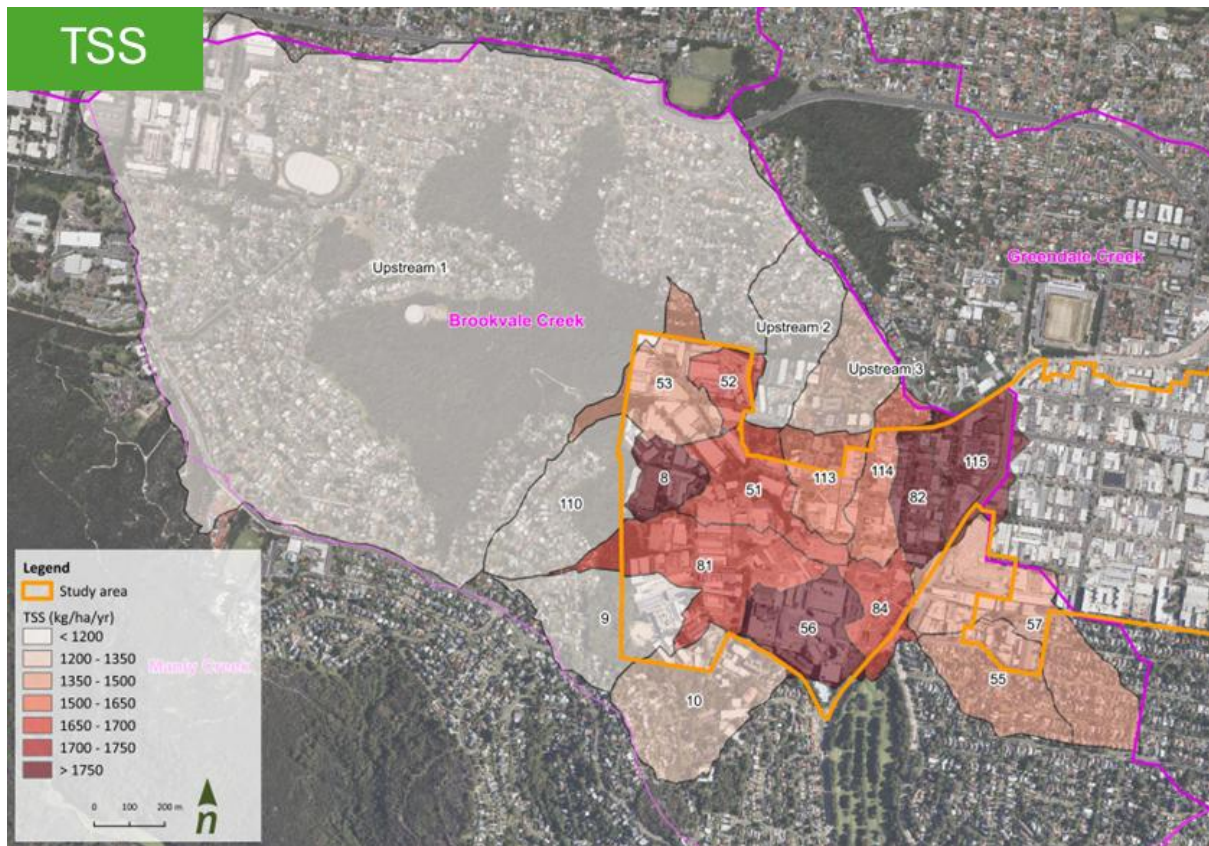


Figure 36. Existing TSS contributions (kg/ha/year) from Manly Lagoon sub-catchments across the study area

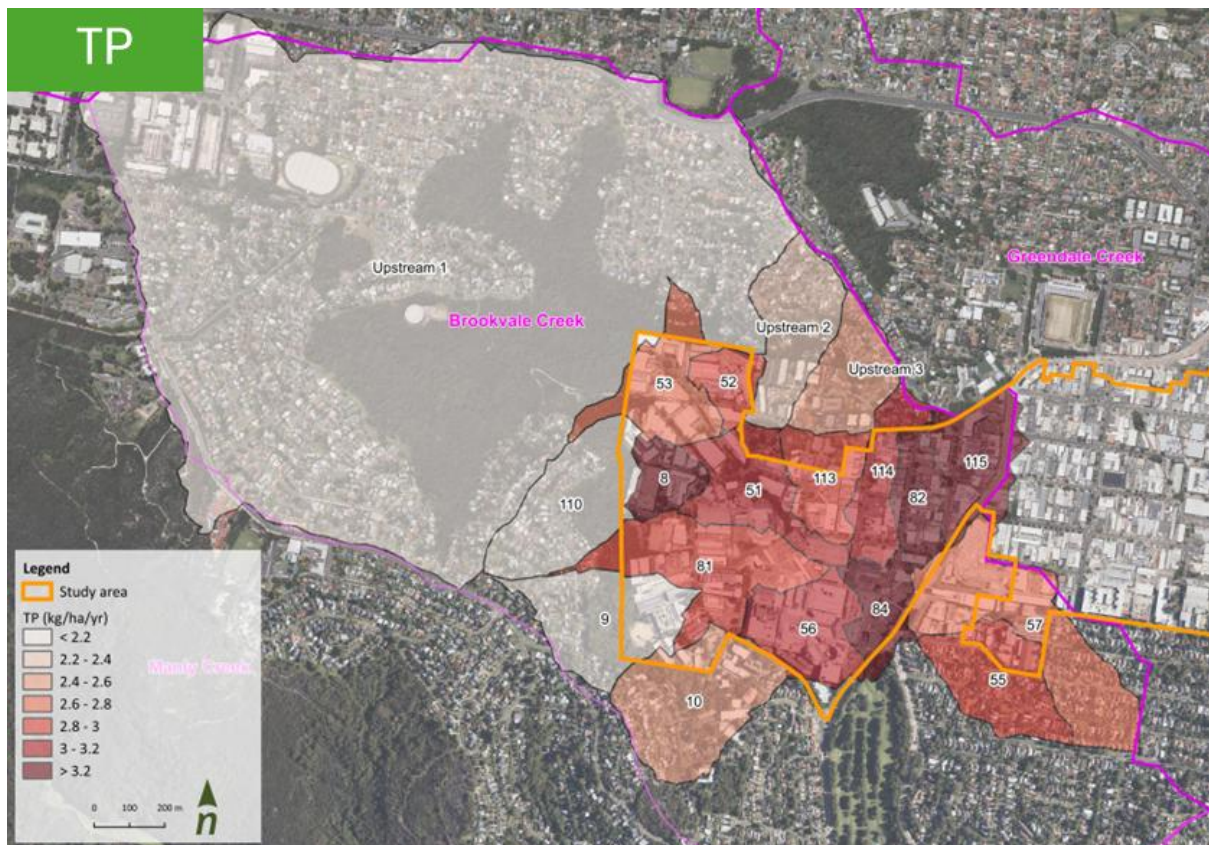


Figure 37. Existing TP contributions (kg/ha/year) from Manly Lagoon sub-catchments across the study area

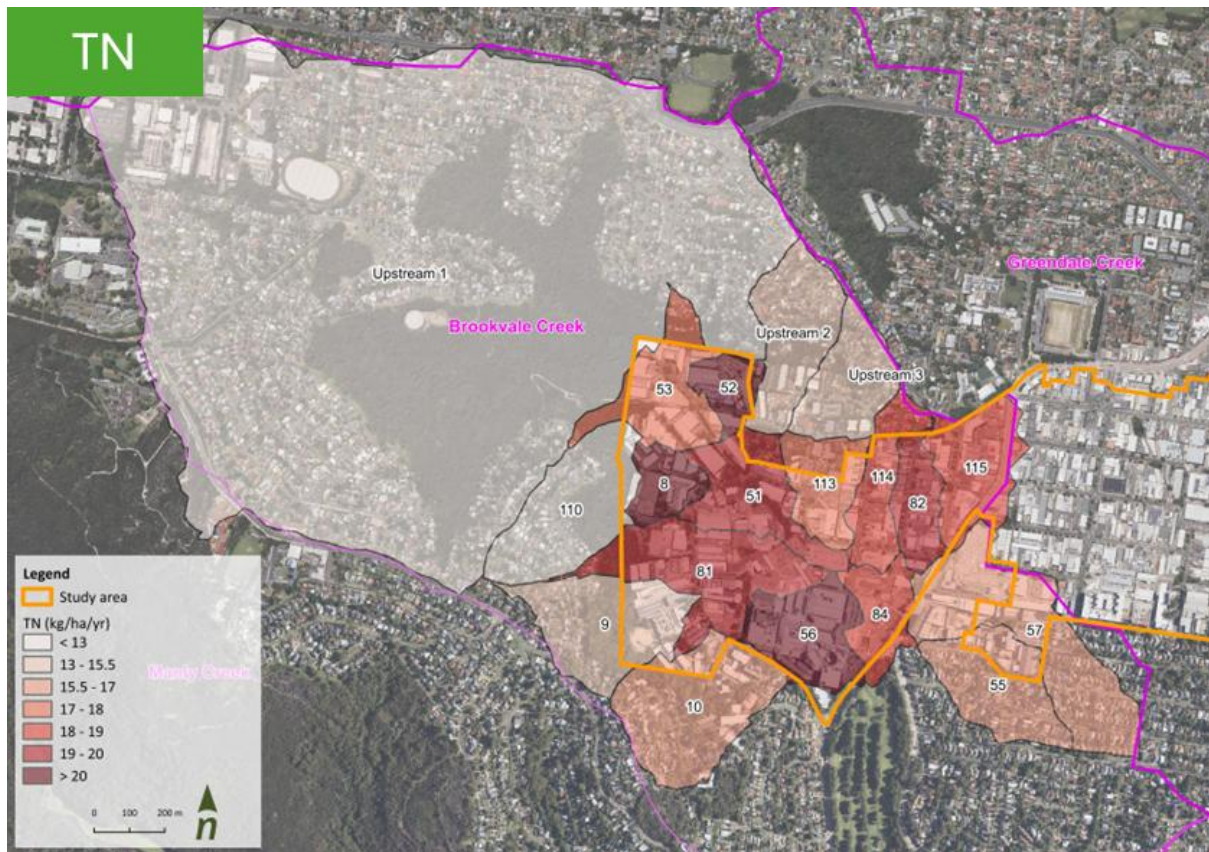


Figure 38. Existing TN contributions (kg/ha/year) from Manly Lagoon sub-catchments across the study area

8.2 Post-developed pollutant load generation

The pollutant load generation for each amalgamated developed parcel was estimated to inform the minimum required load reductions to meet the water quality targets for the extent of the proposed 'rezoned scenario' of the structure plan. The figure below demonstrates the post-developed unit model used to estimate the load contribution for each amalgamated lot. All MUSIC modelling parameters are included in Appendix C.

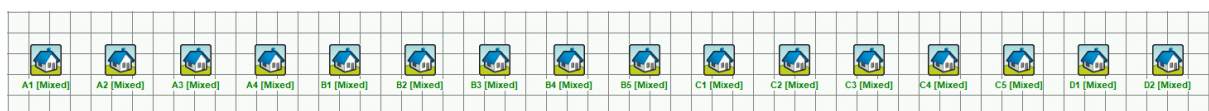


Figure 39. MUSIC model used to understand pollutant load generated for the proposed amalgamated 'rezoned scenario' of the structure plan only

Results from this unit model were mapped to understand the general intensity of pollutant loads generated from each parcel, presented as highest to lowest pollutant loading (Figure 40). Here, the highest stormwater pollutant loads are generally from lot D1 (Warringah Mall), and high loads are also generated from B3, B4 and C5. Amalgamated lots A1 through to A4, D2 and B2 all contribute an average loading, while the remaining lots contribute a lower pollutant load. Lot B1 is the only Council-owned parcel and contributes the lowest pollutant loading into Manly Lagoon (Figure 41). Refer to Table 22 for how much pollution is contributed from each amalgamated lot.

Table 23 outlines the minimum required pollutant load reduction for flow, GP, TSS, TP and TN to meet the water quality targets.

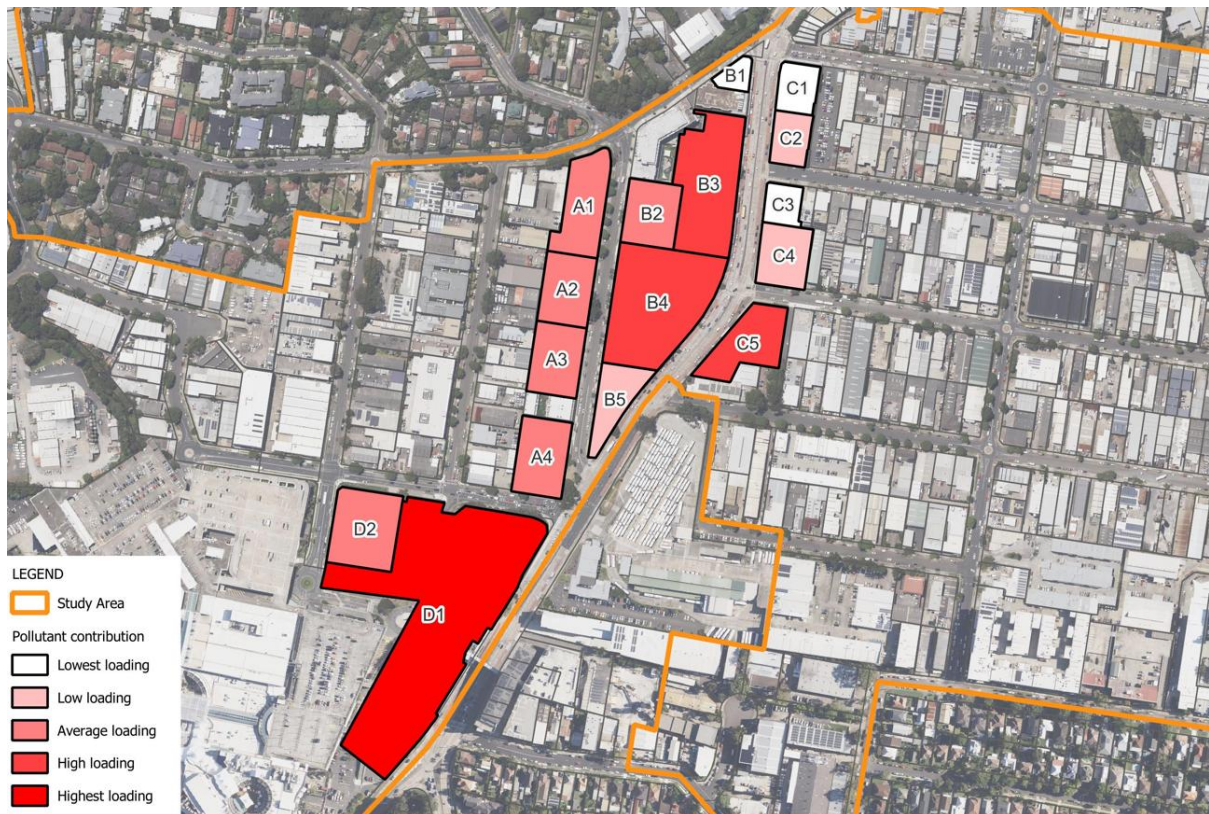


Figure 40. Pollutant load contribution intensity from amalgamated lots.

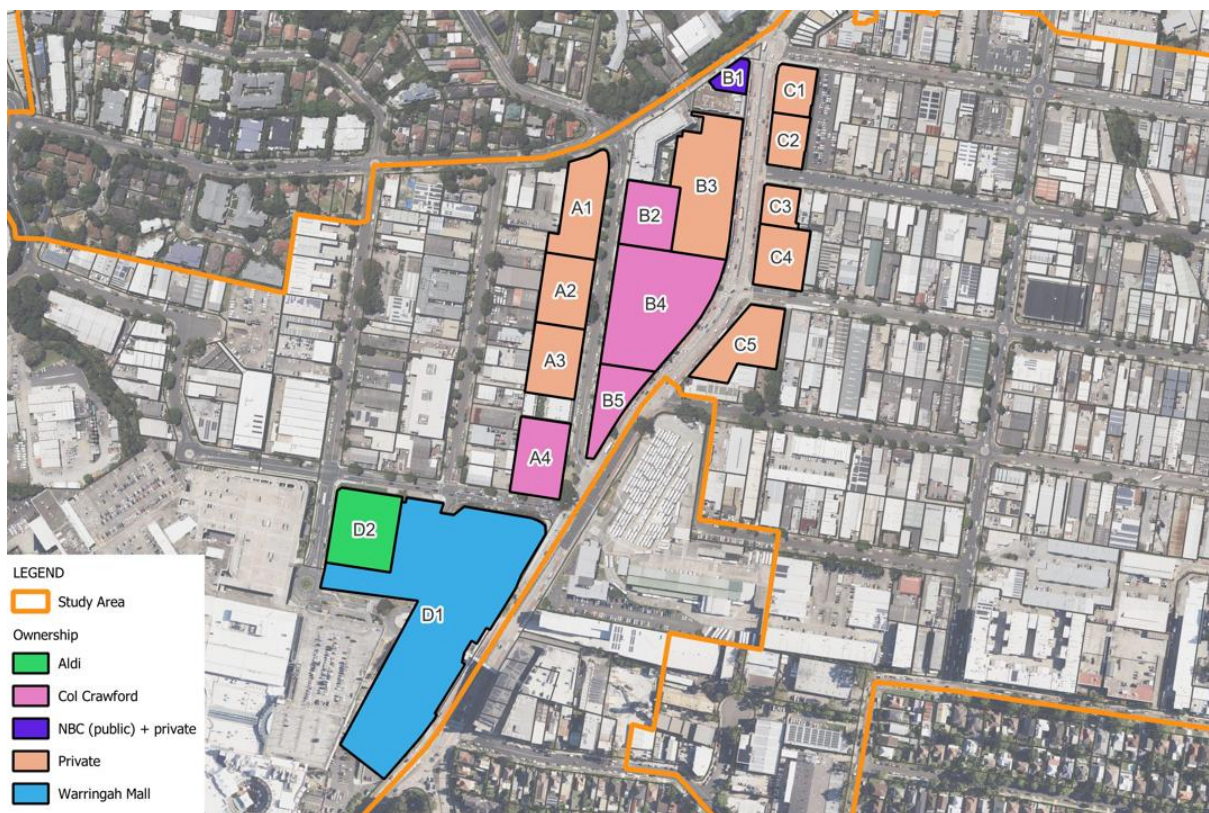


Figure 41. Land ownership of amalgamated parcels.

Table 22. Pollutant load generation of the proposed amalgamated 'rezoned scenario' of the structure plan only

		Area		Pollutant contribution				
Site amalgamation		Development	Open space	Flow	GP	TSS	TP	TN
ID	Ownership	[ha]	[ha]	[ML/year]	[kg/year]	[kg/year]	[kg/year]	[kg/year]
A1	Private	0.43	0	3.92	104	652	1.08	8.26
A2	Private	0.353	0	3.22	85.3	532	0.878	6.7
A3	Private	0.355	0	3.23	85.8	524	0.924	6.77
A4	Col Crawford	0.382	0	3.48	92.3	564	0.994	7.28
B1	NBC (public) + private	0.086	0	0.783	20.8	134	0.218	1.61
B2	Col Crawford	0.339	0	3.09	81.9	520	0.876	6.5
B3	Private	0.798	0	7.27	193	1240	2.04	15.4
B4	Col Crawford	1.064	0.2	10.5	275	1690	2.86	21.5
B5	Col Crawford	0.276	0	2.51	66.7	413	0.688	5.3
C1	Private	0.143	0	1.3	34.5	216	0.363	2.71
C2	Private	0.236	0	2.15	57	355	0.604	4.49
C3	Private	0.113	0	1.03	27.3	169	0.286	2.17
C4	Private	0.307	0	2.8	74.2	465	0.773	5.91
C5	Private	0.678	0	6.18	164	1020	1.71	12.8
D1	Warringah Mall	2.465	0.5	24.5	637	3950	6.77	50.7
D2	Aldi	0.493	0	4.49	119	783	1.26	9.28
Total		8.518 ha	0.7 ha	80.453 ML/year	2,117.8 kg/year	13,227 kg/year	22.324 kg/year	167.38 kg/year

All amalgamated lots are greater than 500 m² and are therefore required to meet the water quality targets outlined in Table 5. Table 23 outlines the minimum required pollutant and stormwater flow reduction volumes for each amalgamated lot to meet the targets.

Table 23. Minimum required water quality and flow reduction volume to meet water quality targets.

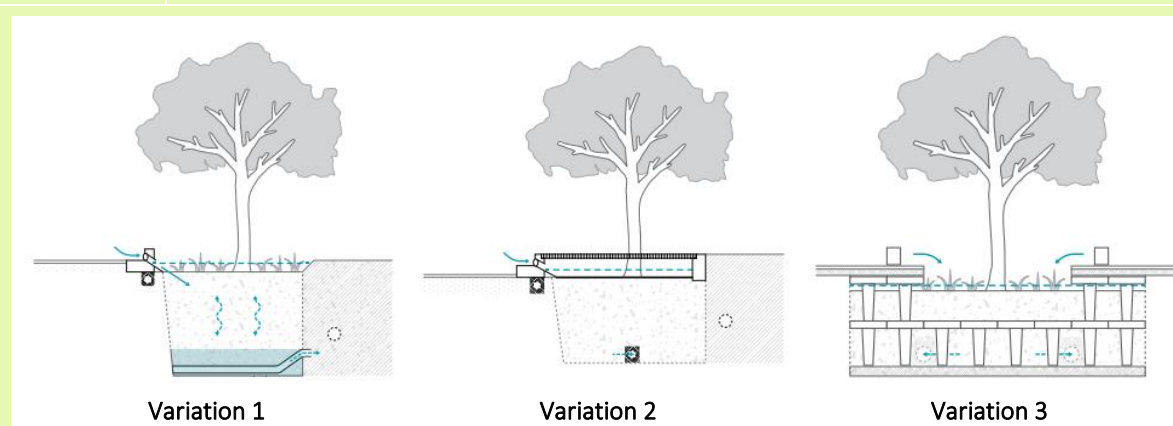
Site amalgamation	Flow	GP	TSS	TP	TN
Load reduction target:	20%	90%	85%	65%	45%
ID	[ML/year]	[kg/year]	[kg/year]	[kg/year]	[kg/year]
A1	0.784	93.6	554.2	0.702	3.717
A2	0.644	76.77	452.2	0.5707	3.015
A3	0.646	77.22	445.4	0.6006	3.0465
A4	0.696	83.07	479.4	0.6461	3.276
B1	0.1566	18.72	113.9	0.1417	0.7245
B2	0.618	73.71	442	0.5694	2.925
B3	1.454	173.7	1054	1.326	6.93
B4	2.1	247.5	1436.5	1.859	9.675
B5	0.502	60.03	351.05	0.4472	2.385
C1	0.26	31.05	183.6	0.23595	1.2195
C2	0.43	51.3	301.75	0.3926	2.0205
C3	0.206	24.57	143.65	0.1859	0.9765
C4	0.56	66.78	395.25	0.50245	2.6595
C5	1.236	147.6	867	1.1115	5.76
D1	4.9	573.3	3357.5	4.4005	22.815
D2	0.898	107.1	665.55	0.819	4.176
Total	16.091 ML/year	1,906.02 kg/year	11,242.95 kg/year	14.511 kg/year	75.321 kg/year

8.3 WSUD options toolkit

A WSUD options toolkit was developed to include a range of solutions deemed appropriate for the structure plan. The toolkit builds on our understanding of what asset types are likely to be accepted by the Northern Beaches Council across Brookvale. Each solution aims to utilise vegetation, filter media, extended detention depth, and drainage to slow, soak, store and treat frequent stormwater flows. The options presented in the toolkit are adaptable and consistent with the vision of the Warringah Mall Concept Design and the Draft Urban Design and Public Domain strategy, i.e., distributed assets that are seamlessly integrated into development, streetscape and open space. Each typical asset was modelled in MUSIC to understand its optimal treatment to catchment area ratio (TCAR), and the associated reduction in pollutant load per unit treatment area. Table 24 through to Table 28 describes each treatment option proposed for the Structure plan, including assumptions and effectiveness for pollutant load removal. The pollutant load reduction for each asset (presented below), along with the minimum required pollutant load to be removed (Table 23), allows us to estimate the required treatment area to meet the water quality targets (Figure 29).

Table 24. WSUD options toolkit: Passively irrigated street tree

Asset type	System 1: Passively irrigated street tree
Base model	Passively irrigated street trees are typically planted on verges or kerb blisters and are designed to redirect urban stormwater runoff from roads to infiltrate into an appropriately sized volume of soil to support a healthy tree. Here, we assume a design for a medium street tree with an 8 m canopy and 20 m ³ soil volume.
Variation 1	Medium passively irrigated street tree with a wicking zone. The wicking zone stores stormwater and allows capillary rise to sustain soil moisture within the system. The wicking zone depth is set by a raised overflow relief pipe connecting to the stormwater network.
Variation 2	A medium passively irrigated street tree without a wicking zone. Underdrainage allows excess water that infiltrates through the tree pit soil volume to be collected and discharged at the base of the tree pit.
Variation 3	Medium passively irrigated street tree with structural cells. Structural cells provide support to the paved system, allowing the soil to remain un-compacted and create room for a larger filter area below the pavement surface. Slotted drainage allows excess water to be infiltrated and discharged at the base of the tree pit.



Credit: DISER (2020)

	Treatment to Catchment Ratio	Flow Reduction (kL/year/ m ²)	GP Reduction (kg/year/ m ²)	TSS Reduction (kg /yr/ m ²)	TP Reduction (kg /yr/ m ²)	TN Reduction (kg /yr/ m ²)
Variation 1	10.7%	2.36	0.23	1.39	0.002	0.01
Variation 2	1.7%	2.53	1.45	7.97	0.01	0.06
Variation 3	1.5%	2.50	1.63	8.56	0.01	0.07

Co-benefits

In comparison to regular urban street trees, passively irrigated street trees, which provide adequate soil volume and soil moisture, produce the following additional benefits:

- increased lifespan, stronger growth rate and canopy, reduced costs from pavement uplift and root intrusion, enhanced ecosystem services through air purification and passive cooling via shading and evapotranspiration, and lowered surface and air temperatures.

Important design considerations include:

- limited soil volume depth due to underground utilities susceptible to damage from roots or water, reduced available space from above- and below-ground infrastructure such as powerlines, awnings, and seating, and the need to interface with road surfaces to enable stormwater infiltration.

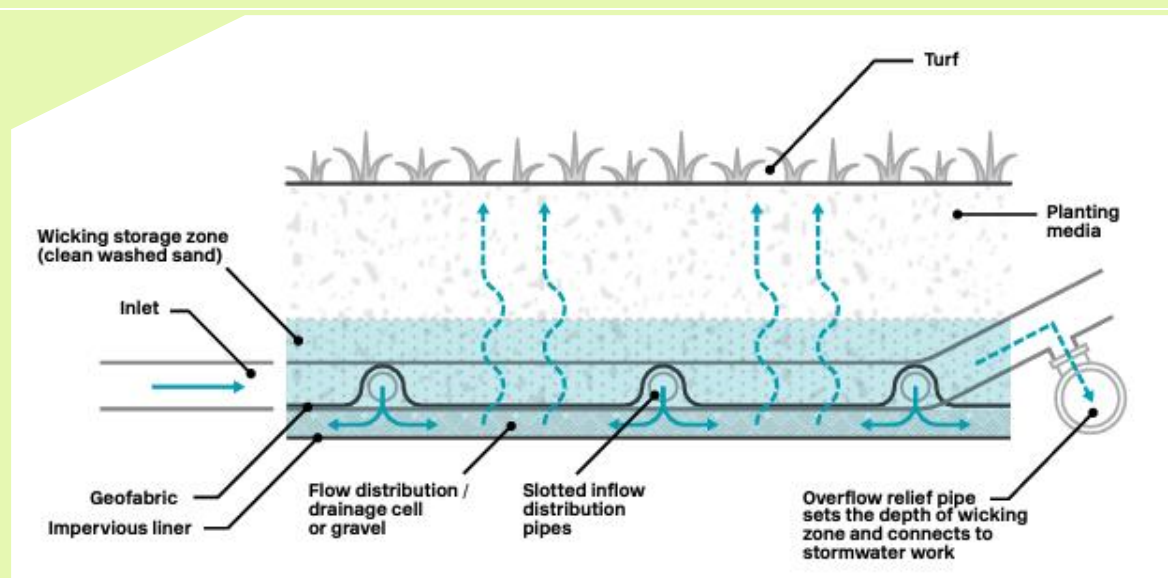
Table 25. WSUD options toolkit: Rain Garden

Asset type		System 2: Rain garden				
Base model	Rain gardens are a type of bioretention system that captures stormwater to infiltrate through a filter media and discharge through underdrainage back into the stormwater network. The surface of the rain garden traps litter, leaves and sediment while the soil filter media, plants and root system filter and break down nutrients, heavy metals and hydrocarbons.					
Variation 1	Raingarden that acts as a divider between carparks. Assuming a standard car parking space of 2.4 m x 5.4 m, this size rain garden is assumed to have a 1.5 m width and 2.4 m length.					
Variation 2	Raingarden that lies on the kerb. It is assumed to have a 1.5 m width and 5.4 m length, to match a parallel parking space length.					
Variation 3	Raingarden is the size of a parking space, assumed to be 2.4 m x 5.4 m in size.					
  						
Variation 1		Variation 2			Variation 3	
Credit: (from left to right) Sloan, A. (2019), Melbourne Water (2022), Cooks River Alliance (2024)						
	Treatment to Catchment Ratio	Flow Reduction (kL/year/ m ²)	GP Reduction (kg/year/ m ²)	TSS Reduction (kg /yr/ m ²)	TP Reduction (kg /yr/ m ²)	TN Reduction (kg /yr/ m ²)
Variation 1	1.4%	1.75	1.39	7.48	0.009	0.05
Variation 2	1.4%	1.75	1.36	7.25	0.01	0.05
Variation 3	1.4%	1.77	1.39	7.49	0.01	0.05
Co-benefits						
In addition to stormwater treatment, rain gardens provide the following benefits:						
self-watering and easy to maintain, conserving water when planted with native drought-tolerant species, reducing stormwater runoff volume and velocity, enhancing neighbourhood aesthetics, providing habitat and supporting healthy waterways, and eliminating the need for fertilisers or herbicides due to nutrient-rich stormwater.						
Important design considerations include:						
maintenance considerations, including removing trash and sediment that accumulate on the surface during rain events and allowing excess runoff from heavy storms to bypass into the drainage system, as rain gardens are designed to treat lower flows.						

Table 26. WSUD options toolkit: Wicking lawn

Asset type System 3: Wicking lawn

A wicking lawn is a lined vegetated system such as a turf open space, sports field or vegetated garden bed, which has a subsurface reservoir. The stormwater flows into the soil profile underneath the lawn, where capillary rise driven by evapotranspiration draws the water reserves from the wicking zone to the active root zone.



Credit: DISER (2020)

	Treatment to Catchment Ratio	Irrigation demand met	Flow Reduction (kL/year/m ²)	GP Reduction (kg/year/m ²)	TSS Reduction (kg/yr/m ²)	TP Reduction (kg/yr/m ²)	TN Reduction (kg/yr/m ²)
Effective-ness	100%	84.5 %	0.92	0.03	0.2	0.0003	0.002

Co-benefits

In addition to reduced potable water for irrigation demand, wicking lawns provide the following benefits:

- providing a passive cooling through evapotranspiration, scalability for use from large sports fields to podium landscapes, eliminating the need for scheduled irrigation, allowing turf to access water while the space is in use, preventing contact between people and stormwater through physical separation, promoting deep root growth for more resilient turf with faster recovery, maintaining even turf colour for improved visual amenity, utilising stormwater nutrients to reduce fertiliser needs, avoiding water loss from aerial spray evaporation, and preventing over-irrigation by supplying only the water the turf requires.

Important design considerations include:

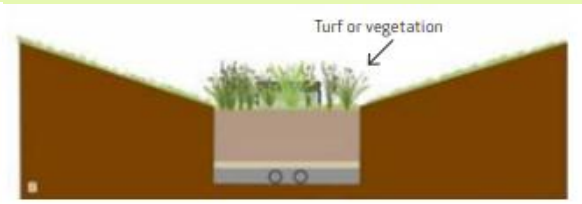
- incorporating overflow relief and drainage to enhance space usability after heavy rainfall and improve access for mowing and maintenance.

Table 27. WSUD options toolkit: Swale

Asset type	System 4: Swale					
Base model	A swale is a shallow, graded vegetated channel, primarily designed to convey stormwater. Typically located in median strips and carparks. Note that the treatment to catchment ratio represents the length of the system to the area.					
Variation 1	A typical vegetated swale with an impervious area below.					
Variation 2	A bioretention swale. A bioretention system is located at the base of the swale, consisting of a filter media flowing downwards to a perforated pipe. This allows the swale to convey stormwater while filtering pollutants from the runoff.					



Variation 1



Variation 2

Credit: Water by Design (2020)

	Treatment to Catchment Ratio	Flow Reduction (kL/year/ m ²)	GP Reduction (kg/year/ m ²)	TSS Reduction (kg /yr/ m2)	TP Reduction (kg /yr/ m2)	TN Reduction (kg /yr/ m2)
Variation 1	2.9%	0.00	0.85	4.59	0.0044	0.014
Variation 2	1.9%	2.20	1.3	7.01	0.01	0.05

Co-benefits

In addition to conveying stormwater runoff, swales provide the following benefits:

- contribute to the aesthetic streetscape, remove coarse and medium sediments, provide low levels of extended detention, and capture and attenuate frequent flow events, while bioretention swales additionally remove fine sediments and dissolved contaminants.

Important design considerations include:

- the need for a sloped surface and, typically, the addition of bunds to increase extended detention depth, particularly for bioretention swales.

Table 28. WSUD options toolkit: Stormwater harvesting

Asset type

System 5: Stormwater harvesting

Submerged stormwater detention tank to reduce irrigation demand of open space features in the Warringah Mall structure plan.



Credit: Ausdrain (2023)

	Treatment to Catchment Ratio	Irrigation demand met	Flow Reduction (kL/year/ kL tank)	GP Reduction (kg/year/ kL tank)	TSS Reduction (kg /yr/ kL tank)	TP Reduction (kg /yr/ kL tank)	TN Reduction (kg /yr/ kL tank)
Effective-ness	100%	81.7 % ¹	13.33	34.5	10	0.01	0.033

Co-benefits

Along with the reduction in irrigation demand, submerged stormwater detention tanks produce the following benefits:

- harvesting reduces stormwater volumes, flows, and runoff frequencies while providing increased certainty of supply.

Important design considerations include:

- level of stormwater treatment for the intended end use, the volume of non-potable water needed to meet irrigation demand, the presence of underground utilities, and the space needed for the submerged stormwater detention tank.

¹ Assuming an irrigation demand (reuse) of 960 kL per year, monthly distributed, from a 60 kL tank.

8.4 Constraints and land ownership

The WSUD options toolkit includes several system typologies, some with different variations. Each variation has different levels of design, from moderately low-intervention solutions like variation 1 of the passively irrigated street trees to highly engineered solutions like variation 3 of the passively irrigated street trees. As such, it is critical to understand how constrained the site is due to existing services, and what land is council-owned (Figure 42) and operated around the Structure plan. Figure 43 presents the existing utilities (approximated and mapped from Dial Before You Dig [DBYD]) and where there is council-owned land (mapped from the Northern Beaches Council Land Register portal) within the area where development may occur.

In assessing these options, it is important to consider constraints specific to stormwater management and water quality (WQ) objectives. For example, shallow-buried services or rock outcrops may limit opportunities for infiltration-based systems, while high groundwater levels or poor soil permeability may restrict subsurface treatment systems. Solutions requiring significant underground storage or conveyance elements, such as biofiltration and structurally passively irrigated street trees, or large stormwater harvesting tanks, may require excavation that could be constrained by existing utilities, geotechnical conditions, or land tenure. These constraints should be identified early to inform feasible system selection and avoid costly redesign.



Figure 42. Council-owned land within the study area

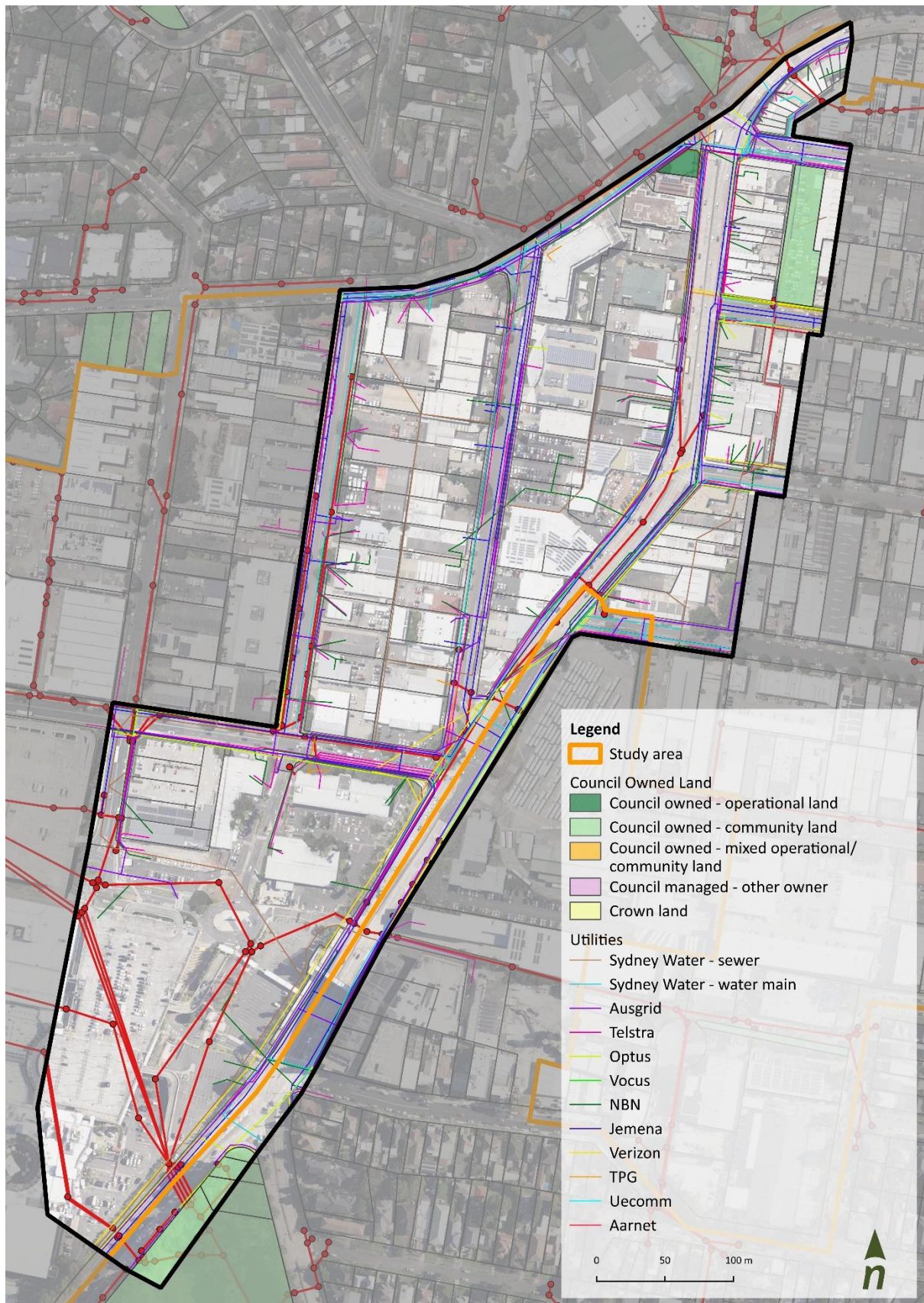


Figure 43. Map showing existing infrastructure/services (mapped from DBYD) and council-owned land

8.5 Water quality WMS

Each amalgamated sub-catchment low point was allocated to Pittwater Road, Roger Street, Cross Street, or Warringah Mall to define the contributing sub-catchment. The allocation of each amalgamated lot to these receiving streets is summarised in Table 29.

Based on the required pollutant load reductions and the assumed treatment effectiveness of each WSUD system, the minimum treatment area required for each individual asset type was calculated. These minimum areas, which assume that only a single treatment asset is delivered in isolation for each street, are presented in Table 30. Except for variation 1 of the passively irrigated street tree system (TP1), most systems produced comparable minimum treatment areas. The reduced performance of TP1 is attributed to the inclusion of a saturated zone, which appears to significantly limit treatment effectiveness. Table 30 also summarises the treatment to catchment area ratio (TCAR), which is the percentage of the catchment area that is required to be treated to meet the stormwater quality targets.

Wicking lawns and vegetated swales were assessed but deemed unsuitable as standalone solutions for meeting the adopted water quality targets. Consequently, these systems were excluded from the minimum treatment area assessment. It is noted that wicking lawns were sized assuming 100% of the available open space is turfed, while swales were sized based on an indicative total length rather than surface area. Although these assets do not achieve water quality objectives on their own, they are recognised for providing additional benefits, including reduced irrigation demand (wicking lawns) and flow attenuation (swales), and should form part of a broader treatment train where there is an opportunity.

Stormwater harvesting (System 5) primarily contributes to a reduction in potable irrigation demand and provides limited benefit in terms of pollutant load reduction. For this reason, stormwater harvesting has not been included in the assessment of minimum treatment areas required to meet water quality targets.

Using the assumptions outlined in the WSUD asset catalogue, the total number of typical WSUD assets required across the study area was estimated. A summary of the number of an individual type of asset that is required to meet the stormwater quality targets is presented in Table 31.

WSUD asset location

The location of WSUD assets across the Brookvale Structure Plan must be coordinated with urban design, landscape design, and any proposed upgrades to the stormwater drainage network along Pittwater Road, Roger Street, Cross Street and Warringah Mall. A preliminary “Before You Dig” assessment indicates that the road corridors, particularly beneath existing footpaths, are highly constrained due to the presence of underground and above-ground services.

To identify potential opportunities for WSUD integration, Ethos Urban’s Masterplan from the Draft Urban Design and Public Domain Strategy was adapted to illustrate indicative WSUD locations, as shown in Figure 44 and summarised in Table 33. The layouts consider a range of WSUD asset types, including raingarden variation 2 (RG2), raingarden variation 3 (RG3), passively irrigated street tree variation 2 (TP2), passively irrigated street tree variation 3 (TP3), stormwater harvesting (SWH), and gross pollutant traps (GPT). The identification of indicative WSUD locations is based on the following key assumptions:

- Most street trees proposed in the Ethos Urban Masterplan are assumed to be passively irrigated
- Larger treatment devices with increased surface area (e.g. TP3, RG3, and RG2) are preferentially located immediately upstream of existing stormwater gully pits
- Due to the inclusion of a setback from the road to the property boundary, it is assumed that each system can be located without conflicting with existing utilities
- Some required treatment assets may extend beyond Pittwater Road, Roger Street, Cross Street, and Warringah Mall to achieve the necessary treatment performance.

The next phase of design should include detailed due diligence, detailed costing and service investigations to confirm feasibility and resolve potential conflicts. As part of development approval, proponents will also be required to submit a detailed MUSIC model demonstrating that the proposed treatment train achieves the adopted water quality targets.

Table 29. Street location of amalgamated lots

Updated lot name:	A1	A2	A3	A4	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2
Pittwater Road					✓		✓	✓	✓	✓	✓	✓	✓	✓		
Roger Street	✓	✓	✓	✓		✓		✓	✓							
Cross Street				✓												
Warringah Mall															✓	✓

Table 30. Estimated required treatment areas for an individual type of asset across Pittwater Road, Roger Street, Cross Street, and Warringah Mall to ensure water quality targets are met for the proposed 'rezoned scenario' of the structure plan. This assumes that only one variation of the asset is recommended across the development

Asset	System 1: Passively irrigated street tree			System 2: Rain garden			System 3: Wicking lawn	System 4: Swale	
	Variation 1: Medium street tree <u>with</u> wicking zone	Variation 2: Medium street tree <u>without</u> wicking zone	Variation 3: Medium street tree <u>with</u> structural modules and <u>without</u> wicking zone	Variation 1: Car park central median rain garden	Variation 2: Rain garden behind the kerb	Variation 3: Rain garden to replace car park	Variation 1: Wicking lawn	Variation 1: Vegetated Swale	Variation 2: Bioretention Swale
TCAR Site	10.70% [m ²]	1.70% [m ²]	1.50% [m ²]	1.40% [m ²]	1.40% [m ²]	1.40% [m ²]	100.00% [m ²]	2.90% [m]	1.90% [m]
Pittwater Road	3350	532	470	438	438	438	NA	NA	595
Roger Street	2609	414	366	341	341	341	NA	NA	463
Cross Street	204	32	29	27	27	27	NA	NA	36
Warringah Mall	3700	588	519	484	484	484	NA	NA	657
Total	9863 m ²	1567 m ²	1383 m ²	1291 m ²	1291 m ²	1291 m ²	NA	NA	1751 m

Table 31. Number of an individual typical type of asset required across Pittwater Road, Roger Street, Cross Street, and Warringah Mall to ensure water quality targets are met for the proposed 'rezoned scenario' of the structure plan

Asset	System 1: Passively irrigated street tree			System 2: Rain garden			System 3: Wicking lawn	System 4: Swale	
	Variation 1: Medium street tree <u>with</u> wicking zone	Variation 2: Medium street tree <u>without</u> wicking zone	Variation 3: Medium street tree <u>with</u> structural modules and <u>without</u> wicking zone	Variation 1: Car park central median rain garden	Variation 2: Rain garden behind the kerb	Variation 3: Rain garden to replace car park	Variation 1: Wicking lawn	Variation 1: Vegetated Swale	Variation 2: Bioretention Swale
TCAR Site	10.70% [m²]	1.70% [m²]	1.50% [m²]	1.40% [m²]	1.40% [m²]	1.40% [m²]	100.00% [m²]	2.90% [m]	1.90% [m]
Pittwater Road	149	355	23	137	68	42	NA	NA	59
Roger Street	116	276	18	107	53	33	NA	NA	46
Cross Street	9	22	1	8	4	3	NA	NA	4
Warringah Mall	164	392	26	151	76	47	NA	NA	66
Total	438	1045	68	403	201	125	NA	NA	175

Table 32. Percentage of the total treatment required

Receiving location	Percentage of total treatment area required by location
Pittwater Road	34%
Roger Street	26%
Cross Street	2%
Warringah Mall	38%

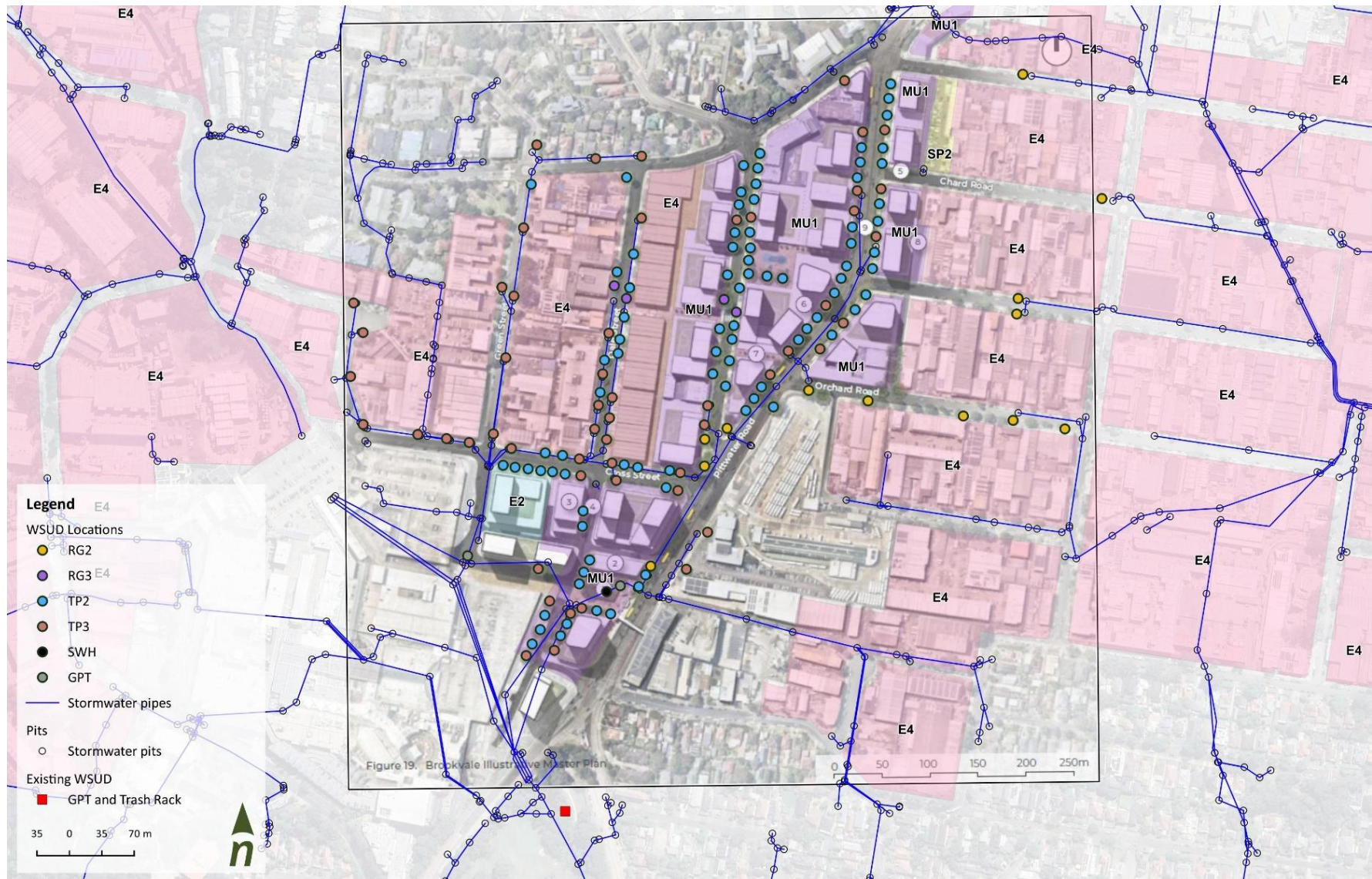


Figure 44. Plan showing suggested locations of WSUD assets for the Brookvale Structure plan

Table 33. Summary of the number of typical WSUD assets proposed for each street, the estimated treatment performance and high level, indicative capital costs

Road Name	Gross pollutant traps (GPT - Humegard HG45 or similar)	System 1: Passively irrigated street tree			System 2: Rain garden		Total
		TP2 - Variation 2 Medium street tree without wicking zone	TP3 - Variation 3 Medium street tree with structural modules and without wicking zone	Stormwater harvesting (SWH)	RG2 - Variation 2 Rain garden behind the kerb	RG3 - Variation 3 Rain garden to replace car park	
Winbourne Road	0	0	0	0	1	0	1
Warringah Mall	2	12	6	1	0	0	19
Sydenham Road	0	0	0	0	2	0	2
Rogers Street	0	24	4	0	3	2	33
Pittwater Road	0	29	14	0	1	0	44
Orchard Road	0	0	0	0	5	0	5
Old Pittwater Road	0	2	3	0	0	0	5
Green Street	0	0	5	0	0	0	5
Dale Street	0	8	8	0	0	2	18
Cross Street	0	12	14	0	0	0	26
Chard Road	0	0	0	0	1	0	1
Total	2	87	54	1	13	4	159
Stormwater quality reduction performance							
Flow (kL/year)	-	330	2,700	13	146	74	3,263
GP (kg/year)	9,678	189	1,760	35	113	58	11,833
TSS (kg/year)	26,200	1,040	9,245	10	603	312	37,410
TP (kg/year)	2	1	11	0	1	0	16
TN (kg/year)	94	8	76	0	4	2	184
Indicative capital cost estimates							
Indicative capital cost per asset	\$135,000	\$4,323	\$57,640	\$310,000	\$13,413	\$21,797	
Indicative capital cost ¹	\$351,000	\$488,931	\$4,046,328	\$403,000	\$226,680	\$113,344	\$5,629,283

¹ 30% contingency applied to capital cost

The indicative capital cost provided in Table 33 are highly conservative and include a 30% contingency. Here, an assumed capital cost per asset was multiplied by the number of assets proposed. It should be noted that these costs would be highly dependent on site-specific conditions, including existing geology, contamination, utilities, and proximity to buildings or other key infrastructure.

Table 33 summarises the treatment performance of each system proposed. Here, the proposed treatment train will be over the treatment of gross pollutants (GP), total suspended solids (TSS) and total nitrogen (TN). This was due to the inclusion of two additional gross pollutant traps (GPTs) to account for the shortfall in phosphorus. Table 34 and Table 35 presents the WSUD performance without and with the additional GPTs, respectively. It should be noted that the load reduction for GP, TSS and TN in Table 35 are significantly higher than the required load reduction in Table 23. This is likely due to the GPT being strategically placed online to a larger, external catchment. This additional stormwater reduces the pollutant load beyond the requirements of the development and therefore meets 100% of the load reduction.

Table 34. Summary of the pollution reduction performance compared to the required targets, excluding two GPTs (Humegard HG45 or similar)

	Pollutant reduction targets	Estimated treatment effectiveness	Target achieved
GP Reduction (kg/year)	90%	100%	✓
TSS Reduction (kg/year)	85%	85%	✓
TP Reduction (kg/year)	65%	60%	X (limiting constituent)
TN Reduction (kg/year)	45%	54%	✓

Table 35. Summary of the pollution reduction performance compared to the required targets, including two GPTs (Humegard HG45 or similar)

	Pollutant reduction targets	Estimated treatment effectiveness	Target achieved
GP Reduction (kg/year)	90%	100%	✓
TSS Reduction (kg/year)	85%	100%	✓
TP Reduction (kg/year)	65%	72%	✓ (limiting constituent)
TN Reduction (kg/year)	45%	100%	✓

The WSUD system locations shown in Figure 44 are indicative only and are intended to illustrate potential opportunities rather than define final asset placement. Where opportunities arise to embed WSUD within development lots or within new laneways (Figure 50) and pedestrian links (Figure 51), this would be encouraged. Figure 45 to Figure 51, adapted from Ethos Urban, illustrate indicative locations for these proposed assets.

Design considerations (Alluvium)

- **System 1** - tree volumes for urban trees are often undersized and compressed by highly loaded surfaces, including pathways and roads. Variation 3 allows for tree soil volumes to remain uncompacted in urban environments, therefore maximising good quality soil volume and potentially tree canopy. BYD assessment of Cross street suggests that these proposed locations are highly constrained by existing services. Existing services need to be considered when designing the extent of each intervention. In constrained environments, system 1, variation 2 could be considered.
- **System 2** - raingardens could be located within the setback from the corridor to the building edge. These systems should be sized to take roof and pathway runoff. The assets should be terraced and consider the zone of influence from the adjacent buildings.

Legend

	Highly constrained zone with existing services
	Terraces and podium raingarden
	Passively irrigated street tree variation 2 or 3
	Direction of stormwater flow
	Building zone of influence

-  Footpath
-  Deep Soil
-  Flexi-Zone/ Active Transport
-  Carriageway
-  Opportunity for Passive Irrigation/Rain Garden
-  Opportunity for Roof Water Collection to Existing Trees
-  Road Fall

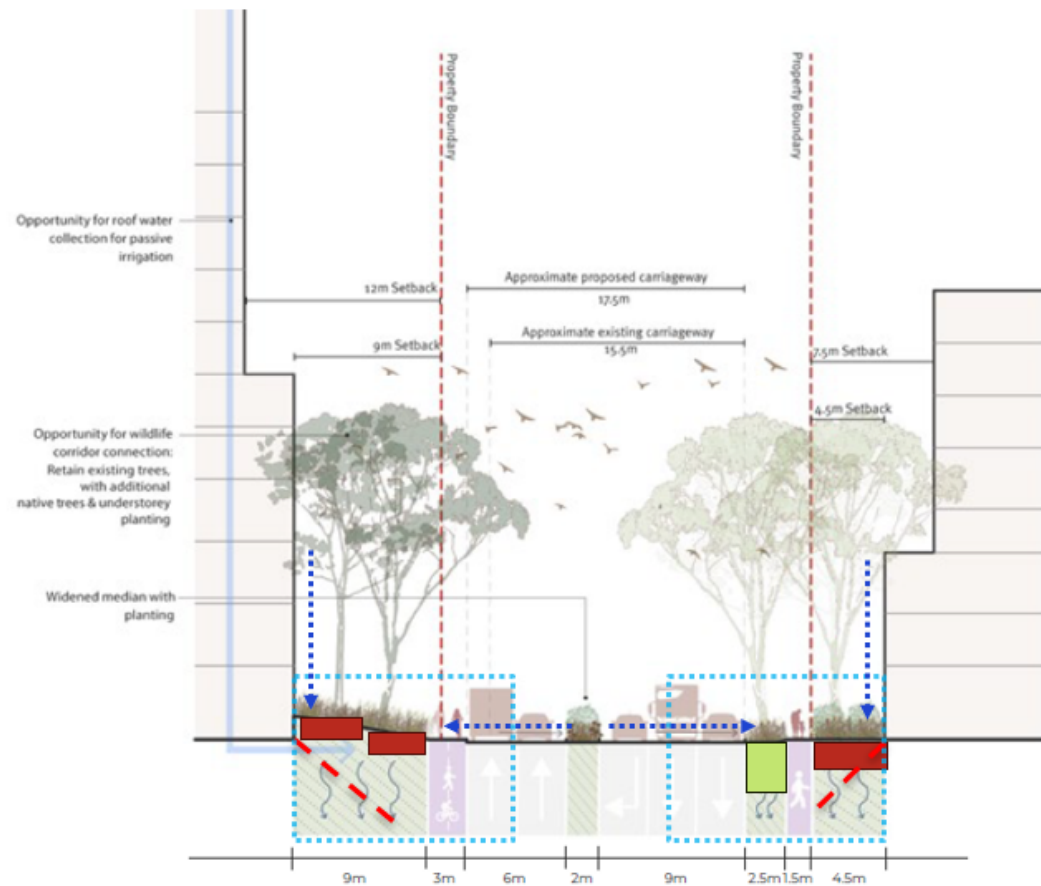


Figure 45. Adapted section A (Cross Street) from Ethos Urban

Section B: High Street



Design Considerations (Alluvium)

- **System 3** - wicking lawn in the open space would decrease the irrigation demand, improve local water quality, and improve passive cooling through evapotranspiration.

Legend

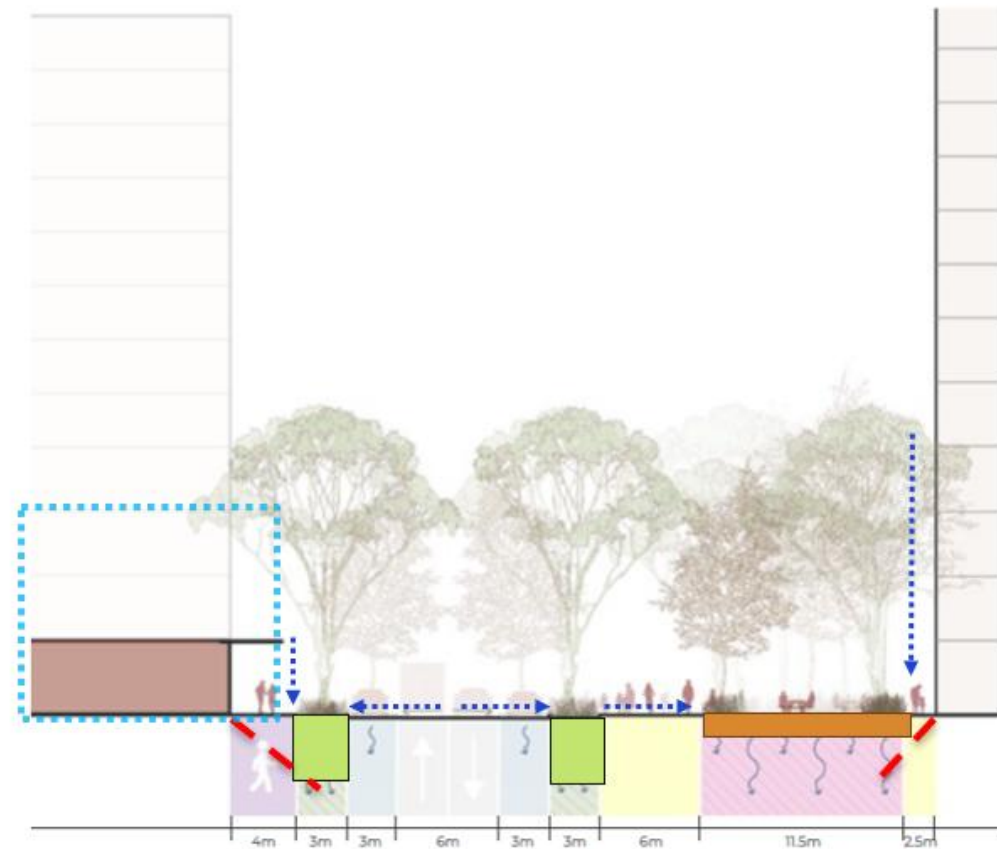


Figure 46. Adapted section B (High Street) from Ethos Urban

Section C: Pittwater Road South & Town Square

Design Considerations (Alluvium)

- **System 3** - wicking lawn in the open space would decrease the irrigation demand, improve local water quality, and improve passive cooling through evapotranspiration.
- **System 5** - stormwater harvesting could be explored under the bus stop for irrigating the adjacent open space. Noting, this is a highly constrained environment with existing services.

Legend

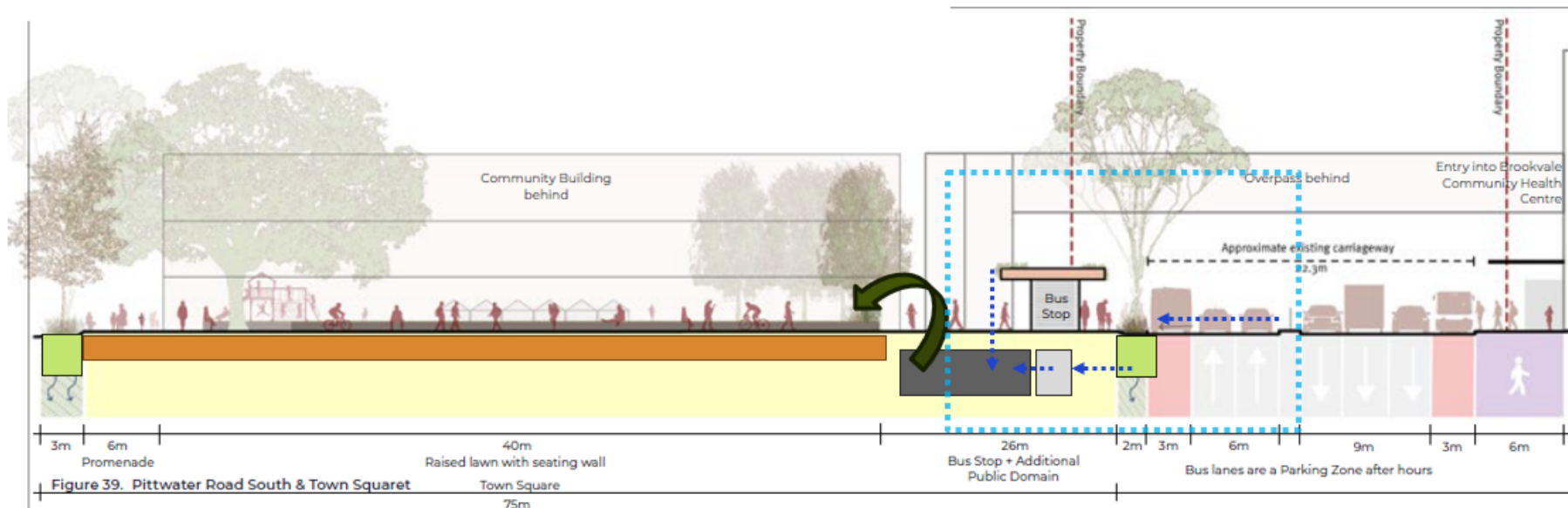
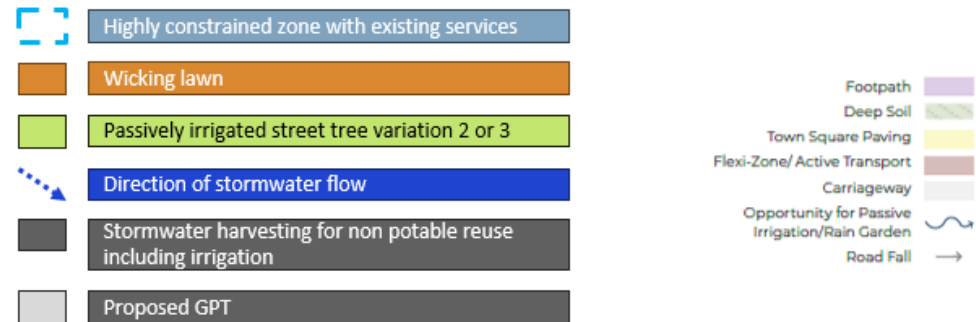


Figure 47. Adapted section C (Pittwater Road South and Town Square) from Ethos Urban

Section D: Roger Street

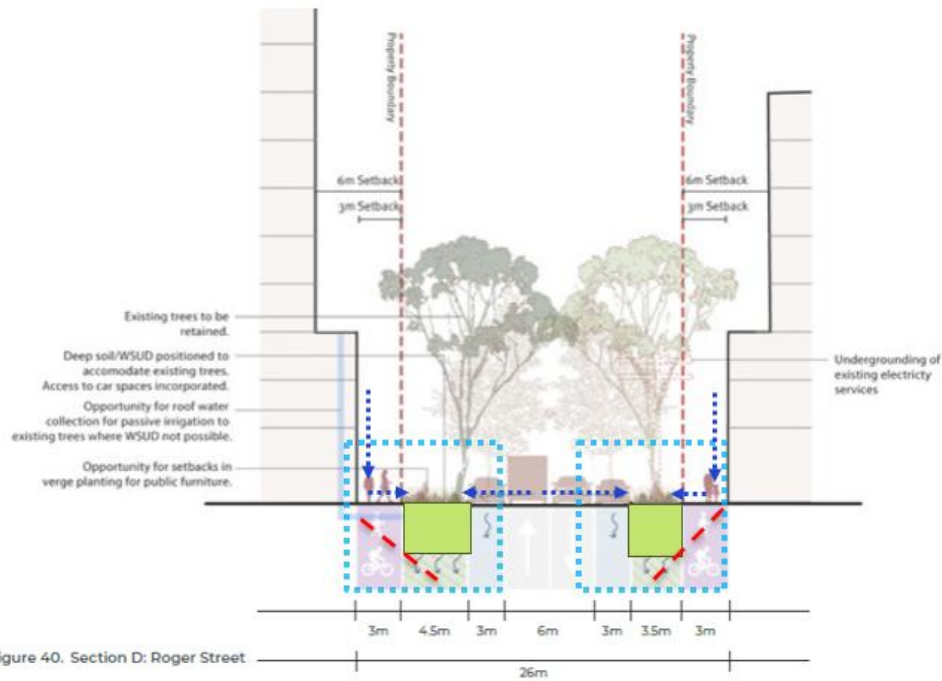


Figure 40. Section D: Roger Street

Section E: Pittwater Road North

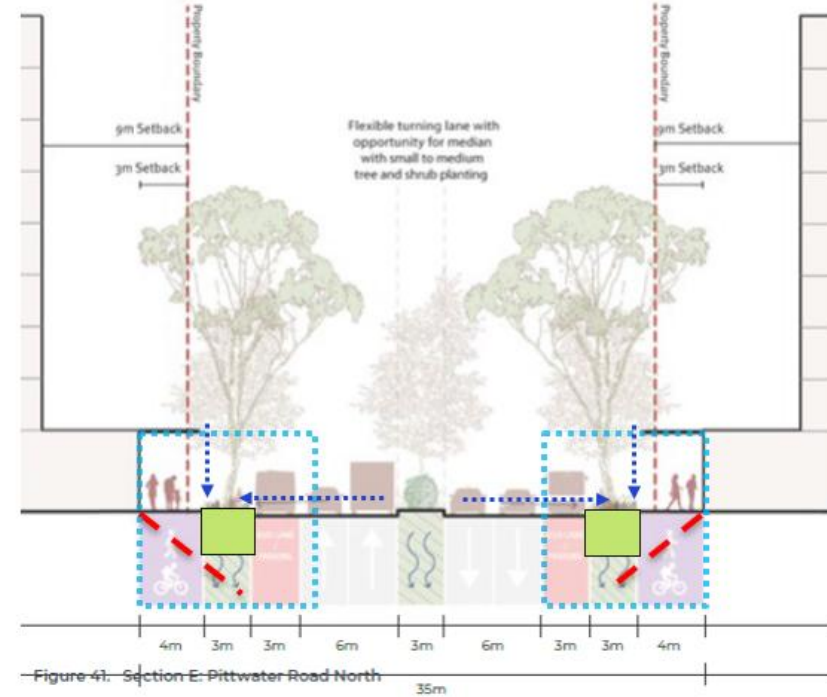


Figure 41. Section E: Pittwater Road North

Figure 48. Adapted section D (Roger Street) from Ethos Urban

Figure 49. Adapted section E (Pittwater Road North) from Ethos Urban

Legend



Section F: New Laneway East of Pittwater Road

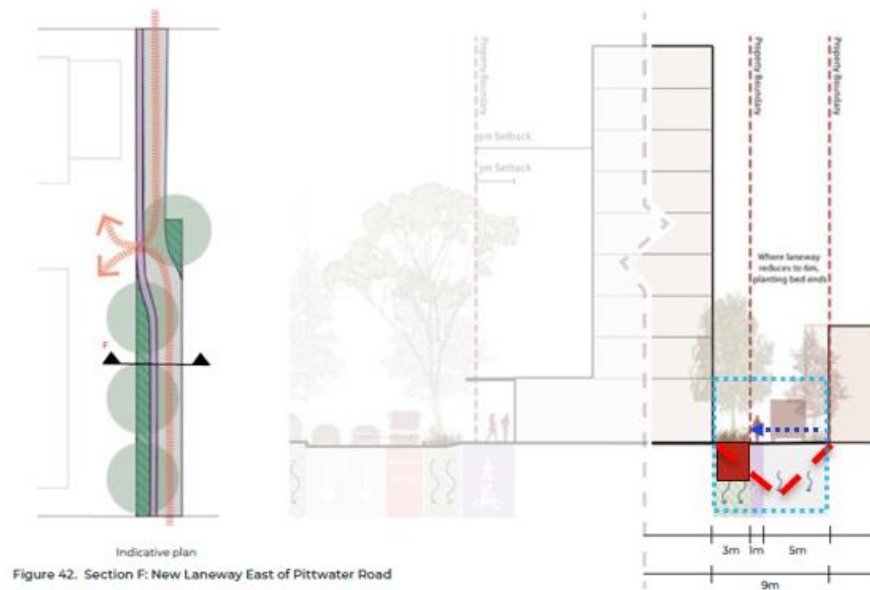


Figure 50. Adapted section F (New Laneway East of Pittwater Road) from Ethos Urban

Section G: New Pedestrian Through-Site Link

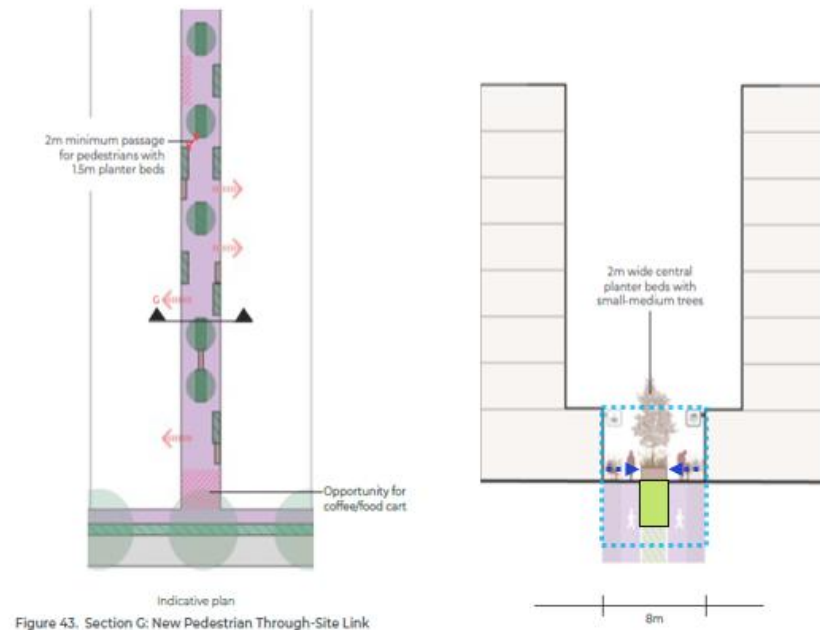
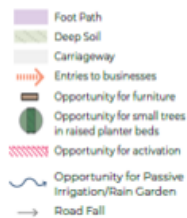
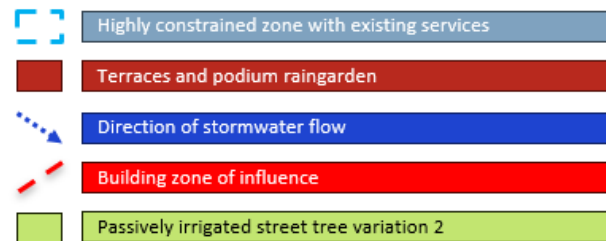


Figure 51. Adapted section G (New Pedestrian Through-Site Link) from Ethos Urban

Legend



Public open space and integrated water reuse opportunities

Opportunities are being explored to deliver public open space in the northern portion of the precinct, including Roger Street and the Council car park site on Winbourne Road, both of which would be managed by Council and are subject to site constraints such as limited deep soil availability and existing utilities. Figure 44 shows passively irrigated trees located in the open space along Rogers Street, although there is flexibility on what these assets could be. Where opportunities arise at the next step of design, alternative or complementary treatments may be considered, including the incorporation of raingardens within open space or the use of subsurface water storage, such as wicking lawn systems, to retain stormwater below ground and reduce irrigation demand. These approaches would improve urban cooling, tree health and landscape resilience while responding to or adhering to spatial and servicing constraints.

Private development integration, design flexibility and broader WSUD delivery

On-site stormwater retention and harvesting is strongly encouraged within adjoining key development sites for non-potable reuse, including irrigation, toilet flushing and laundry, which would also improve the overall water quality outcomes for individual developments. Opportunities to support public open space irrigation through stormwater harvesting on private land may be explored through future planning controls, subject to detailed design and approvals. Structural cell passively irrigated tree pits (variation 3) are widely supported and provide a robust solution for maintaining uncompacted soil volumes for street trees in highly constrained and impervious urban environments. The proposed WSUD locations provide a high degree of flexibility, recognising that system types, locations and costs may evolve through functional and detailed design in response to site-specific conditions, including utilities, tree canopy outcomes and required soil volumes, constructability and funding considerations.

Scentre Group site

Indicative WSUD assets proposed on the Warringah Mall / Scentre Group site currently include raingardens (RG2), passively irrigated street trees (TP2 and TP3), stormwater harvesting and two gross pollutant traps. Given the extent of treatment required from the Scentre Group catchment and the highly constrained nature of the site, it is anticipated that WSUD delivery may need to extend beyond the site boundary into surrounding industrial streets, including Winbourne Road, Sydenham Road, Orchard Road, Old Pittwater Road, Green Street, Dale Street, Cross Street and Chard Road, as shown in Figure 44. Much of Warringah Mall and Cross Street, and portions of Pittwater Road, are located on mapped acid sulfate soils, and some of the proposed WSUD solutions are also located within flood-affected areas. From a WSUD perspective, these constraints will require careful consideration during detailed design, including material selection, system configuration and constructability, and will have significant implications on feasibility and cost. While WSUD outcomes on the Scentre Group site will ultimately be progressed through separate State Significant Development processes, the recommendations in this report are intended to inform and influence outcomes at a precinct scale by identifying feasible and complementary WSUD opportunities across both public and private land.

Asset ownership

The indicative WSUD locations shown on Figure 44 are predominantly situated outside the road verge, within setback areas defined by Council, and across a mix of transport land and privately owned property. As such, ownership and maintenance responsibility for WSUD assets will not be uniform and will depend on the final land tenure and functional integration of each asset. WSUD assets located within Council-owned land may be considered for Council ownership, subject to detailed design, feasibility and agreement at the development approval stage. With that being said, Figure 42 suggests minimal Council-owned land within the study site. Assets located within privately owned setback areas or open space, including land delivered by Scentre Group, would be expected to remain the responsibility of the relevant landowner. Infrastructure associated with transport facilities, such as the bus interchange, would be subject to Transport for NSW ownership and maintenance arrangements. There is a strong preference for stormwater harvesting and irrigation infrastructure to be owned and maintained by a single landowner where systems service private catchments, including large roof, podium and paved areas. Given the location of the proposed stormwater harvesting system and associated GPT, this is assumed to become a Scentre Group. Final allocation of ownership and maintenance responsibilities will need to be confirmed during the next phase of design, informed by detailed WSUD layouts, land ownership mapping and agreement between Council, private landowners and relevant agencies. It is noted that Northern Beaches Council's Brookvale Water Quality Project has been cancelled due to reprioritisation. Accordingly, any proposed stormwater quality devices within the study area are not anticipated to be constructed or maintained by Council and should be delivered under private or relevant agency ownership arrangements.

9 Multi-criteria analysis

Multi-criteria analysis (MCA) is a decision-making tool that enables Northern Beaches Council to prioritise the catalogue of proposed solutions. MCA is a commonly used analytical tool originating from operations research that aims to compare different options (or actions, projects, etc.) according to a variety of objectives and criteria. MCA uses the decision makers' criteria to identify the preferred option given a portfolio of potential options. The criteria adopted for the Structure plan are outlined in Table 36 and Table 37.

Table 36. MCA Criteria – water quality

MCA Category	Criterion	Description
Environmental benefits	Stormwater flow benefits	Reduction in peak flow rates or site runoff volumes
	Treatment to Catchment Area Ratio (TCAR)	The ratio of the treatment size to the catchment size that the system can effectively reduce pollutants
	Greening/canopy	Introduction of vegetation or tree canopy
	Benefits of urban heat	Cooling effects due to the type of vegetation present
	Innovation in design	Design uses more advanced engineering technology
Environmental disbenefits	Acid sulfate soils	Whether design causes contact with acid sulfate soils
	Operational environmental impacts	Magnitude of environmental disturbance
	Construction environmental impacts	Potential for construction phase impacts as a result of works within the channel, plus the general extent of works
	Sustainable materials	Whether the design uses sustainable, renewable materials
	Carpark	Whether the design has any impact on car parking
Stakeholders	Complexity of landholder impacts	How many landholders need to be involved, the extent and location of the land-take required
	OH&S risks	Extent of manual works that lead to potential OH&S risks
	Existing services	Extent to which design clashes with existing services
Operational considerations	O&M risks - operations	Chance that an O&M failure will impact delivery
	Susceptibility to climate changes	The extent to which the system is affected by higher intensity rainfall, drought or heatwave conditions
Economic	Capital Cost	Estimated capital cost to construct the asset
	Operations & Maintenance Cost	Relative O&M cost

Table 37. MCA Criteria – flooding

Criterion	Description
Impact on flood behaviour	How the design alters flood levels, flow paths, and inundation extents, whether it mitigates or worsens flooding.
Technical Feasibility	Whether the proposed solution is technically achievable given site constraints, available technology, and engineering standards.
Community Acceptance	The acceptability of the solution to residents and stakeholders, including perceived benefits and concerns.
Environmental/Ecological Benefits	Measure of the positive impact on local ecosystems, such as improved habitat, water quality, or biodiversity.
Impact on SES	Whether the design supports or hinders emergency response efforts during flood events.
Political/Administrative Issues	Potential political or administrative barriers, such as planning approvals, inter-agency coordination, or policy alignment.
Long Term Benefit	Evaluates the sustainability and effectiveness of the solution over time, including resilience and maintenance needs.
Risk to Life	Potential for the design to reduce or increase risks to human life during flood events.
Susceptibility to climate changes	How vulnerable the solution is to future climate conditions, such as increased rainfall intensity or sea level rise.
Economic	Considers both capital and ongoing costs, as well as cost-effectiveness relative to flood mitigation outcomes.

The simplicity of the aggregation of scores under criteria (weighted average) in an MCA is a major advantage when compared to other tools, particularly as the information inputs can be a mix of different measurement types, including consensus scores developed by users (e.g., in a workshop situation). However, the technique is not without some conceptual limitations, e.g., outcomes are highly sensitive to weightings applied to objectives and criteria. The scoring descriptions are provided in Table 38, with the weightings included in the results of the MCA presented in Table 39 and Table 40.

Table 38. MCA scoring descriptions and weightings

MCA Criterion	Scoring Descriptions		
	0	1	2
WATER QUALITY			
Stormwater flow benefits	No or minimal benefit	Flow detention (reducing the peak)	Flow retention (reducing the volume)
Treatment to Catchment Area Ratio (TCAR)	TCAR > 10%	5% < TCAR < 10%	0% < TCAR < 5%
Greening / canopy	No canopy and urban greening	Minimal canopy and urban greening outcomes	Moderate canopy and urban greening outcomes
Benefits to urban heat	No benefits to urban heat	Passive cooling through evapotranspiration	Passive cooling through evapotranspiration and shading
Innovation in design	Low innovation	Moderately innovative design	Highly innovative design
Acid sulfate soils	Large asset in PASS area	Small asset in PASS area	No disturbance
Operational environmental impacts	Altered hydraulics, major channel footprint within Brookvale Creek	Moderate disturbance as a result of increased piped network connections and larger channels, though not within Brookvale Creek	Minimum disturbance
Construction environmental impacts	Extensive construction works including within Brookvale Creek	Moderate disturbance, though not within Brookvale Creek	Minimum disturbance
Sustainable materials	Mostly composed of single-use, non-renewable materials which must be discarded at end of project life	Mostly composed of sustainable, renewable materials	Fully composed of sustainable, renewable materials
Carpark	Loss of car park	Some impact to car parking	No impact to car parking
Complexity of landholder impacts	Most landholder impacts	Moderate landholder impacts	Least landholder impacts, mainly located on Council owned land
OH&S risks	Regular and complex maintenance and operation, major structure in Brookvale Creek, leading to most OH&S risks compared to others	A moderate level of OH&S risks compared to other options	Least complex operation and maintenance requirements translating to the least OH&S risks
Existing services	Presence of many existing services, causing complexity in design implementation and risk to services operation	Presence of some existing services, however design can be retrofitted to interface with these surfaces	Minimal impact with existing services
O&M risks - operations	System failure causes significant flood impacts, reducing safety and severely affecting water quality	System failure causes minor flood impacts and moderate effects on water quality, with minimal decrease in safety	System failure is highly unlikely, or causes minimal flooding and water quality impacts
Susceptibility to climate changes	Moderate risk of system failure due to heatwave and drought conditions causing vegetation wilt and reduced frequency of watering	Less risk of system failure due to drought resilient planting or increased soil storage, and some risk of erosion scour from high intensity rainfall	Low risk of system failure, however possible reduced capacity of system due to higher sediment loads from higher intensity rainfall events or less frequent inflows

MCA Criterion	Scoring Descriptions		
	0	1	2
FLOODING			
Impact on flood behaviour	Increases flood levels or worsens flood extent	No significant change to flood behaviour	Reduces flood levels or extent significantly
Technical Feasibility	Not technically feasible or requires major redesign	Feasible with moderate design adjustments	Easily feasible with standard engineering practices
Community Acceptance	Strong community opposition or concern	Mixed community response or limited engagement	Strong community support or co-designed with stakeholders
Environmental/ Ecological Benefits	Causes ecological degradation or habitat loss	No significant ecological impact	Enhances habitat, biodiversity, or waterway health
Impact on SES	Hinders emergency access or response	No impact on emergency services	Improves emergency access or reduces response time
Political/ Administrative Issues	Major political or administrative barriers	Some administrative complexity	Politically supported and administratively straightforward
Long Term Benefit	Short lifespan or high degradation risk	Moderate lifespan with some maintenance needs	Long-lasting with minimal maintenance and strong resilience
Risk to Life	Increases risk to life during flood events	No change in safety risk	Reduces risk to life significantly
Susceptibility to climate changes	Highly vulnerable to future climate impacts	Moderately resilient to climate variability	Designed for climate resilience and adaptability
Economic	High cost with low benefit	Moderate cost-benefit ratio	Cost-effective with strong return on investment

Table 39. Multi-criteria analysis results – water quality

Category			Environmental benefits					Environmental disbenefits					Stakeholders			Operational considerations		Without cost		Economic		With cost	
Criterion			Stormwater flow benefits	Treatment to Catchment Area Ratio (TCAR)	Greening / canopy	Benefits to urban heat	Innovation in design	Acid sulfate soils	Operational environmental impacts	Construction environmental impacts	Sustainable materials	Carpark	Complexity of landholder impacts	OH&S risks	Existing services	O&M risks - operations	Susceptibility to climate changes			Capital cost	Operations & maintenance cost		
Weightings			5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%	Score		5.9%	5.9%	Score	
Option	System	Variation																					
1a	Passively irrigated street tree	Saturated zone	1	0	2	2	1	1	2	1	1	2	1	2	0	2	1	1.1	7	0	1	1.2	8
1b	Passively irrigated street tree	Freely drained	1	2	2	2	1	1	2	2	2	2	1	2	0	2	1	1.4	1	2	2	1.6	1
1c	Passively irrigated street tree	Structural	1	2	2	2	2	1	2	1	1	2	1	2	0	2	1	1.3	2	0	1	1.4	4
2a	Rain garden	Carpark central median	1	2	2	1	1	1	2	1	1	1	1	2	1	2	1	1.2	5	1	1	1.3	6
2b	Rain garden	Verge	1	2	2	1	1	1	2	2	1	2	1	2	1	2	1	1.3	2	1	1	1.4	2
2c	Rain garden	Parking space	1	2	2	1	1	1	2	1	1	0	0	2	1	2	1	1.1	9	1	1	1.2	8
3	Wicking lawn	Wicking Lawn	1	0	1	1	2	1	2	1	1	2	2	2	2	2	1	1.2	4	1	1	1.4	4
4a	Swale	Vegetated swale	1	1	1	1	0	1	2	2	2	2	1	2	1	2	1	1.2	5	2	2	1.4	2
4b	Swale	Bioretention swale	1	2	1	1	1	1	1	1	1	2	1	2	1	2	1	1.1	7	1	1	1.2	7
5	Stormwater harvesting	Stormwater harvesting	2		0	0	2	0	0	0	0	2	2	1	1	2	2	0.8	10	0	0	0.8	10
6	GPT / Forebay	GPT / Forebay	0	2	0	0	0	0	0	0	0	2	2	0	2	1	2	0.6	11	0	0	0.6	11

Table 40. Multi-criteria analysis results – flooding

Criterion		Impact on flood behaviour	Technical Feasibility	Community Acceptance	Environmental /Ecological Benefits	Impact on SES	Political/ Administrative Issues	Long Term Benefit	Risk to Life	Susceptibility to climate changes	Without cost		Economic	With cost	
Weightings		10%	10%	10%	10%	10%	10%	10%	10%	10%	Score		10%	Score	
Option	System														
F1	Urban renewal and increased pervious areas	1	2	2	2	1	2	2	1	1	1.4	1	1	1.5	1
F2	WSUD integration	1	2	2	2	1	1	2	1	2	1.4	1	1	1.5	1
F3	Clearview Place Levee	1	1	0	0	2	0	2	2	1	1.0	4	0	1.0	4
F4	Planning controls	1	2	1	1	2	1	2	2	2	1.4	1	1	1.5	1

The results of the MCA are summarised in Table 41. The MCA results provide an evaluation of various water quality and flood mitigation options. The key findings indicate that:

- *Passively irrigated street trees (freely drained)* and *rain gardens (verge)* are the top-performing options for water quality improvement, both in terms of effectiveness and cost-efficiency.
- *Urban renewal and increased pervious areas, WSUD integration and planning controls* are the most effective and cost-efficient solutions for flood mitigation.
- Options like *stormwater harvesting* and *GPT / forebay* for water quality, and the *Clearview Place Levee* for flood mitigation, are less effective.

These results can guide decision-makers in selecting the most appropriate and cost-effective solutions for improving water quality and mitigating flood risks. It is important to consider the specific context and constraints of each option or project when making final decisions.

Table 41. Summary of MCA Results

WATER QUALITY OPPORTUNITIES						
Option	System	Variation	Without cost		With cost	
			Score	Ranking	Score	Ranking
1a	Passively irrigated street tree	Saturated zone	1.1	7	1.2	8
1b	Passively irrigated street tree	Freely drained	1.4	1	1.6	1
1c	Passively irrigated street tree	Structural	1.3	2	1.4	4
2a	Rain garden	Carpark central median	1.2	5	1.3	6
2b	Rain garden	Verge	1.3	2	1.4	2
2c	Rain garden	Parking space	1.1	9	1.2	8
3	Wicking lawn	Wicking Lawn	1.2	4	1.4	4
4a	Swale	Vegetated swale	1.2	5	1.4	2
4b	Swale	Bioretention swale	1.1	7	1.2	7
5	Stormwater harvesting	Stormwater harvesting	0.8	10	0.8	10
6	GPT / Forebay	GPT / Forebay	0.6	11	0.6	11
FLOOD MITIGATION OPPORTUNITIES						
Option	System		Without cost		With cost	
			Score	Ranking	Score	Ranking
F1	Urban renewal and increased pervious areas		1.4	1	1.5	1
F2	WSUD integration		1.4	1	1.5	1
F3	Clearview Place Levee		1.0	4	1.0	4
F4	Planning controls		1.4	1	1.5	1

9.1 Water quality opportunities

The MCA results highlight the effectiveness and cost-efficiency of certain options for water quality improvement. Notably, passively irrigated street trees (freely drained) (1b) and rain gardens (verge) (2b) emerged as the most effective and cost-efficient options. These options not only provide significant environmental benefits by filtering pollutants but also enhance urban green spaces, offering aesthetic and social advantages. The detailed findings are as follows:

- Passively irrigated street trees (freely drained) scored the highest in both cost and non-cost scenarios, indicating their strong performance in improving water quality. The freely drained system allows for efficient water infiltration and pollutant removal, making it a sustainable choice for urban areas.
- Similarly, rain gardens located on verges performed well. These gardens capture and treat stormwater runoff, reducing the load of pollutants entering water bodies. Their integration into urban landscapes also enhances biodiversity and provides recreational spaces for communities.
- While stormwater harvesting can provide additional water resources, its lower score suggests it may not be as efficient in pollutant removal compared to the top-performing options.
- GPT / forebay systems, designed to trap gross pollutants, also scored lower, indicating they may not address finer pollutants as effectively and have a greater cost than the other options presented.

Two gross pollutant traps (GPTs), Humegard HG45 units or similar, have been incorporated into the proposed WSUD strategy (Figure 44). These systems are intended to intercept plastics and other gross pollutants as close to the source as practicable. The proposed GPTs are located online to a broader, external catchment, increasing their effectiveness in capturing pollutants generated both within and beyond the Structure Plan area and reducing pollutant loads entering Manly Lagoon. While the MCA does not explicitly account for microplastics and therefore underrepresents the benefits of GPTs, their inclusion responds to the Council's strong emphasis on preventing plastic degradation and accumulation within lagoon ecosystems, particularly given the surrounding industrial land uses. Appropriate filter and basket configurations capable of capturing smaller plastic fragments would be encouraged, including degraded thermoplastics from road markings, and should be considered during detailed design. Additionally, the renewal of the GPT south of the intersection between Condamine Street and Pittwater Road (near the golf course) could be considered, although it is unlikely to be as effective as the proposed additional GPTs within the study area.

9.2 Flood mitigation opportunities

From a flood perspective, the options put forward have merit and should be considered as part of a broader integrated flood management strategy. The outcomes of the MCA will be used to guide further engagement with Council and stakeholders. The options have been prioritised based on their combined performance:

- The top three options (F1, F2, F4) consistently score 1.4–1.5, indicating strong performance across multiple criteria even when cost is considered. They share several strengths:
 - Integrated and passive flood mitigation: These approaches reduce runoff and improve infiltration, which helps manage flood peaks and volumes.
 - Co-benefits: They offer environmental and urban design benefits such as improved water quality, urban cooling, and enhanced amenity.
 - Community and stakeholder alignment: These options are generally more acceptable to the public and easier to implement administratively.F1 and F2 are particularly valuable for their ability to be embedded within broader urban renewal and sustainability strategies, while F4 leverages planning controls to reduce flood risk without major infrastructure investment.
- Clearview Place Levee (F3) is the lowest-ranked option, scoring 1.0, indicating limited benefit or higher complexity:
 - Hard infrastructure: Levees can be effective but often come with high capital costs, significant environmental impacts, and potential community resistance.
 - Lower flexibility: Compared to nature-based or planning solutions, levees are less adaptable to future climate conditions and urban growth.
 - Risk concentration: If not properly maintained, levees can increase risk downstream or create a false sense of security.

- Limited operational benefit: Modelling showed the levee provided negligible improvement under standard flood conditions due to efficient flow conveyance through the upstream trunk drainage network. Its effectiveness was primarily realised under a 50% blockage scenario, where it reduced flood levels in downstream areas by containing overflow upstream. As blockage scenarios represent atypical rather than design conditions, this limited applicability contributed to its lower MCA ranking.

As a non-physical measure, the planning controls (F4) complement and enhance the performance of other mitigation options. While they do not directly reduce flood flows or provide treatment areas in the same way as visible infrastructure, they play a pivotal role in shaping long-term flood resilience. By guiding appropriate development, discouraging intensification in high-risk areas, and embedding flood risk considerations into future land use decisions, planning controls act as an enabling framework for all other interventions.

Their minimal disruption, cost-effectiveness, and adaptability to future climate and demographic changes make them an attractive option for immediate delivery. Importantly, F4 can be implemented early in the program to influence development outcomes from the outset, avoiding the creation of new risk and ensuring that structural measures, such as WSUD features or floor level setting, are applied in the most effective locations.

Potential influence of increased building height on flooding

The modelling undertaken for this study assumed a building yield consistent with the earlier precinct plan of approximately 1,350 dwellings. Subsequent planning proposals have considered an increase to around 2,000 dwellings, enabled through additional building height and an incentive bonus for the delivery of a new park in the northern precinct along Roger Street.

From a flood behaviour perspective, the increase in building height is not expected to materially change the results or the recommendations of this study, provided that the building footprints remain unchanged. Flood levels and conveyance patterns are driven primarily by the location and extent of obstruction to overland flow, rather than by the number of storeys above ground.

The primary change associated with a higher dwelling yield would relate to emergency management considerations. A larger residential population would increase the number of people requiring evacuation in a flood, potentially adding pressure to evacuation routes and shelter capacity. These implications would need to be addressed through the precinct's flood emergency management planning, but do not alter the underlying hydraulic performance of the proposed flood mitigation measures.

10 Conclusion

The updated hydraulic modelling presented in this assessment provides a refined understanding of flood behaviour across the Warringah Mall precinct, reflecting the latest rainfall design data, terrain information, and drainage infrastructure upgrades. The model indicates that reductions in rainfall intensity under ARR2019, coupled with improved stormwater conveyance, have resulted in overall decreases in flood levels and extents, particularly within the Warringah Mall area. These outcomes are consistent with observed changes in catchment hydrology and drainage function.

Mapping outputs have delineated the Flood Planning Area, flood function categories, and Flood Category 1, offering a spatial framework for assessing development suitability. These layers confirm the presence of high flood hazard areas and critical flow corridors, particularly under climate-affected and extreme event scenarios. Areas mapped as floodways or subject to high-hazard conditions remain unsuitable for intensified development.

Three development and mitigation scenarios were tested. Modest improvements in flood levels were observed where reduced imperviousness and WSUD were applied, though the catchment-scale flood response remained largely unchanged. Placement of proposed buildings in flow corridors led to measurable increases in flood levels, particularly in extreme events, underscoring the importance of avoiding floodways and high-hazard zones. The Clearview Place levee was found to provide limited benefit under normal conditions but may play a useful role under system failure scenarios such as blockage of trunk drainage.

Two options for drainage systems upgrades were considered. One option considered involves floodgates installed at the top end of trunk drainage to temporarily retain water upstream of Clearview Place which would reduce the volume and velocity of floodwaters reaching downstream areas during peak events. This options resulted in improvements in downstream flood behaviour for events up to 1%AEP. Key development sites, in particular the Warringah Mall site, could be effectively shielded from fast-moving floodwaters by the introduction of floodgates. The second option considered involved trunk drainage upgrade focused on enlarging or duplicating sections of the existing piped stormwater network to increase conveyance capacity in key locations. Improvements or duplication of trunk drainage results in distributed reductions in flood levels (generally up to ~0.2 m) and reduced reliance on overland flow paths by capturing more runoff within the system. While overall flood hazard is lowered, some localised increases in velocity occur near upgraded assets due to more efficient flow conveyance. The upgrade is effective up to the 1% AEP event limited benefit under climate change condition. However, the overall benefits of the trunk drainage upgrade is constrained by downstream capacity limitations.

Constraints and challenges that limit the feasibility of structural interventions, including acid sulfate soils, fully developed land, and underground utilities, necessitates shifting the focus to non-structural options. Opportunities that emerged from the analysis include embedding planning controls, encouraging pervious surfaces, integrating WSUD, and supporting urban renewal in low-hazard areas. The MCA process has identified these options as high performing, particularly those that support resilient and adaptive planning approaches.

From a flood risk management perspective, the options identified are technically sound, support the objectives of the Ministerial Direction, and form a suitable basis for integrated planning across the precinct. Continued refinement of development layouts, informed by flood modelling and planning constraints, will be critical to achieving resilient growth while managing residual flood risks.

The study also investigated the existing stormwater pollutant load generation, the post-developed pollutant load contribution and the required load reduction to meet the stormwater quality targets. Amalgamated lots, all of which are greater than 500 m², are required to achieve stormwater quality targets. A WSUD toolkit was developed, with a range of solutions proposed as suitable for the Brookvale structure plan. Each solution includes a description and an approximate stormwater treatment performance. The developer is required to implement solutions as per the WSUD Toolkit (or similar) at the lot scale or street scale to manage their stormwater runoff and is required to develop and issue a detailed water quality report demonstrating that stormwater targets, as outlined in the Draft Integrated Water Management and Water Sensitive Urban Design DCP (2025), are satisfied.

A Multi-Criteria Analysis (MCA) was undertaken to assess viable options for both water quality and flooding. Freely drained street trees and verge-based rain gardens emerged as the most effective and cost-efficient water quality solutions, offering strong environmental benefits and urban cooling. In contrast, systems like stormwater harvesting and GPTs were rated low, although they provide significant benefits by reducing plastics into the receiving environment and reliance on potable water for irrigation. For flooding, the analysis suggests that nature-based and planning-led flood mitigation strategies (F1, F2, F4) are preferable for this project due to their effectiveness, cost-efficiency, and broader urban benefits. The Clearview place levee (F3), while potentially useful in specific contexts, may be better considered as a supplementary or last-resort measure.

These findings provide a strong foundation for further engagement with the Council and the development of refined flood mitigation strategies in subsequent stages.

References

Alluvium (2016). *Northern Beaches Council WSUD and MUSIC Modelling Guidelines*. Prepared by Alluvium Consulting Australia for Northern Beaches Council, Draft, June 2016.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at: www.waterquality.gov.au/anz-guidelines

BMT WBM (2015). *NSW MUSIC Modelling Guidelines*.

BMT WBM (2013). *Manly Lagoon Flood Study, Final Report*

Cardno (2008). *Concept Drainage Augmentation Works - Stage 1 Expansion Works - Warringah Mall, Brookvale*. Prepared by Cardno (NSW) for Westfield Design & Construction, December 2008.

Cardno (2018). *Warringah Mall – Flood Impact Assessment (Stage 2)*. Prepared by Cardno (NSW/ACT) for SCENTRE Group, August 2018.

Cardno (2021). *Warringah Mall – Flood Impact Assessment (Stage 2B)*. Prepared by Cardno (NSW/ACT) for SCENTRE Group, April 2021.

Cooks River Alliance (2024). *Raingardens*. Available at: <https://cooksriver.org.au/projects/active-project/>.

Department of Industry, Science, Energy and Resources (DISER) (2020). *Designing for a cool city – Guidelines for passively irrigated landscapes*. Prepared by E2Designlab for Cooperative Research Centre for Water Sensitive Cities. Melbourne, Victoria.

Department of Planning, Housing and Infrastructure (2025). *Shelter-in-place guideline for flash flooding*. Available at: https://shared-drupal-s3fs.s3.ap-southeast-2.amazonaws.com/master-test/fapub_pdf/NSW%2BPlanning%2BPortal%2BDocuments/Shelter+in+place+guideline+for+flash+flood+ing.pdf. Accessed 23/01/2025

Geoscience Australia (2019). *ARR Datahub*, Available at: <https://data.arr-software.org/> Accessed 30 November 2024

Howells et al. (2003). *Defining the Floodway – Can One Size Fit All?* Floodplain Management Authorities of NSW 43rd Annual Conference, Forbes

Melbourne Water (2022). *Raingardens*. Available at: <https://www.melbournewater.com.au/building-and-works/stormwater-management/options-treating-stormwater/raingardens>.

Northern Beaches Council (2023). *NBC Flood Hazard Map*. Available at: <https://nb-icongis.azurewebsites.net/planningmap.html?l=NBC%20Flood%20Hazard%20Map>.

Northern Beaches Council (2024). *Presentation – Inception Meeting – Brookvale Structure plan – Water Management Strategy* [PowerPoint presentation].

Northern Beaches Council (2024). *Recommended Future Land Zoning Map* [shapefile].

Northern Beaches Council (2021). *Water Management for Development Policy*.

RHDHV (2023). *Brookvale WSUD Investigation and Concept Design – Stage 1 Report*. Prepared by Royal HaskoningDHV for Northern Beaches Council, September 2023.

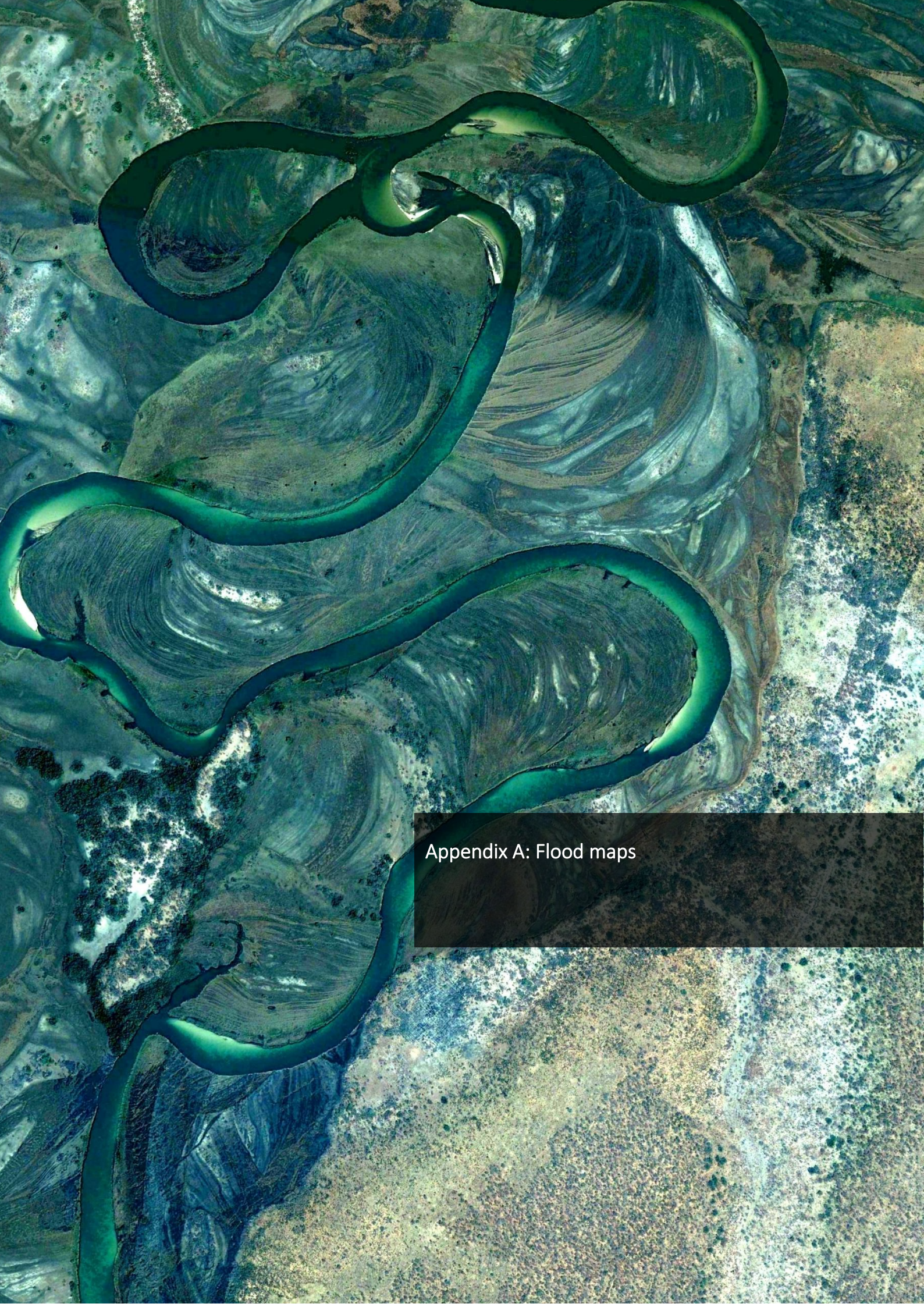
SJB (2024). *Warringah Mall Structure plan – Concept Design*. Prepared by SJB for SCENTRE Group, July 2024.

Sloan, A. (2019). *Many Storms and Seasons Later, How Are These Rain Gardens Holding Up?* Ecological Landscape Alliance. Available at: <https://www.ecolandscaping.org/07/managing-water-in-the-landscape/rain-gardens/many-storms-and-seasons-later-how-are-these-rain-gardens-holding-up/>.

Water by Design (2010). *Construction and Establishment Guidelines: Swales, Bioretention Systems and Wetlands*. South East Queensland Healthy Waterways Partnership, Brisbane.

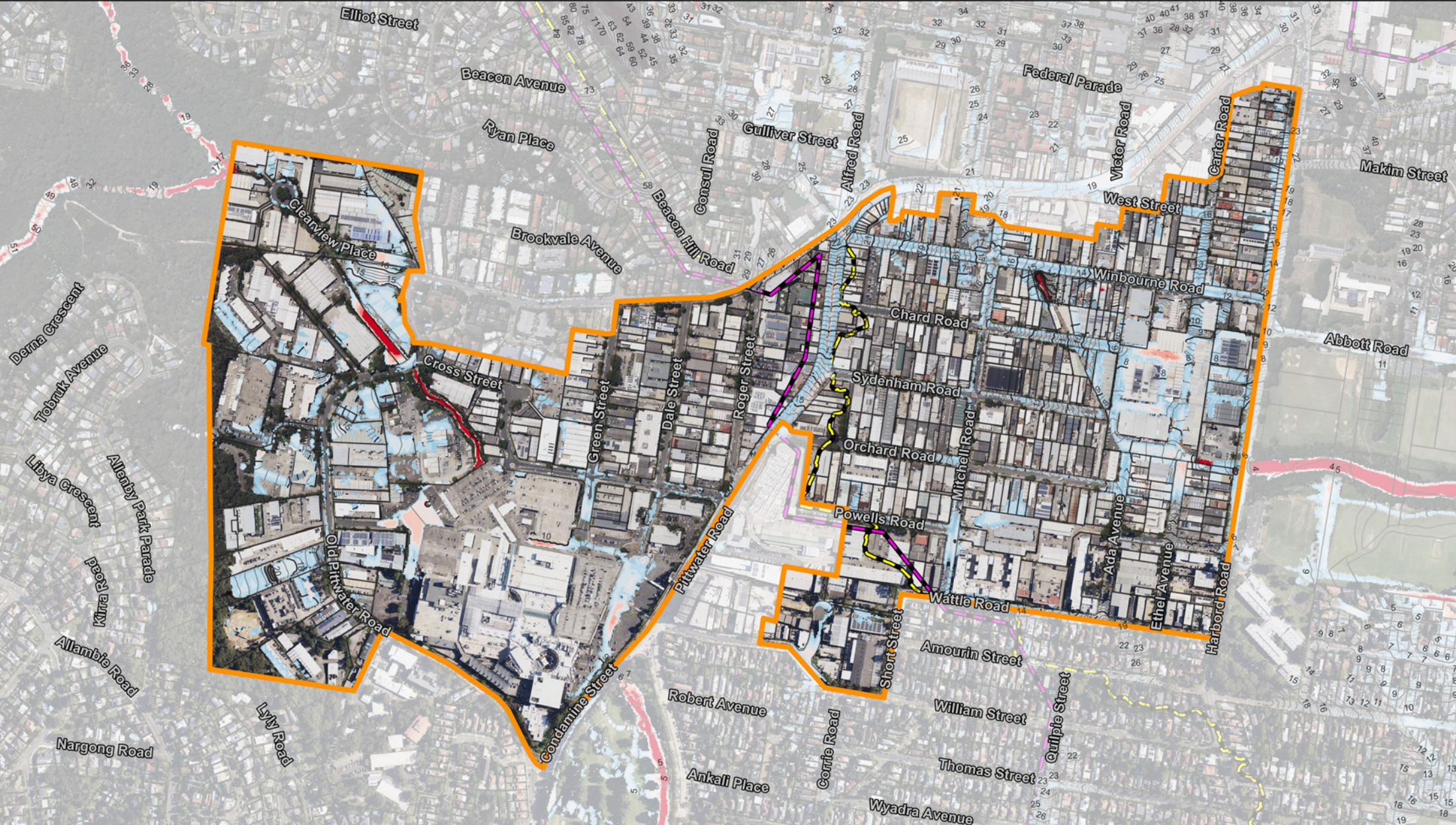
WMAwater (2018). *Manly Lagoon Floodplain Risk Management Study and Plan*

WMAwater (2023). *Greendale Creek Flood Study, Report*



Appendix A: Flood maps

1. Figure A01: Existing Scenario – 20% AEP, Peak Flood Depth
2. Figure A02: Existing Scenario – 5% AEP, Peak Flood Depth
3. Figure A03: Existing Scenario – 1% AEP, Peak Flood Depth
4. Figure A04: Existing Scenario – 0.5% AEP, Peak Flood Depth
5. Figure A05: Existing Scenario – 0.2% AEP, Peak Flood Depth
6. Figure A06: Existing Scenario – PMF, Peak Flood Depth
7. Figure A07: Existing Scenario – 1% AEP + CC, Peak Flood Depth
8. Figure A08: Existing Scenario – 20% AEP, Peak Flood Velocity
9. Figure A09: Existing Scenario – 5% AEP, Peak Flood Velocity
10. Figure A10: Existing Scenario – 1% AEP, Peak Flood Velocity
11. Figure A11: Existing Scenario – 0.5% AEP, Peak Flood Velocity
12. Figure A12: Existing Scenario – 0.2% AEP, Peak Flood Velocity
13. Figure A13: Existing Scenario – PMF, Peak Flood Velocity
14. Figure A14: Existing Scenario – 1% AEP + CC, Peak Flood Velocity
15. Figure A15: Existing Scenario – 20% AEP, Peak Flood Hazard
16. Figure A16: Existing Scenario – 5% AEP, Peak Flood Hazard
17. Figure A17: Existing Scenario – 1% AEP, Peak Flood Hazard
18. Figure A18: Existing Scenario – 0.5% AEP, Peak Flood Hazard
19. Figure A19: Existing Scenario – 0.2% AEP, Peak Flood Hazard
20. Figure A20: Existing Scenario – PMF, Peak Flood Hazard
21. Figure A21: Existing Scenario – 1% AEP + CC, Peak Flood Hazard
22. Figure B01: Building Impacts Scenario – 1% AEP, Difference – Flood Level
23. Figure B02: Building Impacts Scenario – 1% AEP + CC, Difference – Flood Level
24. Figure B03: Building Impacts Scenario – PMF, Difference – Flood Level
25. Figure B04: Building Impacts Scenario – 1% AEP, Difference – Flood Velocity
26. Figure B05: Building Impacts Scenario – 1% AEP + CC, Difference – Flood Velocity
27. Figure B06: Building Impacts Scenario – PMF, Difference – Flood Velocity
28. Figure B07: Levee – 50% Blockage Scenario – 20% AEP, Difference – Flood Level
29. Figure B08: Levee – 50% Blockage Scenario – 5% AEP, Difference – Flood Level
30. Figure B09: Levee – 50% Blockage Scenario – 1% AEP, Difference – Flood Level
31. Figure B10: Levee – 50% Blockage Scenario – PMF, Difference – Flood Level
32. Figure B11: Levee – 50% Blockage Scenario – 20% AEP, Difference – Flood Velocity
33. Figure B12: Levee – 50% Blockage Scenario – 5% AEP, Difference – Flood Velocity
34. Figure B13: Levee – 50% Blockage Scenario – 1% AEP, Difference – Flood Velocity
35. Figure B14: Levee – 50% Blockage Scenario – PMF, Difference – Flood Velocity
36. Figure C01: Developed Scenario – 1% AEP + CC, Flood Planning Area
37. Figure D01: Developed Scenario – 1% AEP, Flood Planning Category 1 (Northern Beaches Council)
38. Figure D02: Developed Scenario – 1% AEP + CC, Flood Planning Category 1 (Northern Beaches Council)
39. Figure E01: Developed Scenario – 1% AEP, Flood Function
40. Figure E02: Developed Scenario – 1% AEP + CC, Flood Function
41. Figure E03: Developed Scenario – PMF, Flood Function
42. Figure E04: Developed Scenario – 1% AEP, Peak Hazard
43. Figure E05: Developed Scenario – 1% AEP + CC, Peak Hazard
44. Figure E06: Developed Scenario – PMF, Peak Hazard
45. Figure F01: Mitigation – Drainage (M03) Scenario – 20% AEP, Difference – Flood Level
46. Figure F02: Mitigation – Drainage (M03) Scenario – 5% AEP, Difference – Flood Level
47. Figure F03: Mitigation – Drainage (M03) Scenario – 1% AEP, Difference – Flood Level
48. Figure F04: Mitigation – Drainage (M03) Scenario – PMF, Difference – Flood Level
49. Figure F05: Mitigation – Drainage (M03) Scenario – 1% AEP + CC, Difference – Flood Level
50. Figure F06: Mitigation – Drainage (M03) Scenario – 20% AEP, Difference – Flood Velocity
51. Figure F07: Mitigation – Drainage (M03) Scenario – 5% AEP, Difference – Flood Velocity
52. Figure F08: Mitigation – Drainage (M03) Scenario – 1% AEP, Difference – Flood Velocity
53. Figure F09: Mitigation – Drainage (M03) Scenario – PMF, Difference – Flood Velocity
54. Figure F10: Mitigation – Drainage (M03) Scenario – 1% AEP + CC, Difference – Flood Velocity
55. Figure G01: Mitigation – Flood Gates (M04) Scenario – 20% AEP, Difference – Flood Level
56. Figure G02: Mitigation – Flood Gates (M04) Scenario – 5% AEP, Difference – Flood Level
57. Figure G03: Mitigation – Flood Gates (M04) Scenario – 1% AEP, Difference – Flood Level
58. Figure G04: Mitigation – Flood Gates (M04) Scenario – PMF, Difference – Flood Level
59. Figure G05: Mitigation – Flood Gates (M04) Scenario – 1% AEP + CC, Difference – Flood Level
60. Figure G06: Mitigation – Flood Gates (M04) Scenario – 20% AEP, Difference – Flood Velocity
61. Figure G07: Mitigation – Flood Gates (M04) Scenario – 5% AEP, Difference – Flood Velocity
62. Figure G08: Mitigation – Flood Gates (M04) Scenario – 1% AEP, Difference – Flood Velocity
63. Figure G09: Mitigation – Flood Gates (M04) Scenario – PMF, Difference – Flood Velocity
64. Figure G10: Mitigation – Flood Gates (M04) Scenario – 1% AEP + CC, Difference – Flood Velocity



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent
- 0.2m flood level contour
- 1m flood level contour

Peak flood depth (m)	
<= 0.02	
0.02 - 0.10	
0.10 - 0.20	
0.20 - 0.40	
0.40 - 0.60	
0.60 - 0.80	
0.80 - 1.00	
1.00 - 1.20	

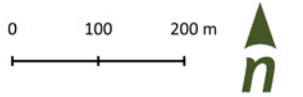
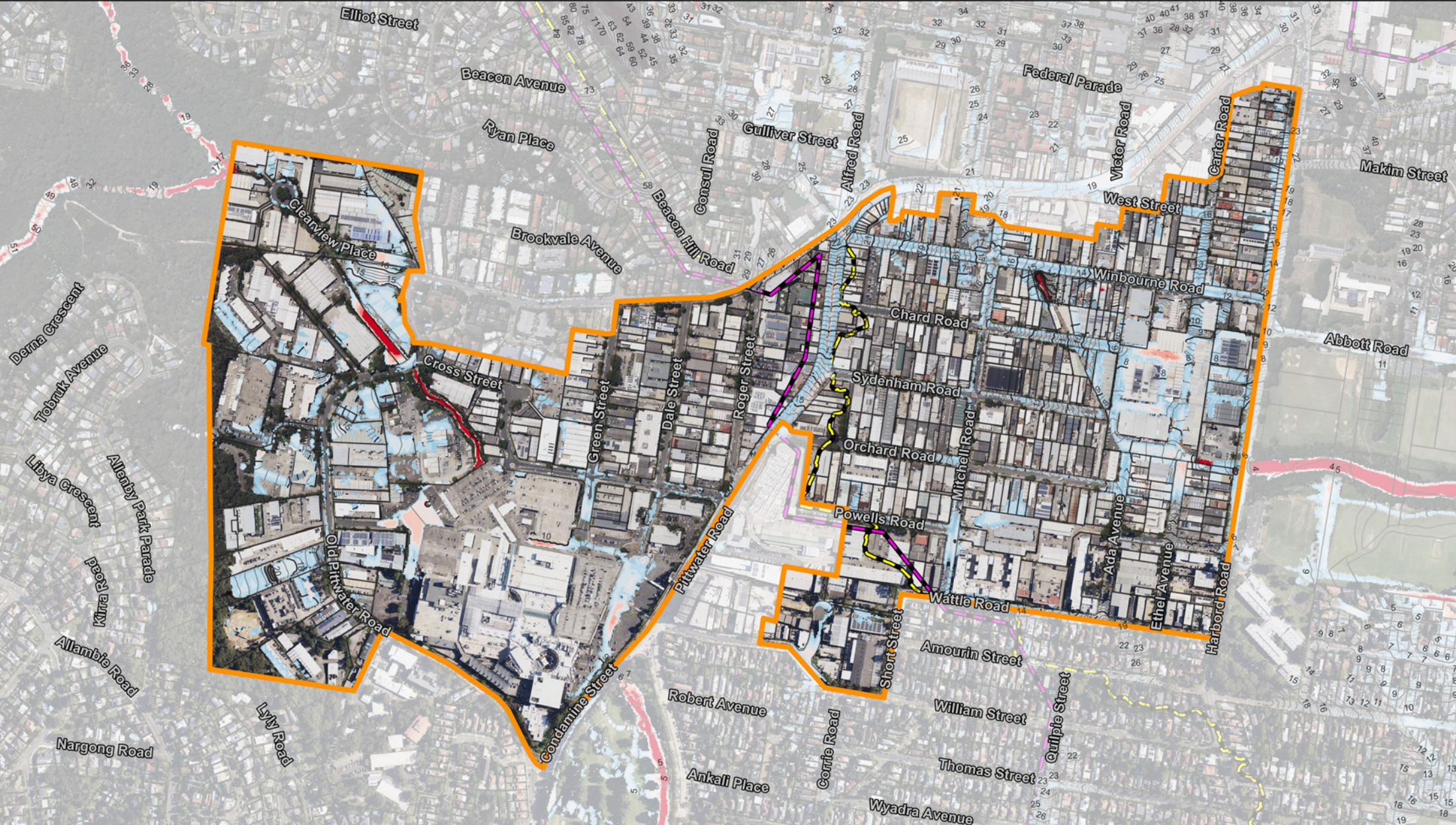


FIGURE A01
Existing Scenario - 20% AEP
Peak Flood Depth



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent
- 0.2m flood level contour
- 1m flood level contour

Peak flood depth (m)	
<= 0.02	
0.02 - 0.10	
0.10 - 0.20	
0.20 - 0.40	
0.40 - 0.60	
0.60 - 0.80	
0.80 - 1.00	
1.00 - 1.20	

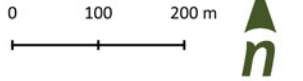
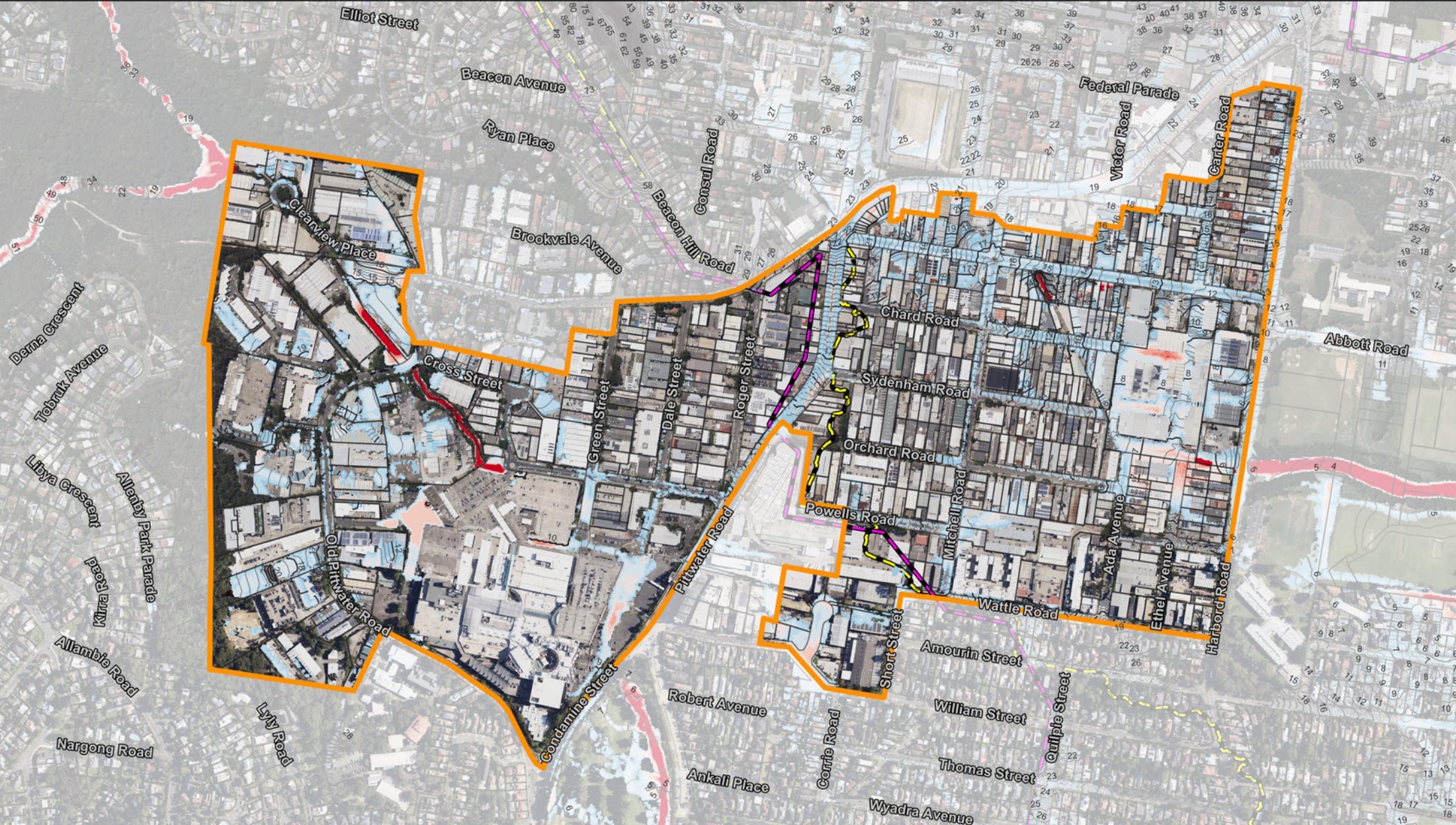


FIGURE A01
Existing Scenario - 20% AEP
Peak Flood Depth



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent
- 1m flood level contour
- 0.2m flood level contour

Peak flood depth (m)

- <= 0.02
- 0.02 - 0.10
- 0.10 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20

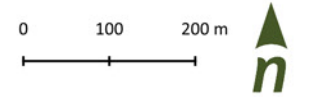
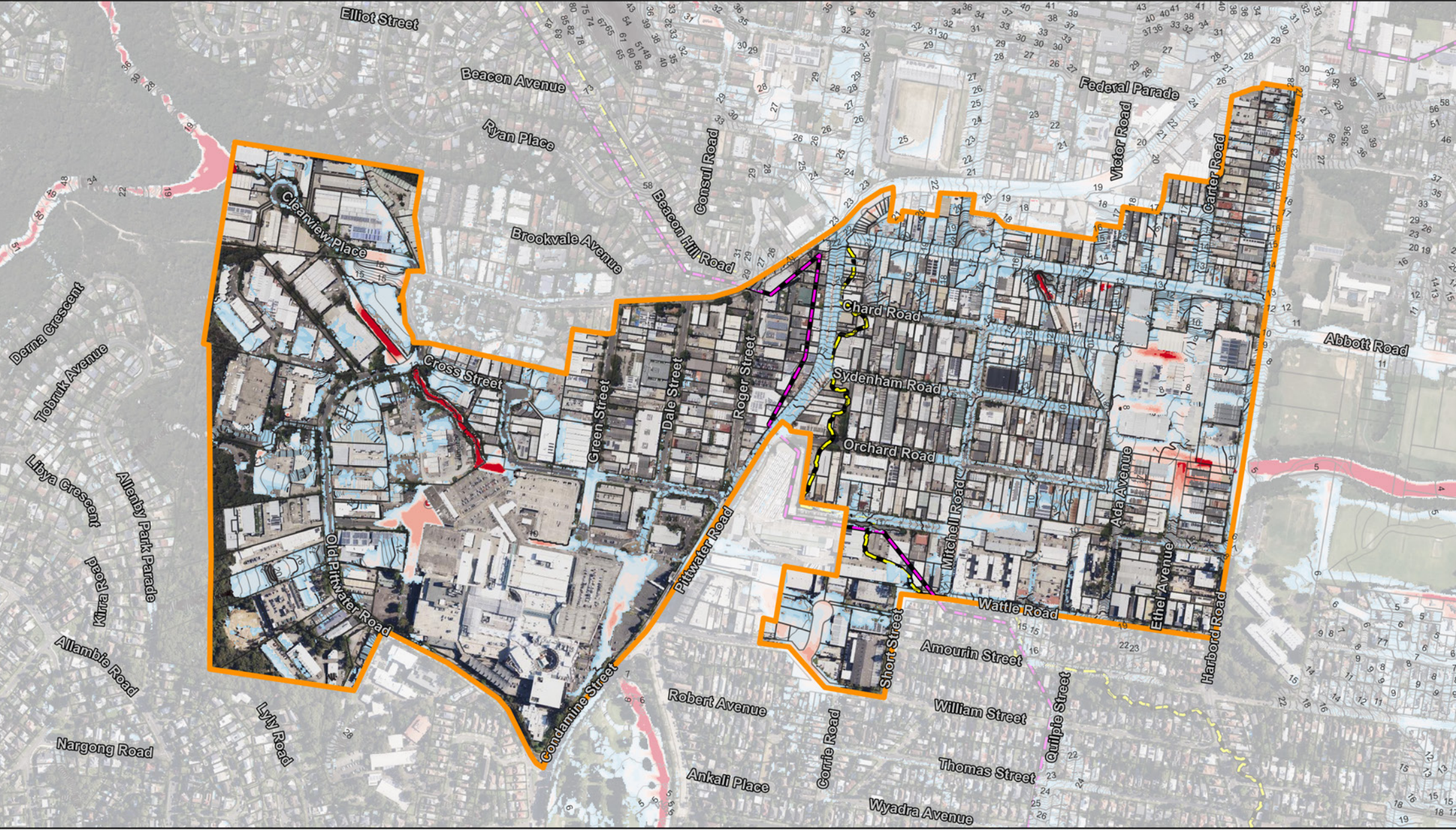


FIGURE A02
Existing Scenario - 5% AEP
Peak Flood Depth



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent
- 1m flood level contour
- 0.2m flood level contour

Peak flood depth (m)

<= 0.02
0.02 - 0.10
0.10 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
0.80 - 1.00
1.00 - 1.20

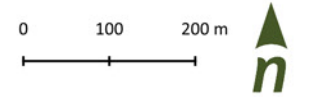
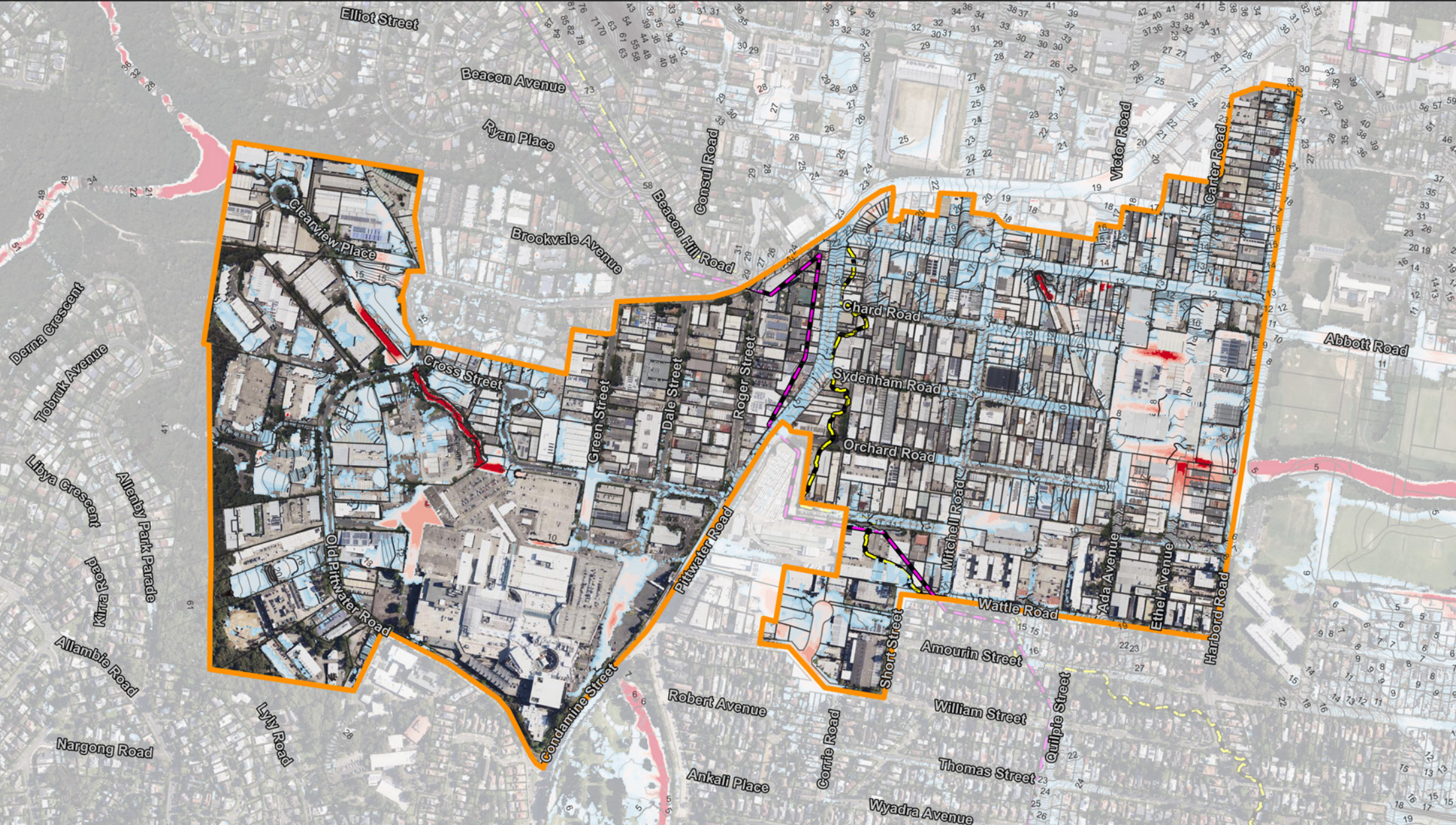


FIGURE A03
Existing Scenario - 1% AEP
Peak Flood Depth



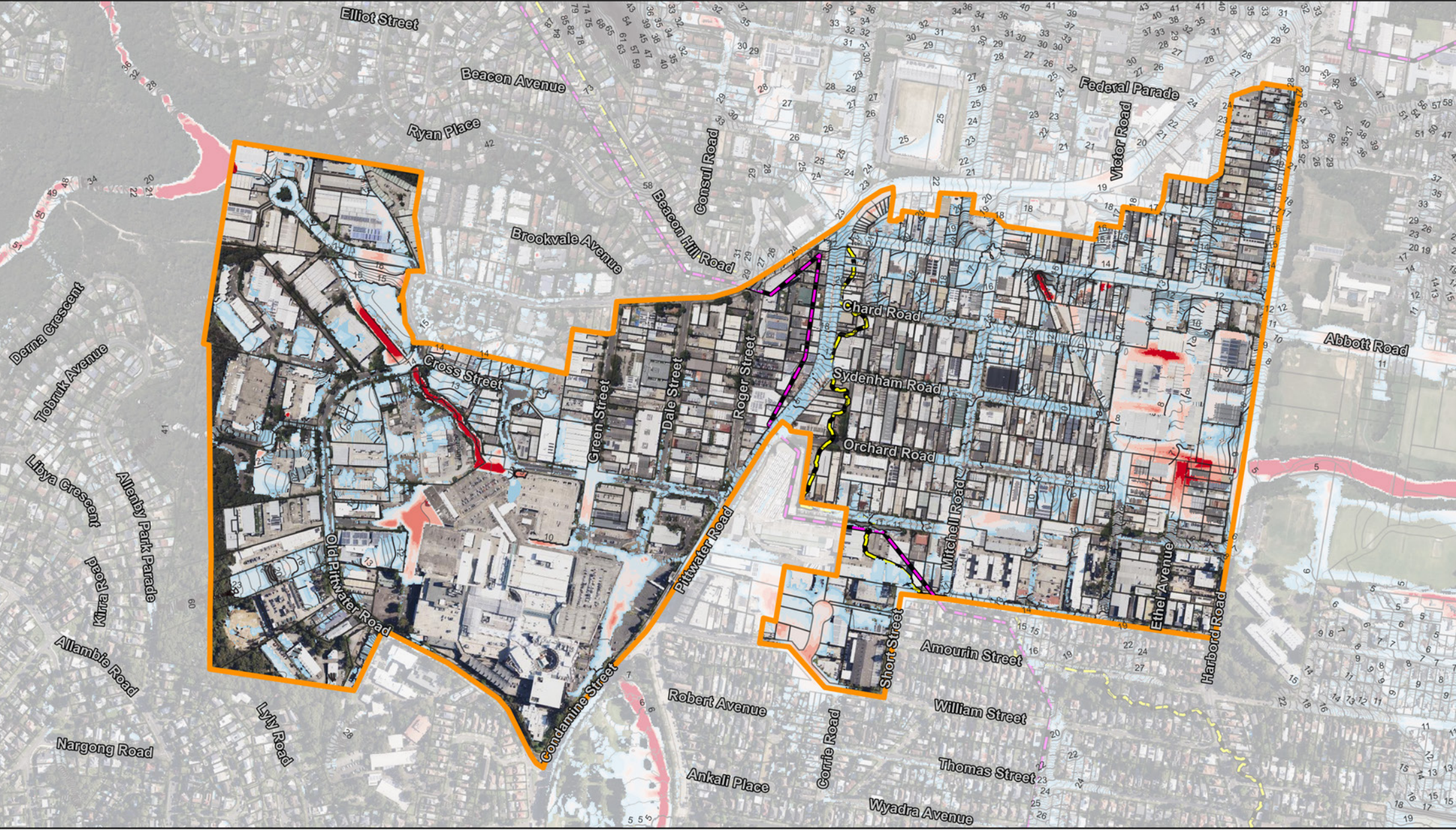
LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent
- 1m flood level contour
- 0.2m flood level contour

Peak flood depth (m)

- <= 0.02
- 0.02 - 0.10
- 0.10 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20

FIGURE A04
Existing Scenario - 0.5% AEP
Peak Flood Depth



LEGEND

- Structure Plan study area
- Lots
- Mainly Lagoon model extent
- Greendale Creek model extent
- 1m flood level contour
- 0.2m flood level contour

Peak flood depth (m)

- <= 0.02
- 0.02 - 0.10
- 0.10 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20

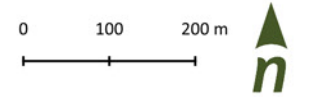
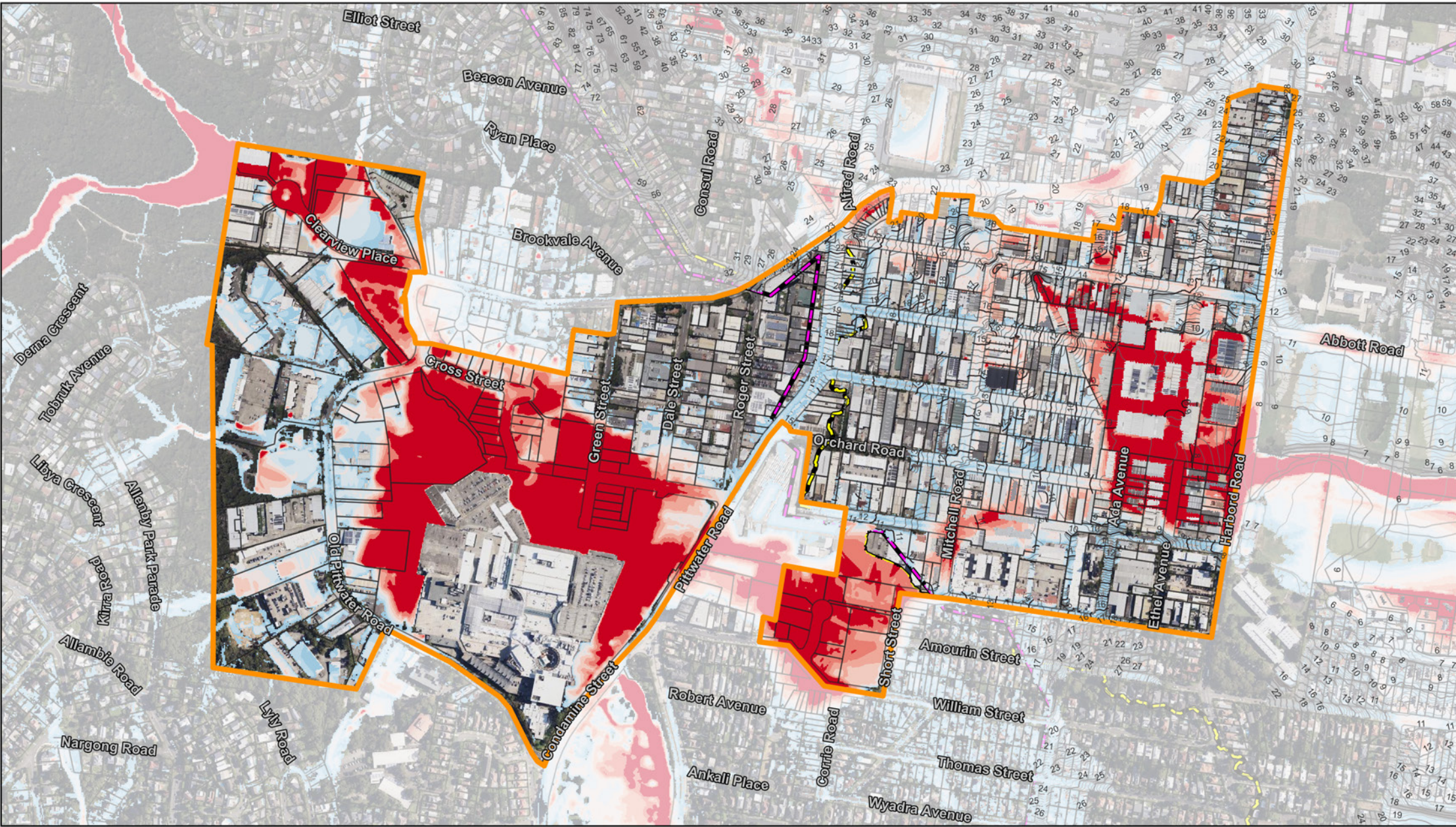
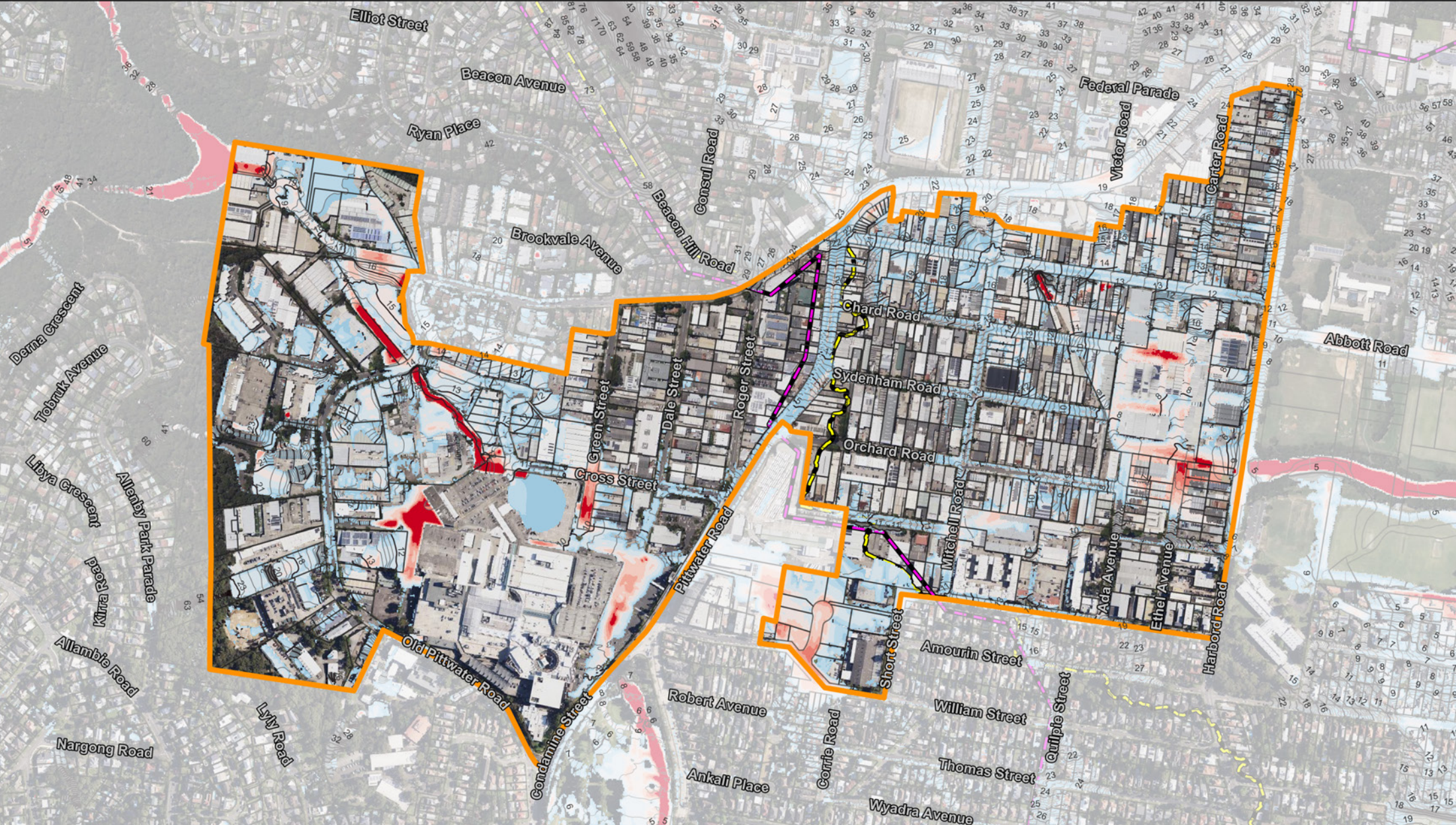


FIGURE A05
Existing Scenario - 0.2% AEP
Peak Flood Depth





LEGEND

- Structure Plan study area
- Lots
- Mainly Lagoon model extent
- Greendale Creek model extent
- 1m flood level contour
- 0.2m flood level contour

Peak flood depth (m)	
	<= 0.02
	0.02 - 0.10
	0.10 - 0.20
	0.20 - 0.40
	0.40 - 0.60
	0.60 - 0.80
	0.80 - 1.00
	1.00 - 1.20

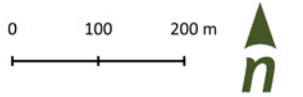
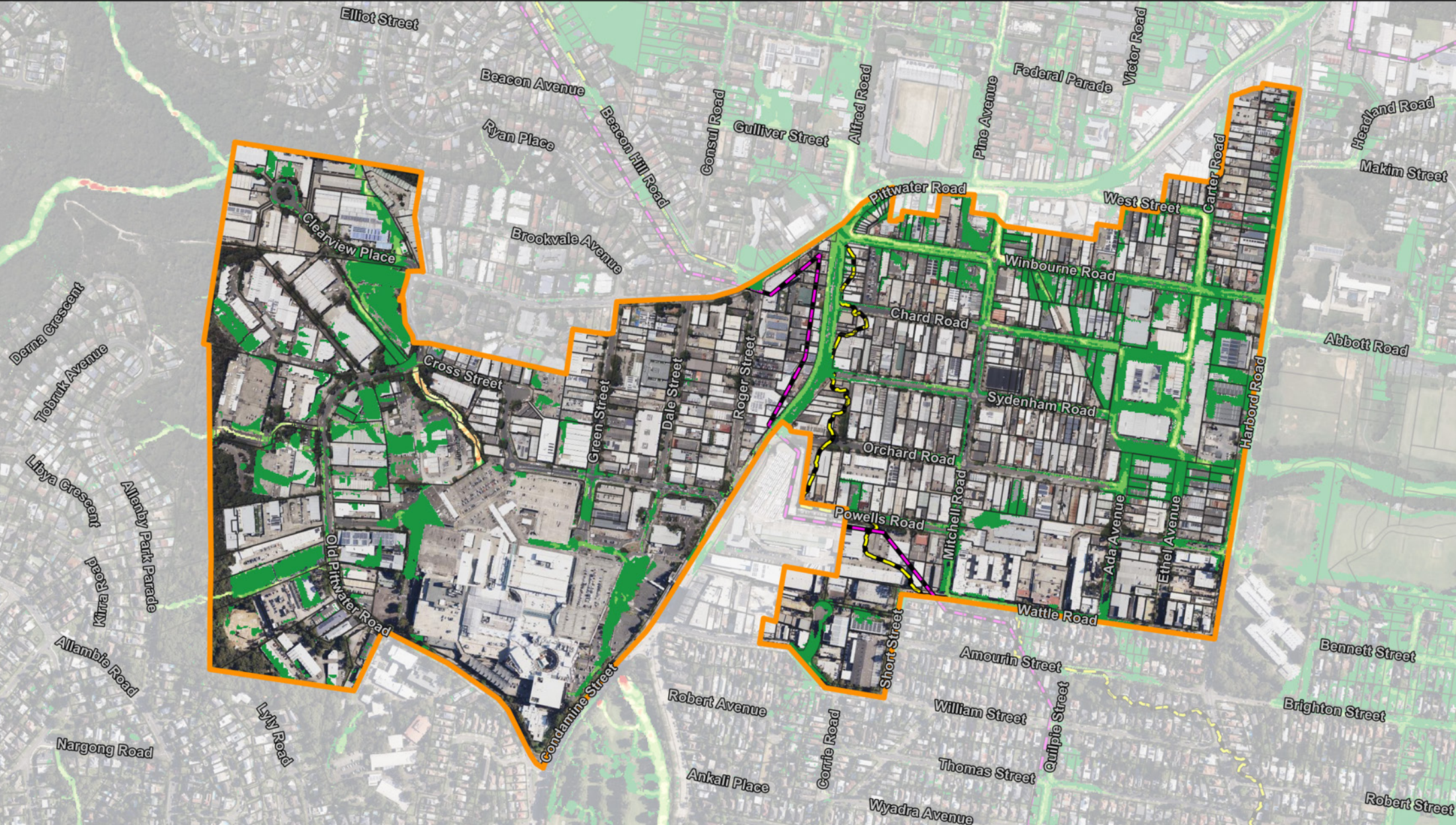


FIGURE A07
Existing Scenario - 1% AEP+CC
Peak Flood Depth



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood velocity (m/s)	
<= 0.50	
0.50 - 1.00	
1.00 - 1.50	
1.50 - 2.00	
2.00 - 2.50	
2.50 - 3.00	
> 3.00	

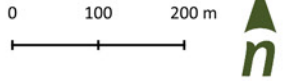
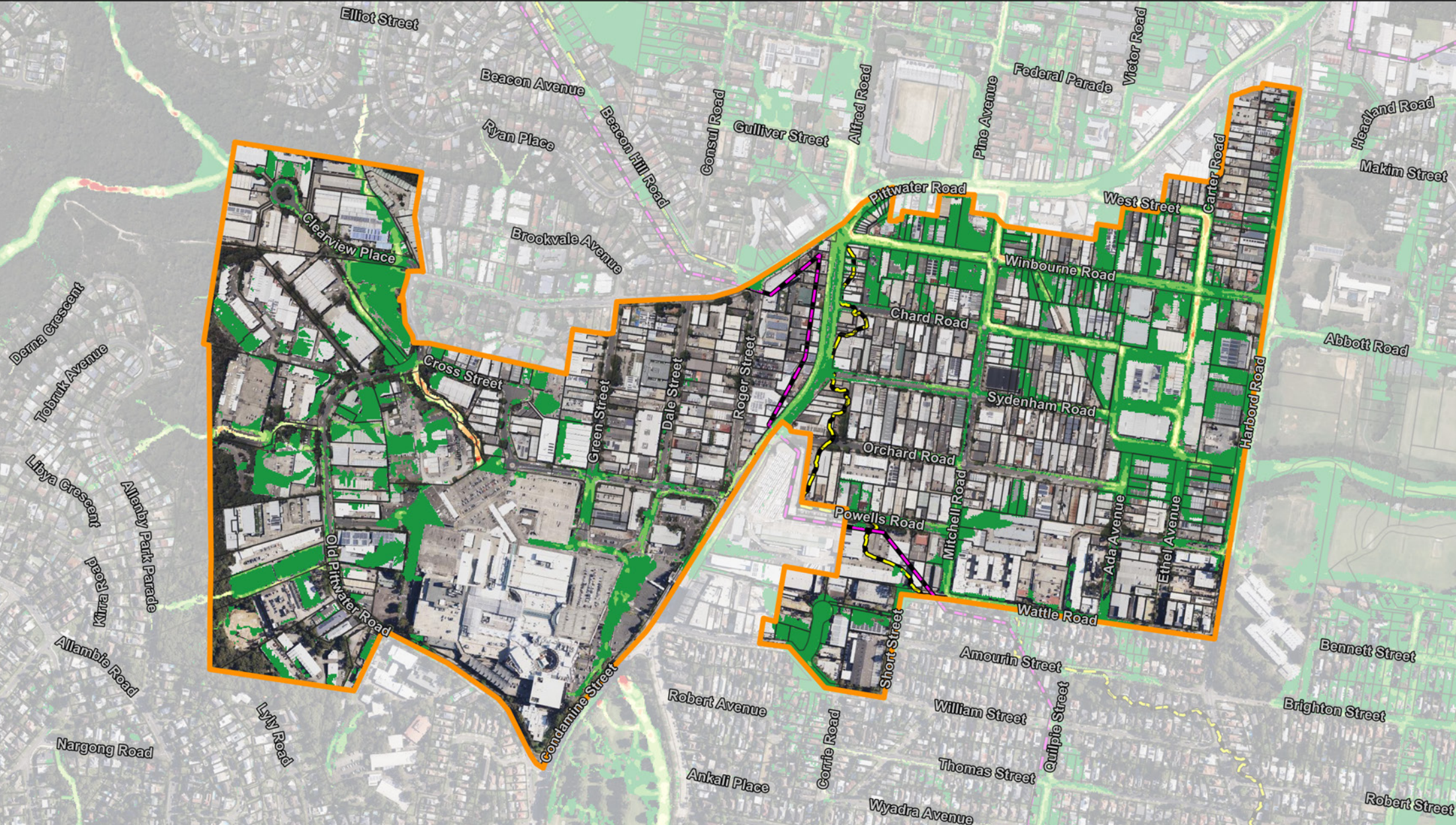


FIGURE A08
Existing Scenario - 20% AEP
Peak Flood Velocity



- LEGEND**
- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Greendale Creek model extent

Peak flood velocity (m/s)	
<= 0.50	
0.50 - 1.00	
1.00 - 1.50	
1.50 - 2.00	
2.00 - 2.50	
2.50 - 3.00	
> 3.00	

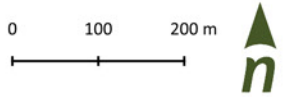
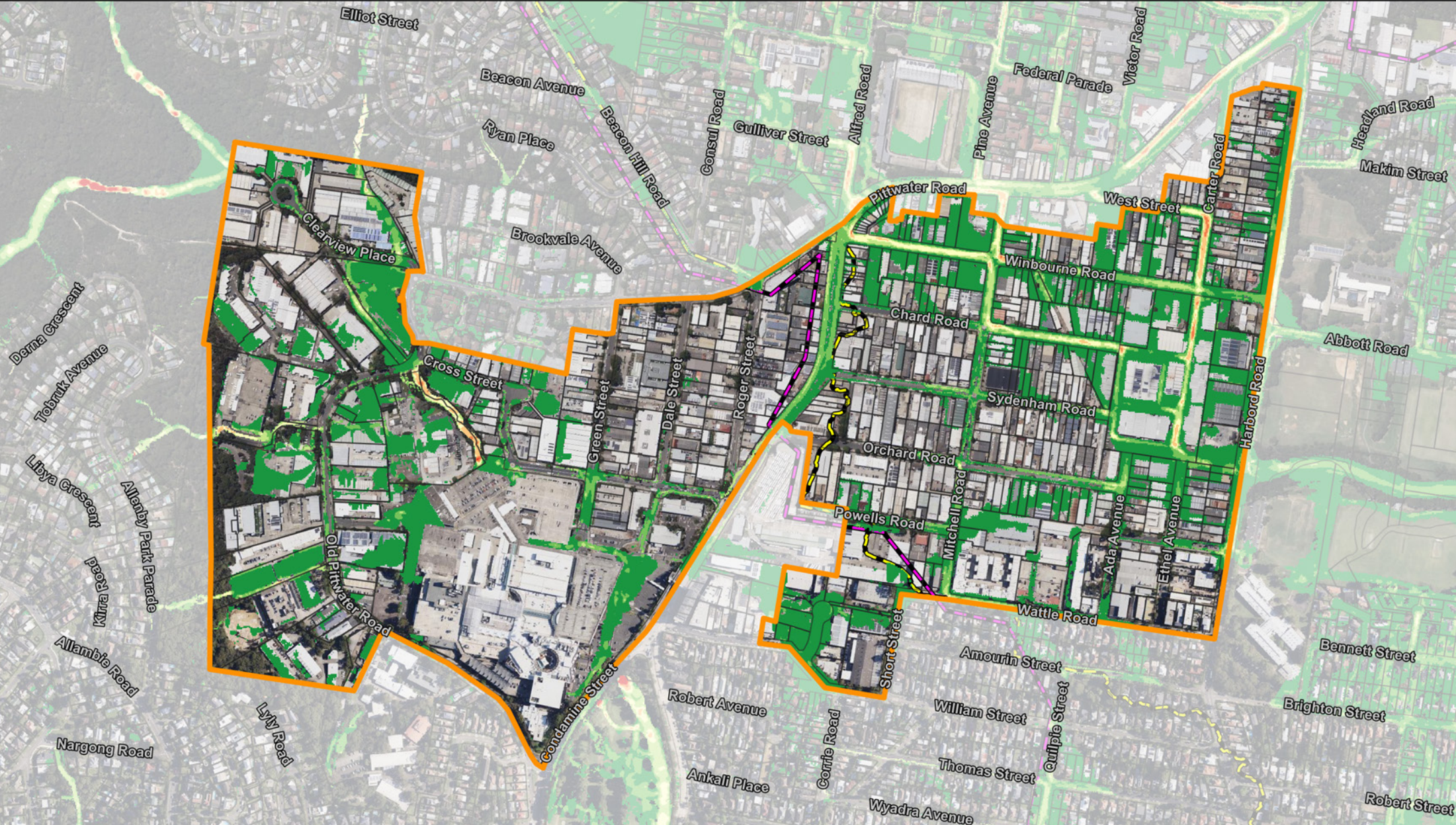


FIGURE A09
Existing Scenario - 5% AEP
Peak Flood Velocity



LEGEND

- Structure Plan study area
- Lots
- Mainly Lagoon model extent
- Greendale Creek model extent

Peak flood velocity (m/s)

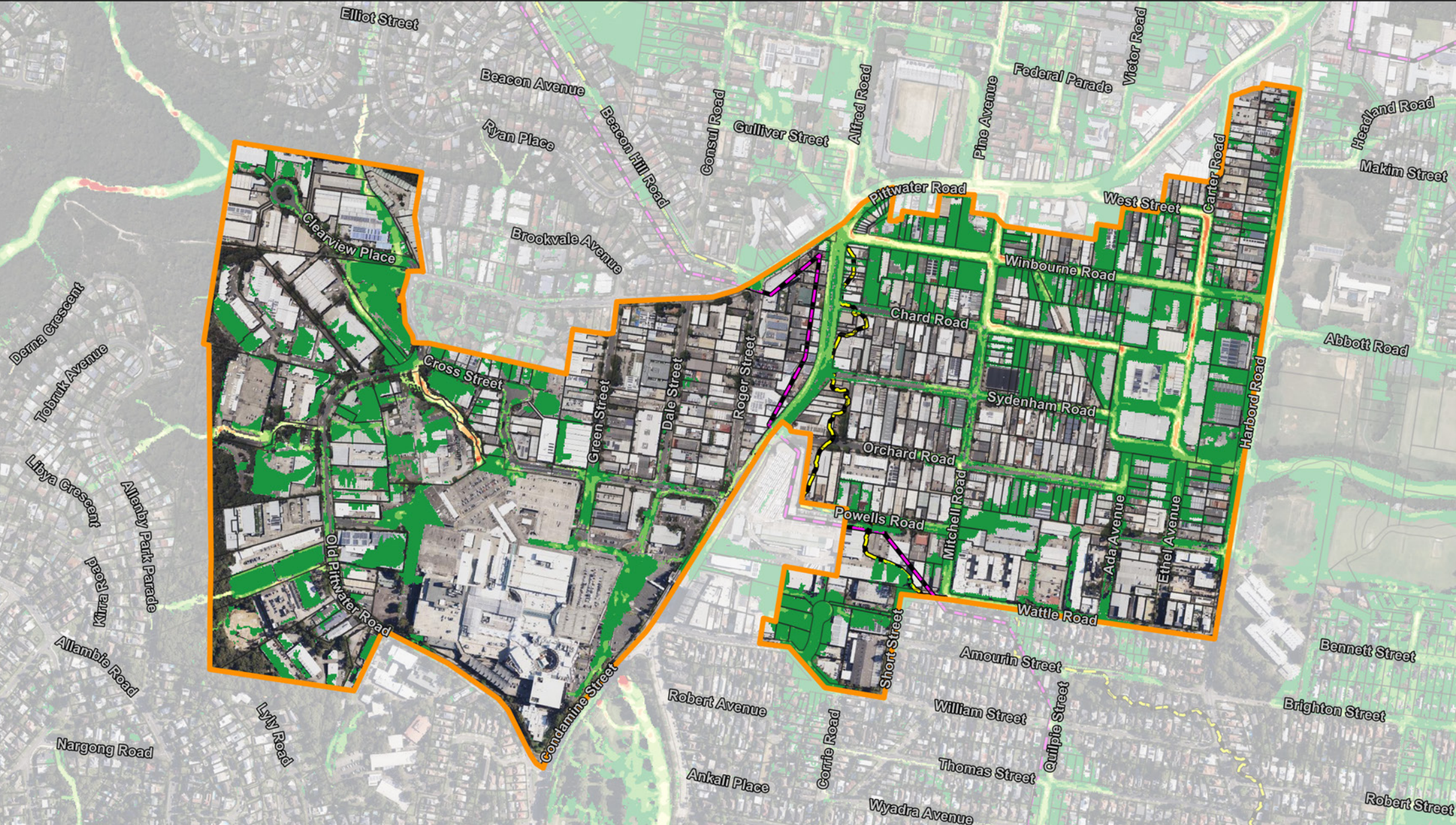
- <= 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- 2.00 - 2.50
- 2.50 - 3.00
- > 3.00

FIGURE A10
Existing Scenario - 1% AEP
Peak Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:8,800 (A4)

Originator:
Checked:
Approved:

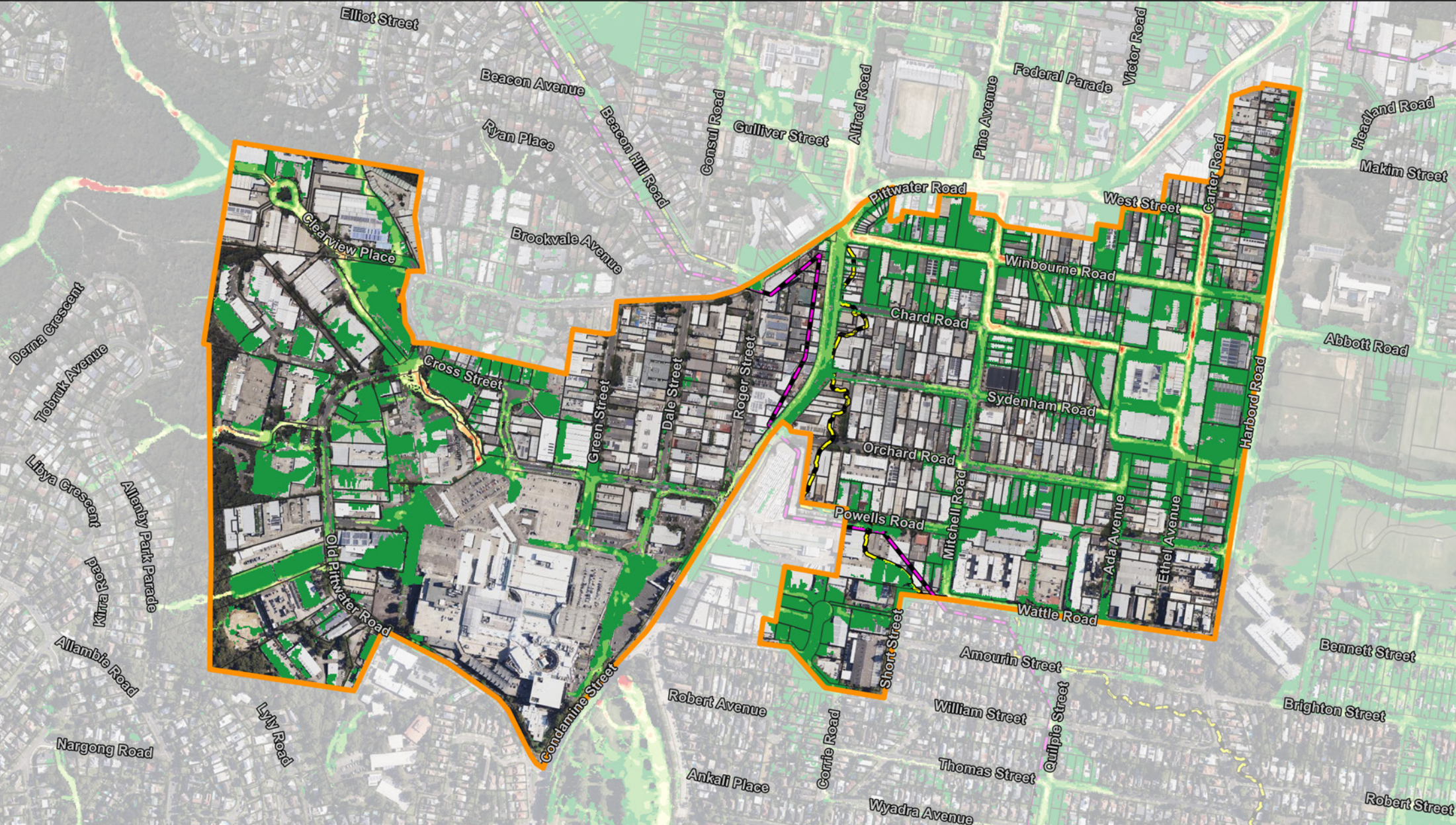
AN
PW
SH



- LEGEND**
- Structure Plan study area
 - Lots
 - Mainly Lagoon model extent
 - Greendale Creek model extent

Peak flood velocity (m/s)	
<= 0.50	
0.50 - 1.00	
1.00 - 1.50	
1.50 - 2.00	
2.00 - 2.50	
2.50 - 3.00	
> 3.00	

FIGURE A11
Existing Scenario - 0.5% AEP
Peak Flood Velocity



- LEGEND**
- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Greendale Creek model extent

Peak flood velocity (m/s)	
<= 0.50	
0.50 - 1.00	
1.00 - 1.50	
1.50 - 2.00	
2.00 - 2.50	
2.50 - 3.00	
> 3.00	

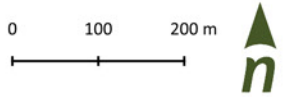
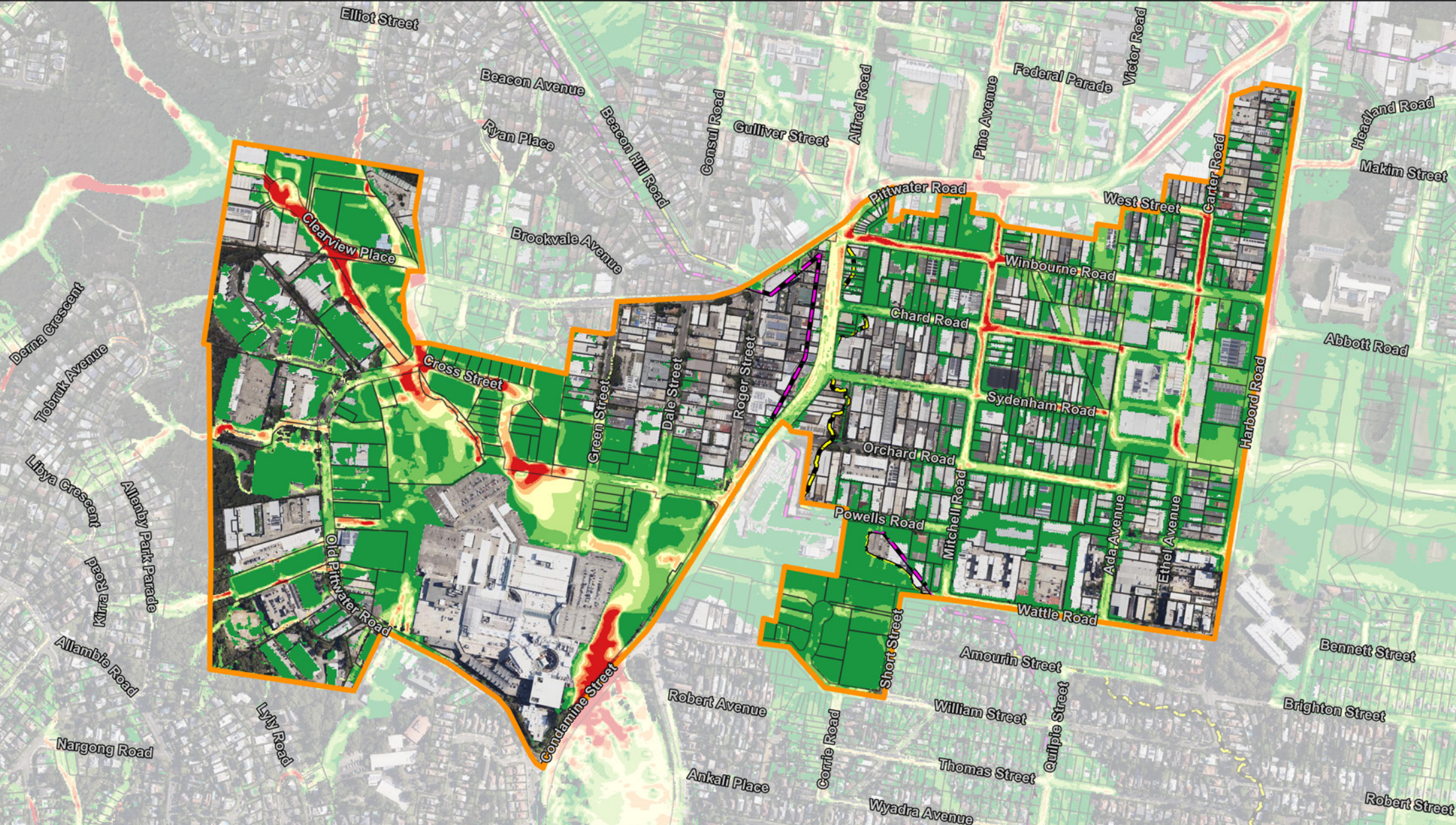


FIGURE A12
Existing Scenario - 0.2% AEP
Peak Flood Velocity



LEGEND

- Structure Plan study area
- Lots
- Mainly Lagoon model extent
- Greendale Creek model extent

Peak flood velocity (m/s)

- <= 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- 2.00 - 2.50
- 2.50 - 3.00
- > 3.00

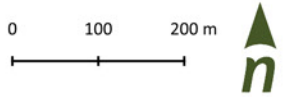
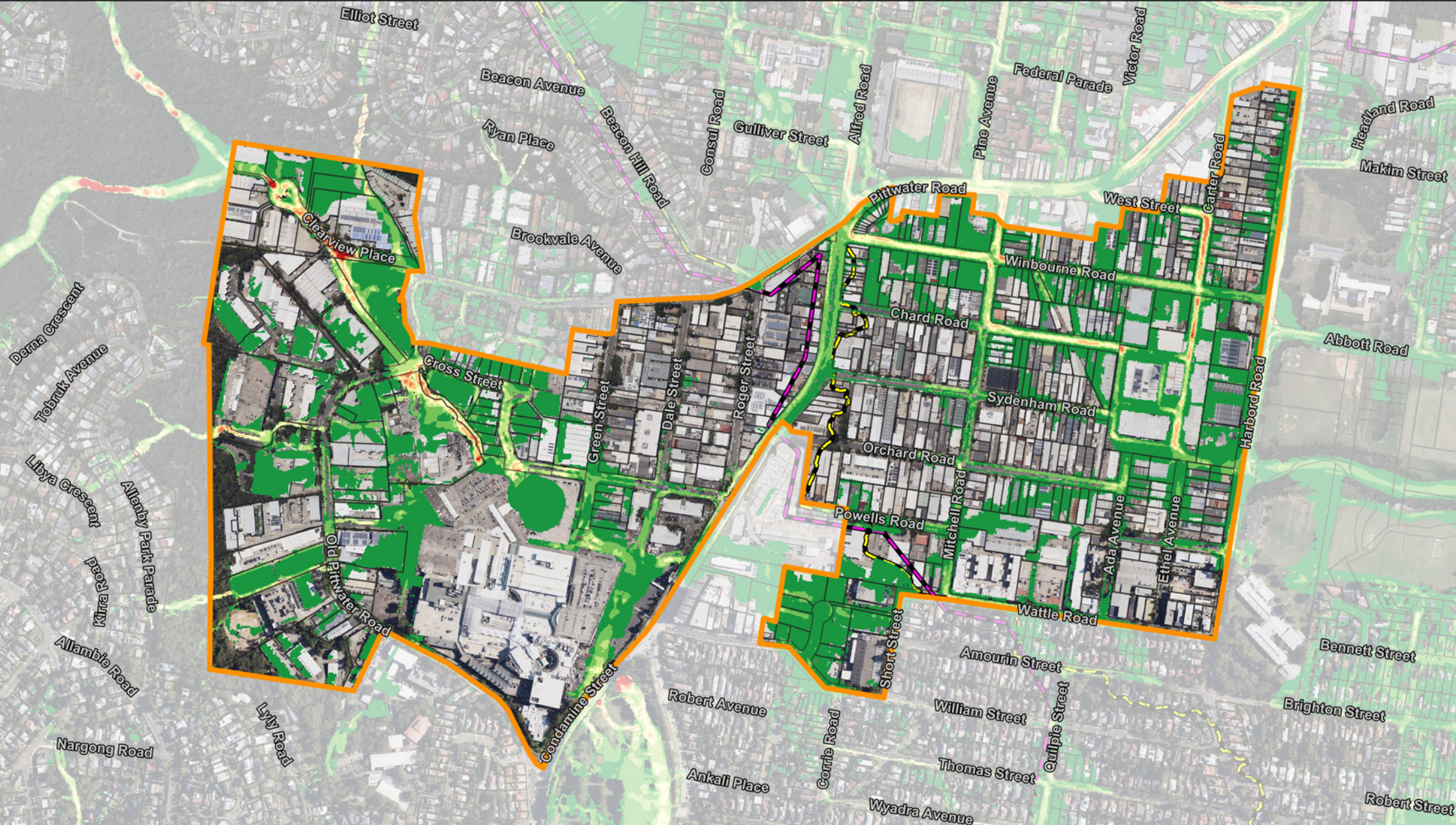


FIGURE A13
Existing Scenario - PMF
Peak Flood Velocity



LEGEND

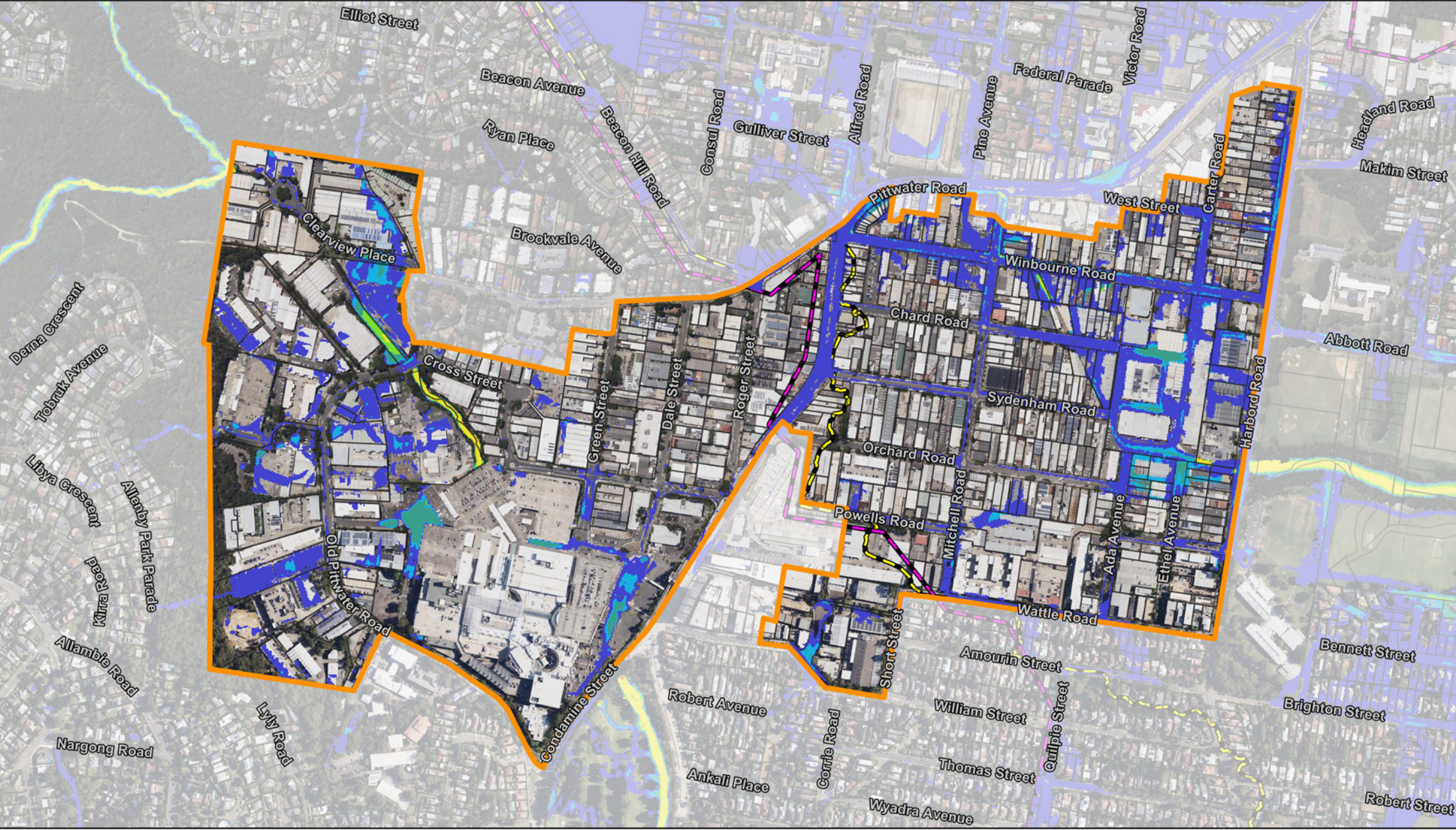
- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood velocity (m/s)	
	<= 0.50
	0.50 - 1.00
	1.00 - 1.50
	1.50 - 2.00
	2.00 - 2.50
	2.50 - 3.00
	> 3.00

FIGURE A14
Existing Scenario - 1% AEP+CC
Peak Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:8,800 (A4)

Originator:	AN
Checked:	PW
Approved:	SH



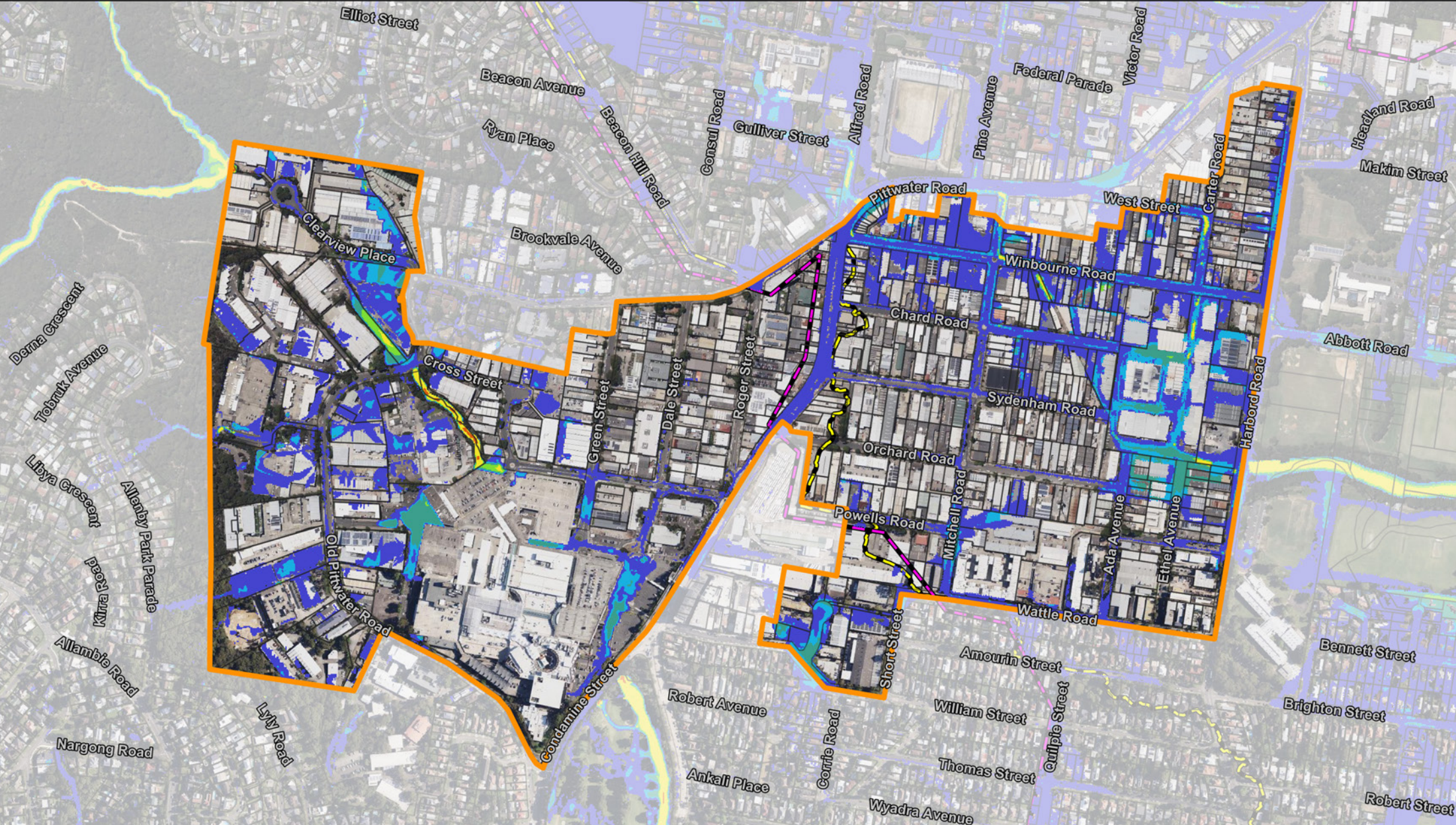
LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

FIGURE A15
Existing Scenario - 20% AEP
Peak Flood Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

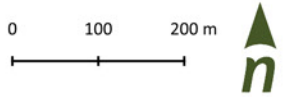
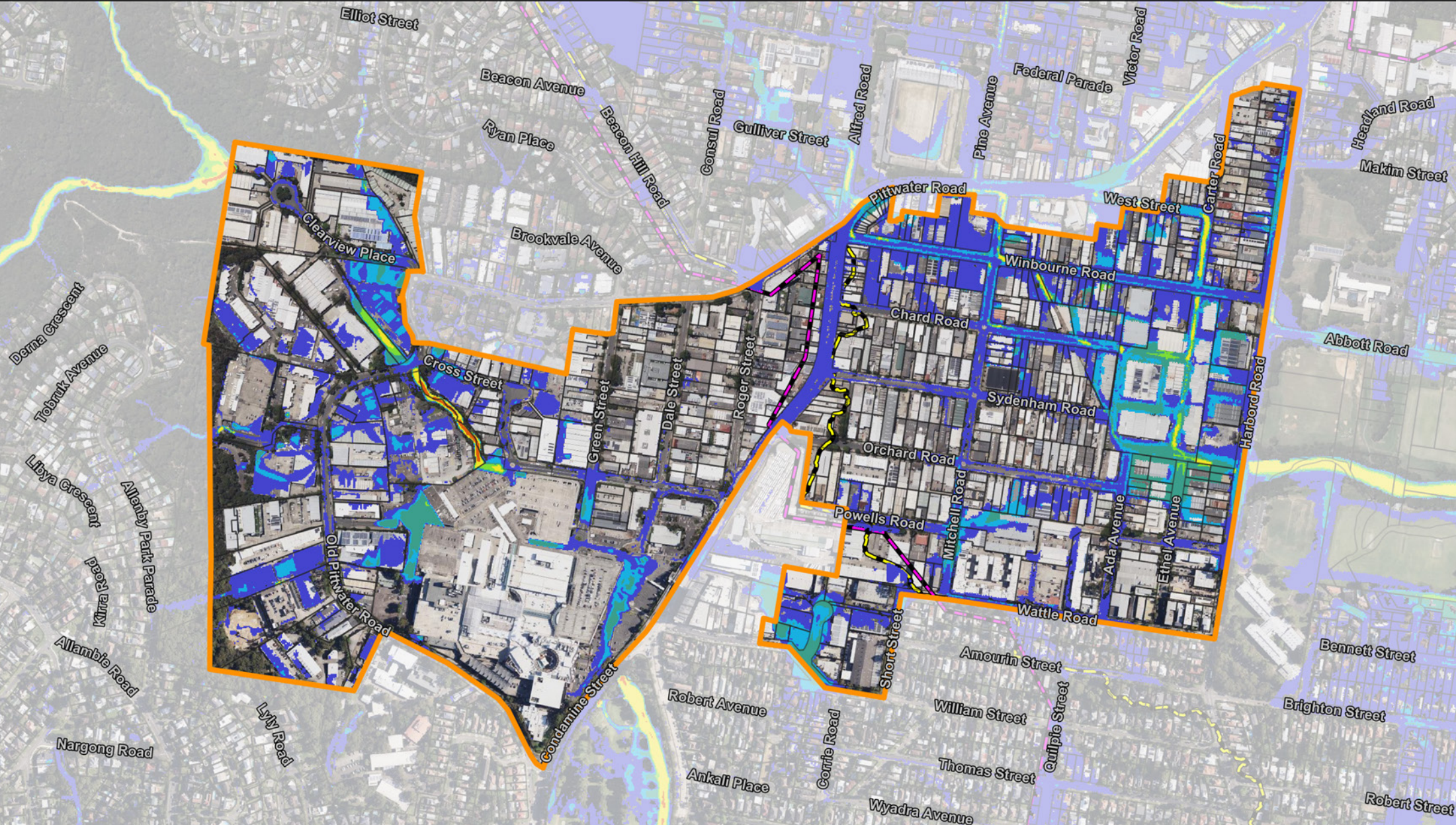


FIGURE A16
Existing Scenario - 5% AEP
Peak Flood Hazard



- LEGEND**
- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Greendale Creek model extent

- Peak flood hazard (ZAEM1)**
- H1
 - H2
 - H3
 - H4
 - H5
 - H6

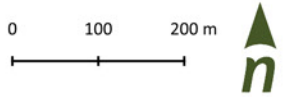
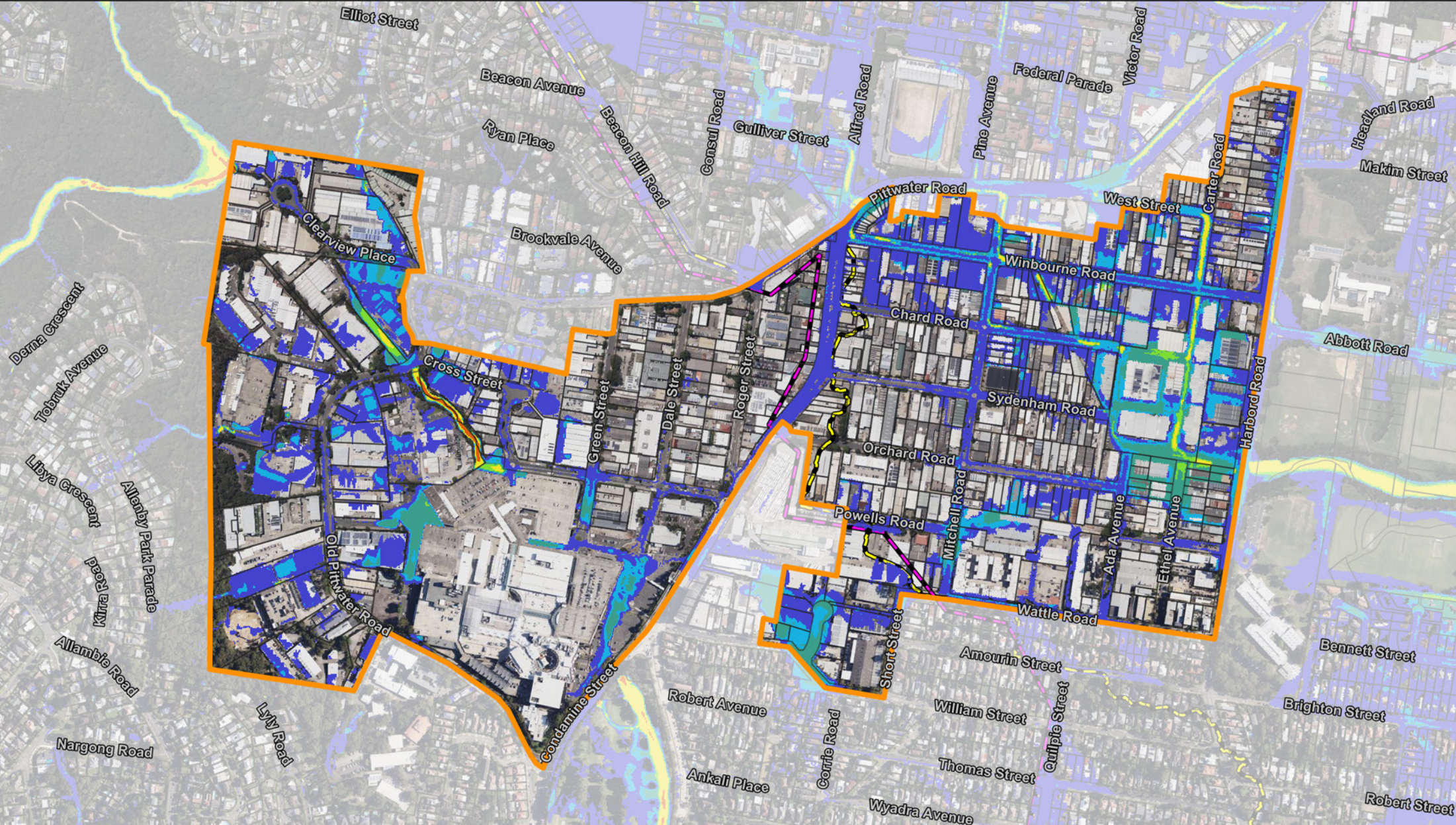


FIGURE A17
Existing Scenario - 1% AEP
Peak Flood Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

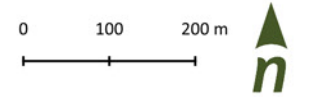
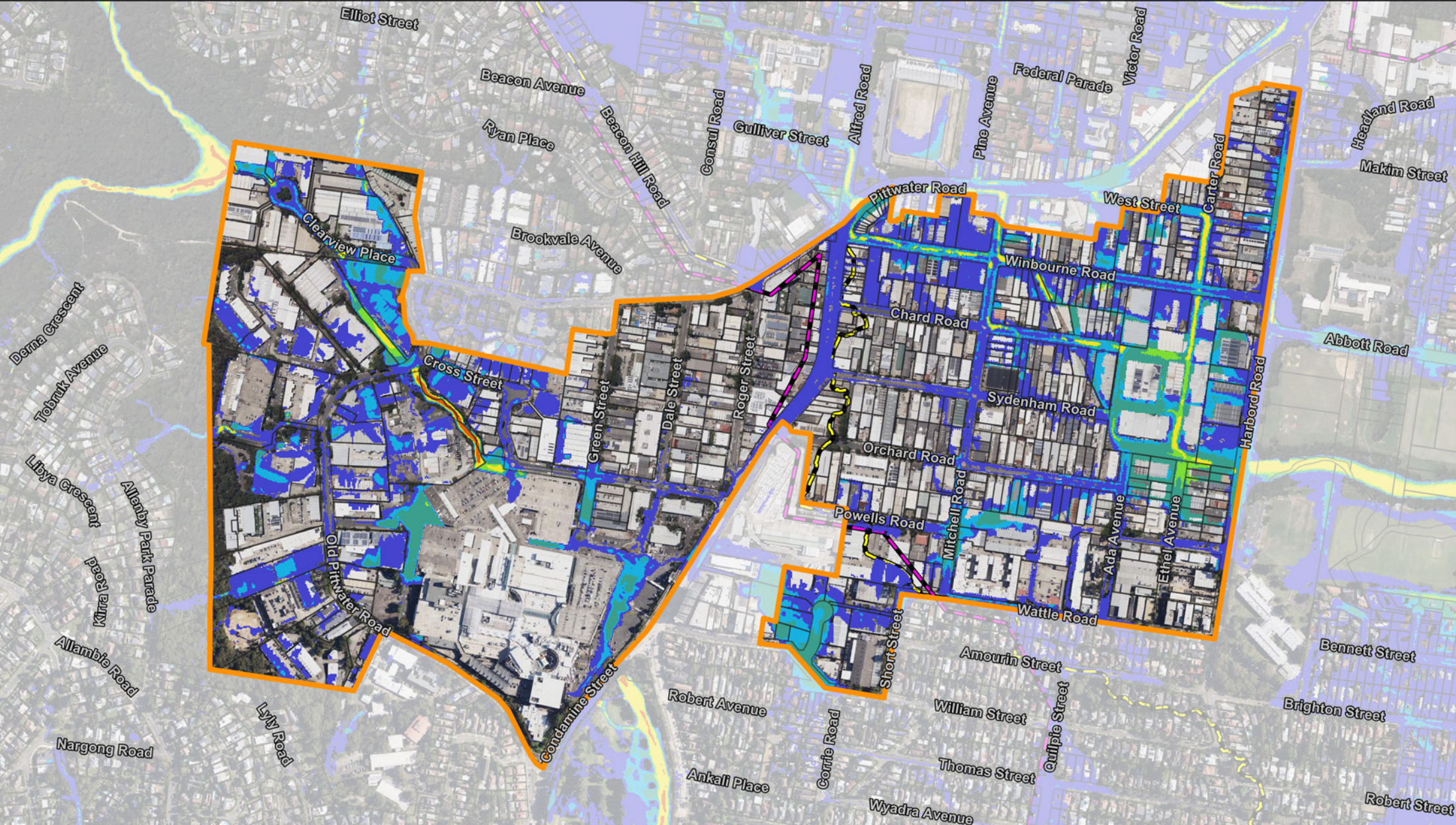


FIGURE A18
Existing Scenario - 0.5% AEP
Peak Flood Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

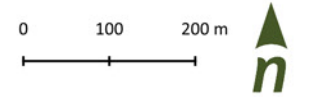


FIGURE A19
Existing Scenario - 0.2% AEP
Peak Flood Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

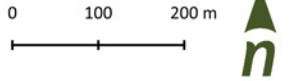
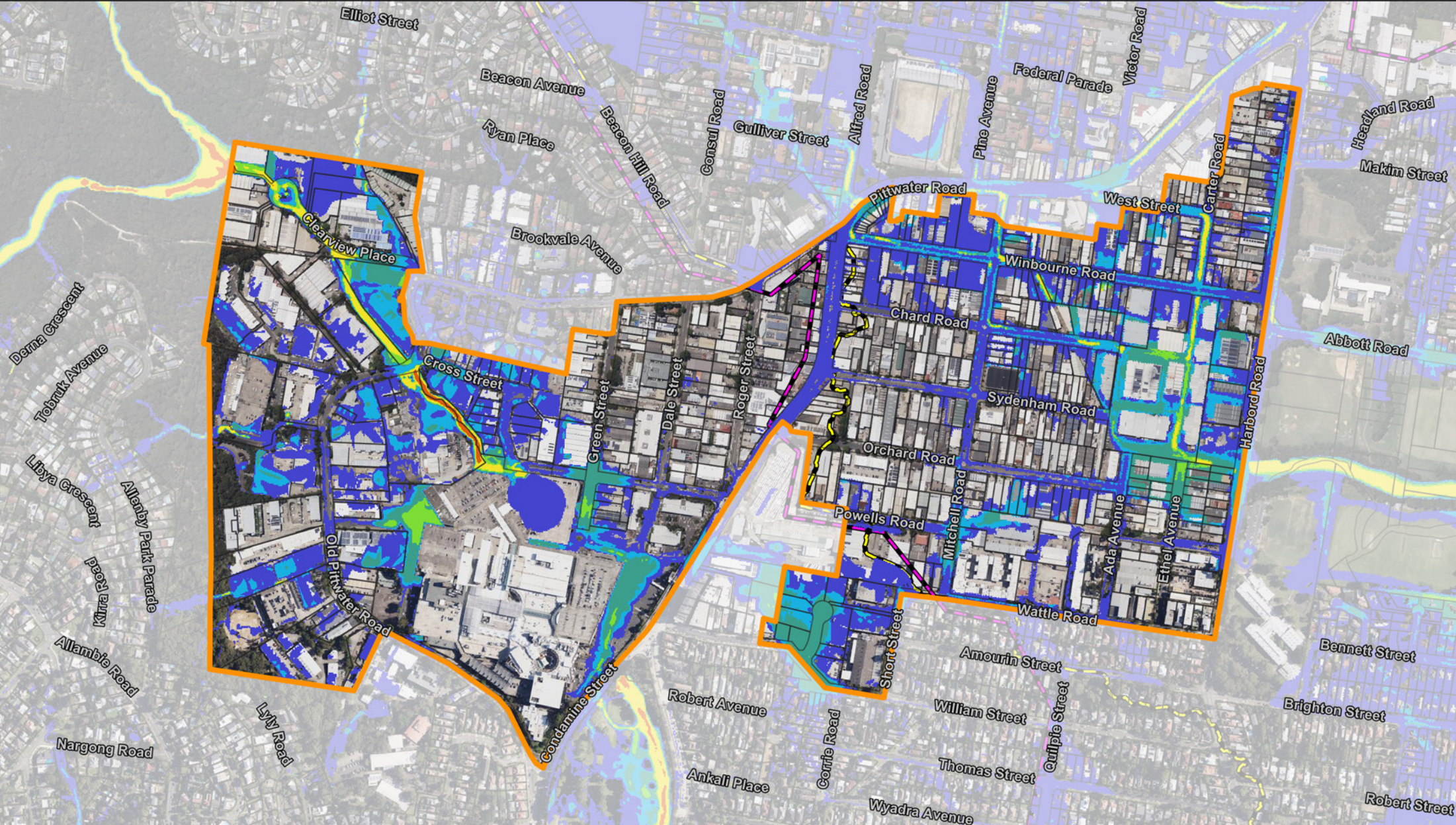


FIGURE A20
Existing Scenario - PMF
Peak Flood Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

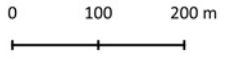
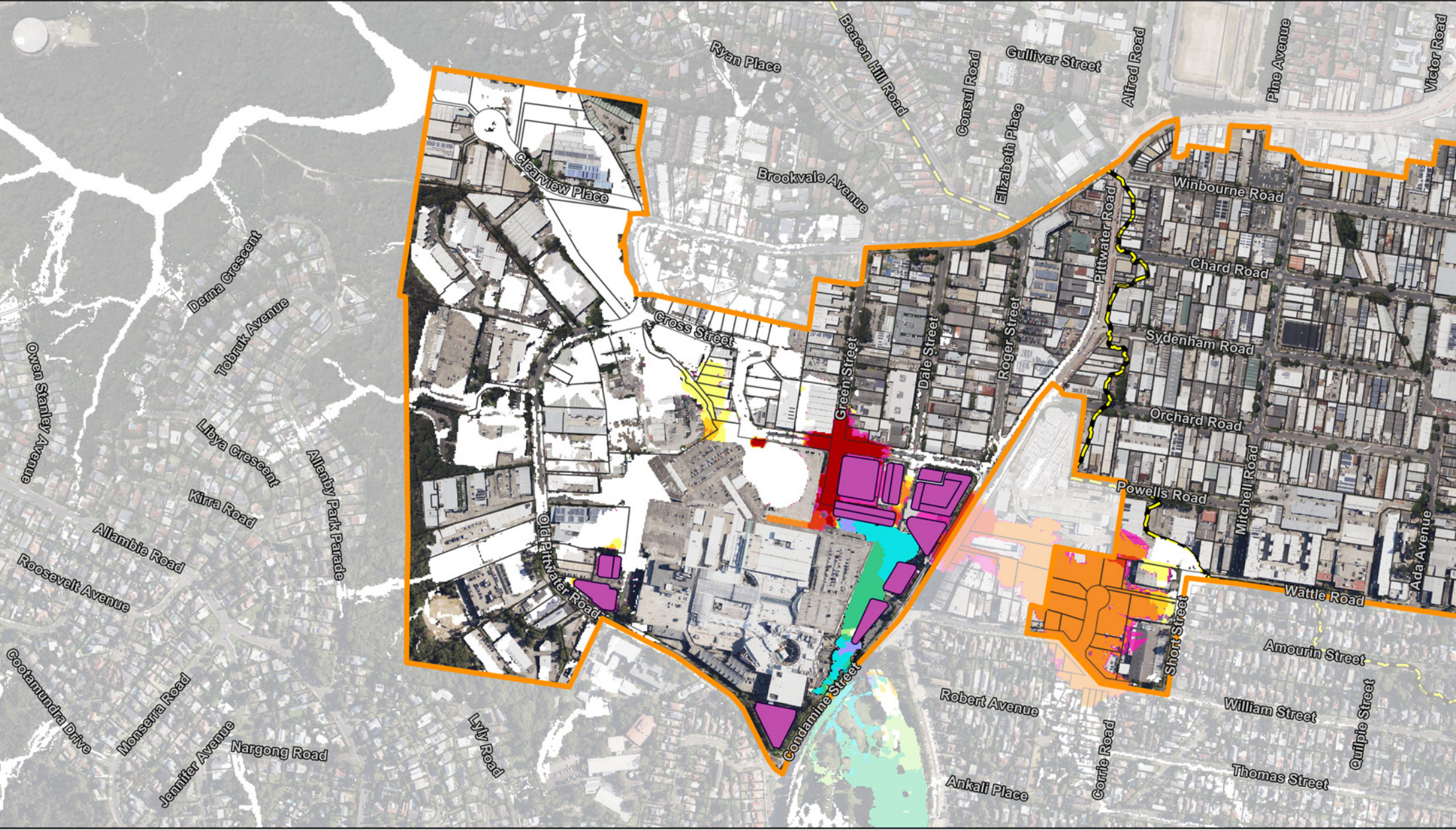


FIGURE A21
Existing Scenario - 1% AEP+CC
Peak Flood Hazard

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:8,800 (A4)

Originator: AN
Checked: PW
Approved: SH



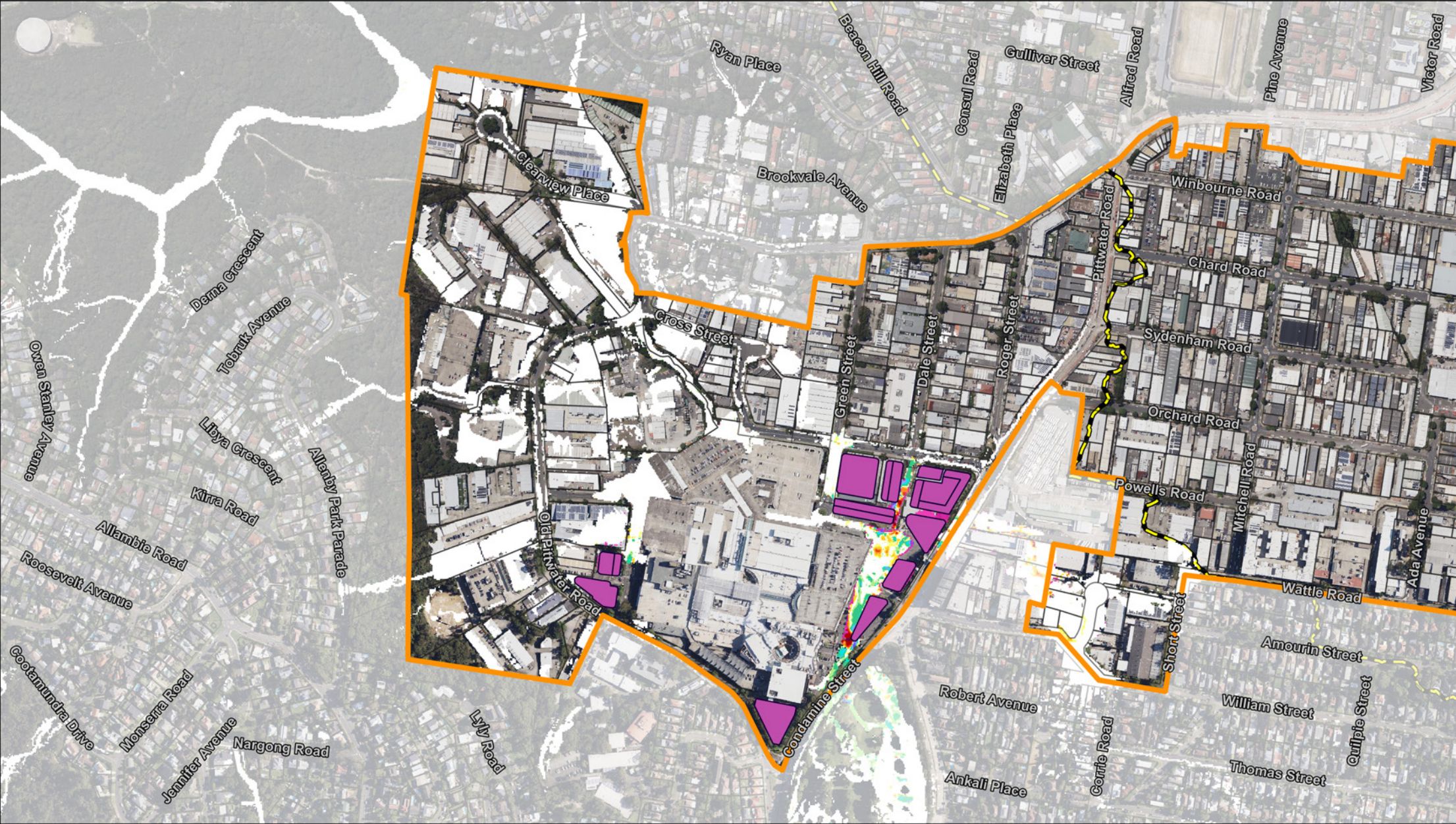
LEGEND

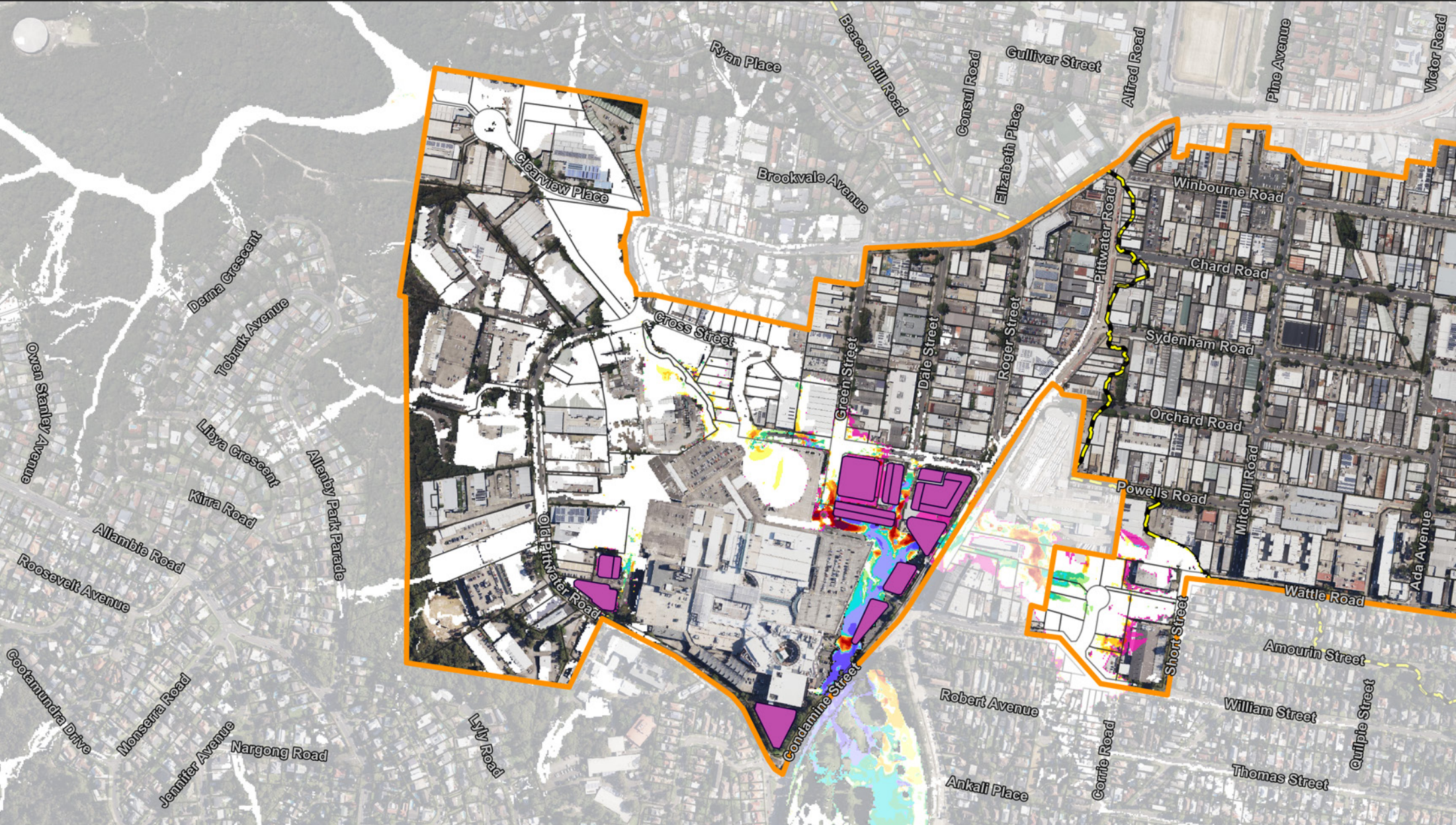
- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Proposed building footprints

Change in flood level (m)	
<= -0.5	
-0.5 - -0.2	
-0.2 - -0.1	
-0.1 - -0.05	
-0.05 - -0.02	
-0.02 - -0.01	
-0.01 - 0.01	

0.01 - 0.02	
0.02 - 0.05	
0.05 - 0.1	
0.1 - 0.2	
0.2 - 0.5	
> 0.5	
Previously wet now dry	
Previously dry now wet	

FIGURE B02
Building Impacts Scenario - 1% AEP+CC
Difference - Flood Level





LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Proposed building footprints

Change in flood velocity (m/s)

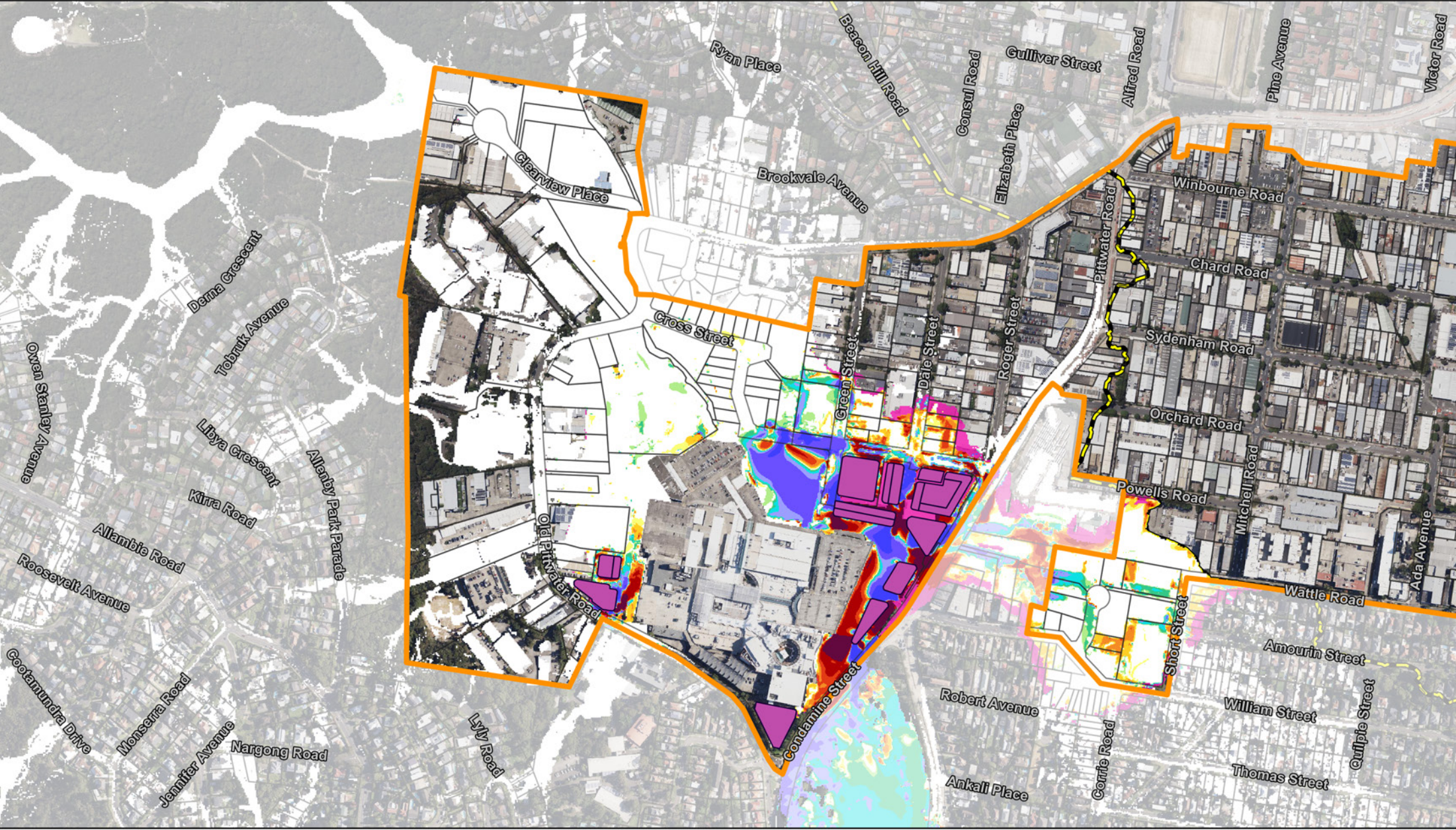
<= -0.5
-0.5 - -0.2
-0.2 - -0.1
-0.1 - -0.05
-0.05 - -0.02
-0.02 - -0.01
-0.01 - 0.01

0.01 - 0.02
0.02 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
> 0.5
Previously wet now dry
Previously dry now wet

FIGURE B05
Building Impacts Scenario - 1% AEP+CC
Difference - Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Proposed building footprints

Change in flood velocity (m/s)

<= -0.5
-0.5 - -0.2
-0.2 - -0.1
-0.1 - -0.05
-0.05 - -0.02
-0.02 - -0.01
-0.01 - 0.01

0.01 - 0.02
0.02 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
> 0.5
Previously wet now dry
Previously dry now wet

FIGURE B06
Building Impacts Scenario - PMF
Difference - Flood Velocity

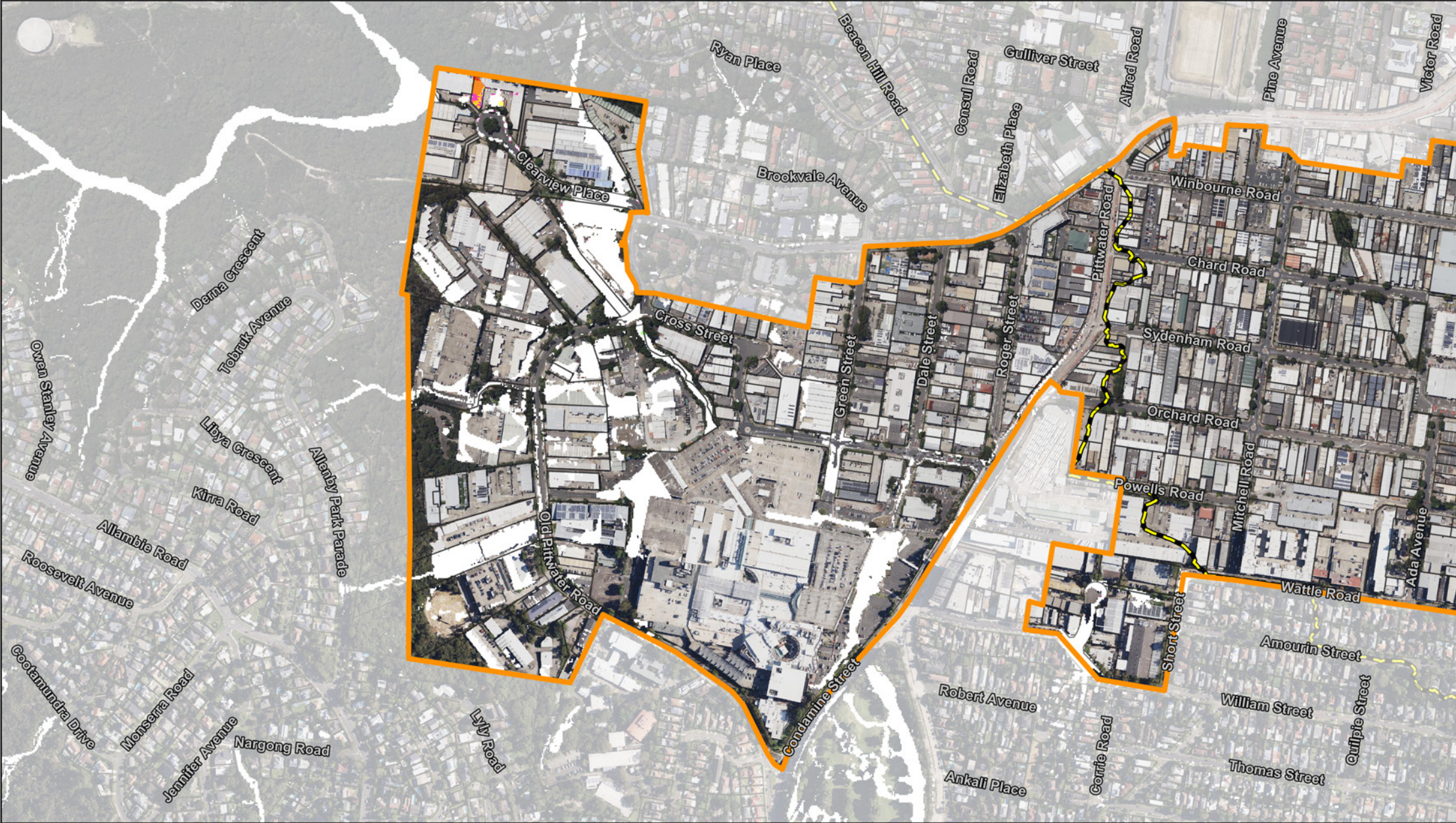


FIGURE B07
Levee - 50% Blockage Scenario - 20% AEP
Difference - Flood Level

Coordinates: GDA94 MGA Zone 56

Created: 9/4/2026

Scale: 1:7,800 (A4)

Originator:

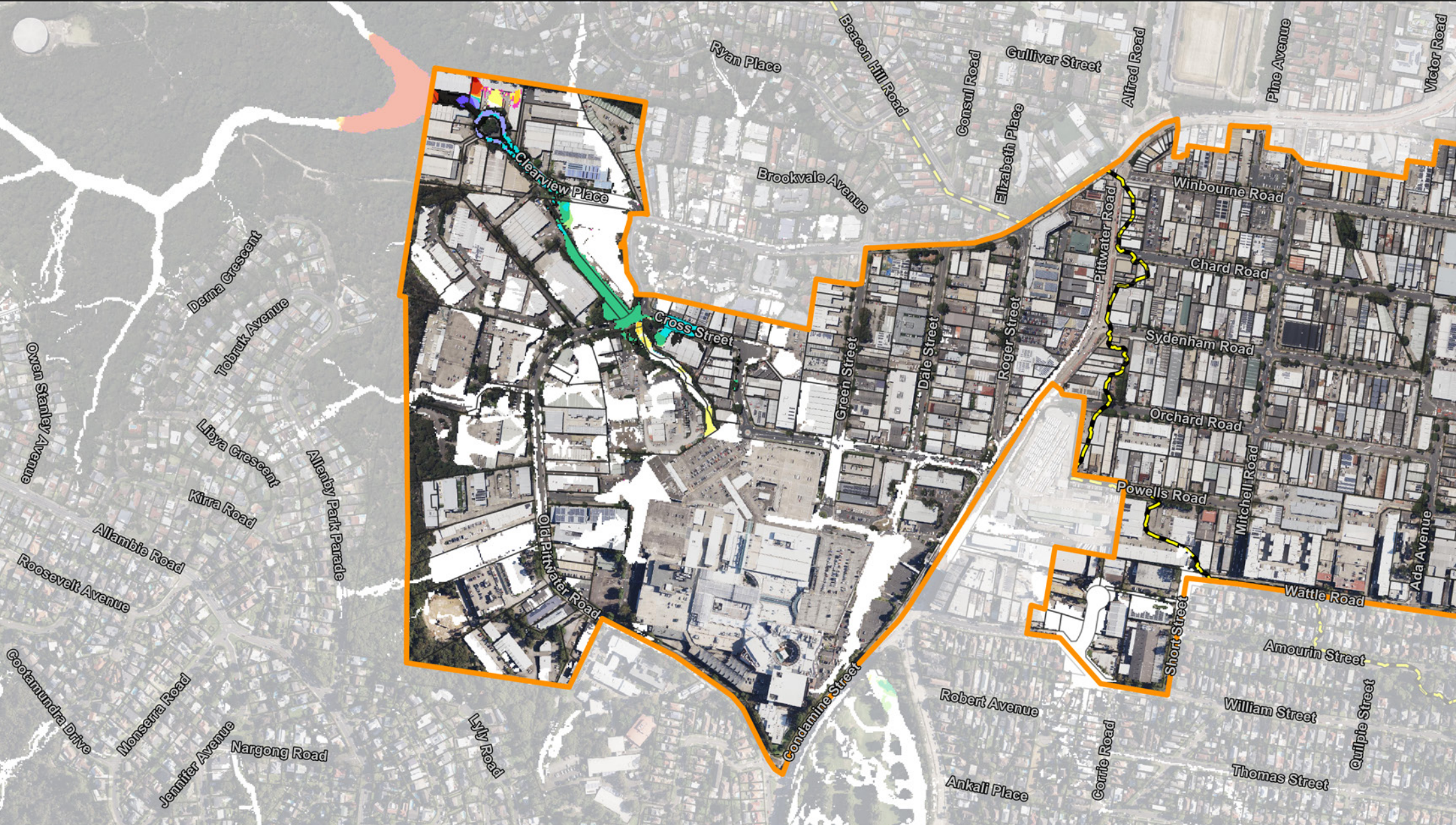
Checked:

Approved:

AN

PW

SH



LEGEND

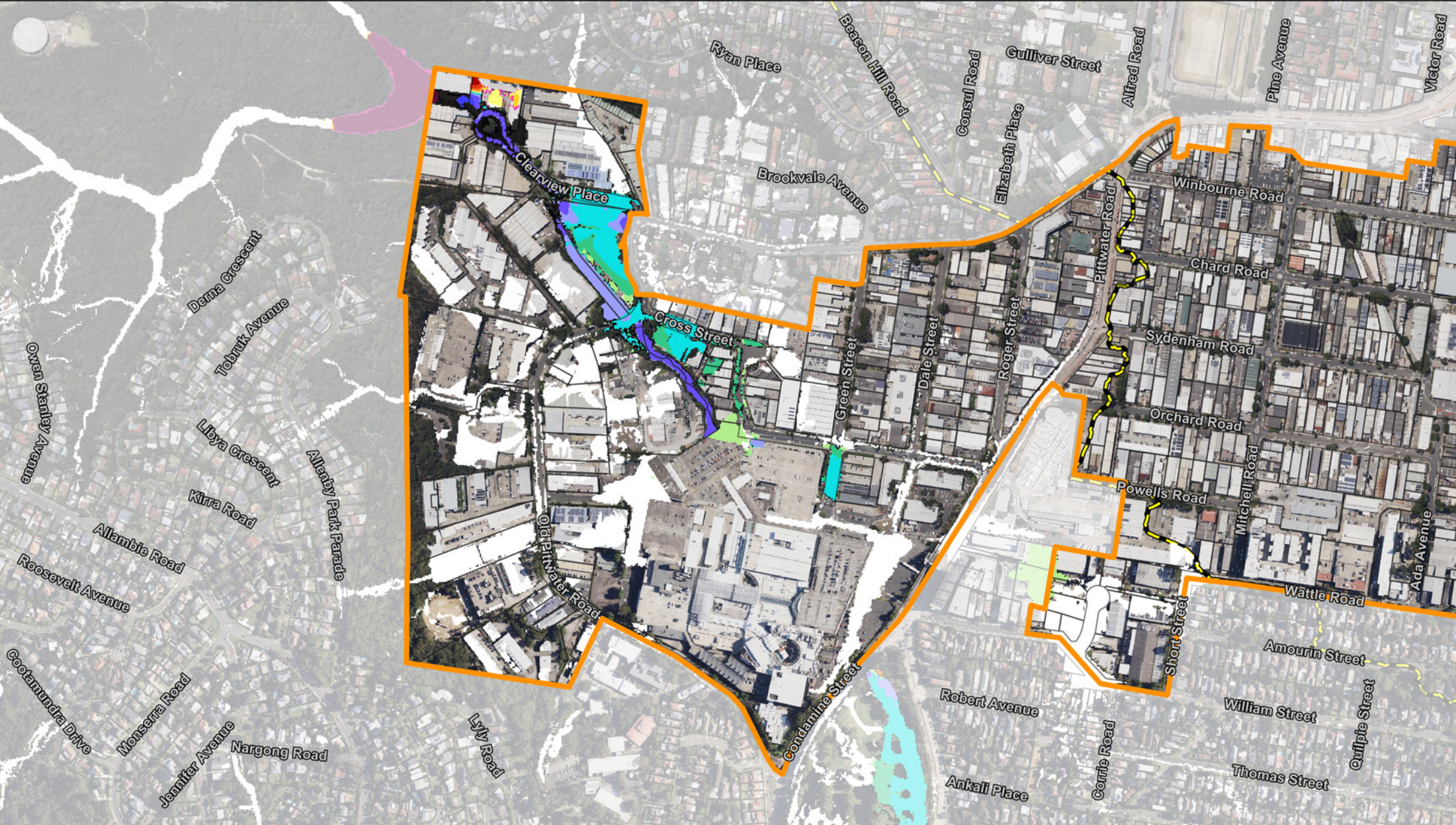
Structure Plan study area

Lots

Manly Lagoon model extent

Change in flood level (m)

	<= -0.5		-0.01 - 0.01
	-0.5 - -0.2		0.01 - 0.02
	-0.2 - -0.1		0.02 - 0.05
	-0.1 - -0.05		0.05 - 0.1
	-0.05 - -0.02		0.1 - 0.2
	-0.02 - -0.01		Previously wet now dry
			Previously dry now wet



LEGEND

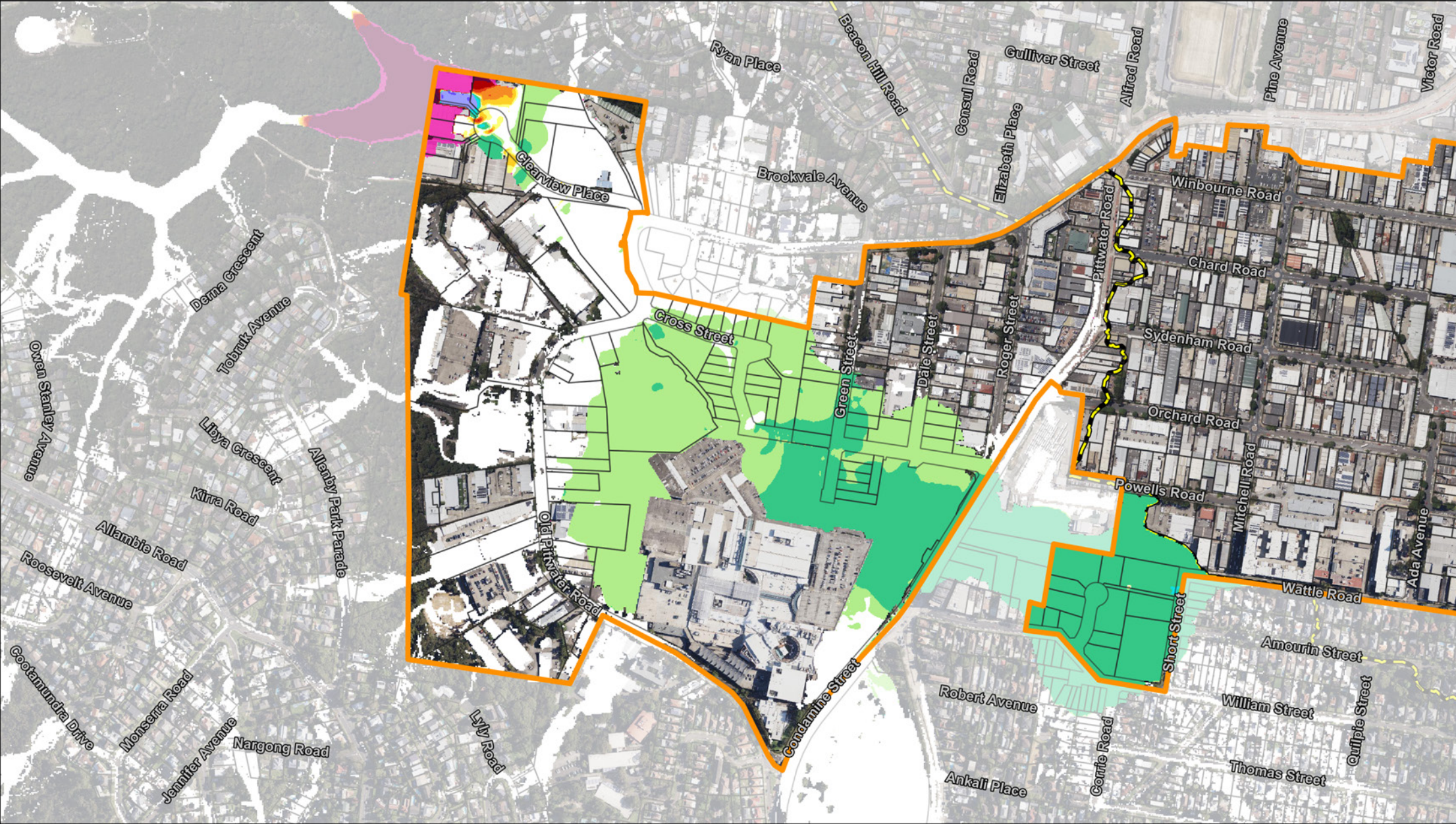
Structure Plan study area

Lots

Manly Lagoon model extent

Change in flood level (m)

	<= -0.5
	-0.5 - -0.2
	-0.2 - -0.1
	-0.1 - -0.05
	-0.05 - -0.02
	-0.02 - -0.01
	-0.01 - 0.01
	0.01 - 0.02
	0.02 - 0.05
	0.05 - 0.1
	0.1 - 0.2
	Previously wet now dry
	Previously dry now wet



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent

Change in flood level (m)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01

- 0.01 - 0.01
- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- Previously wet now dry
- Previously dry now wet

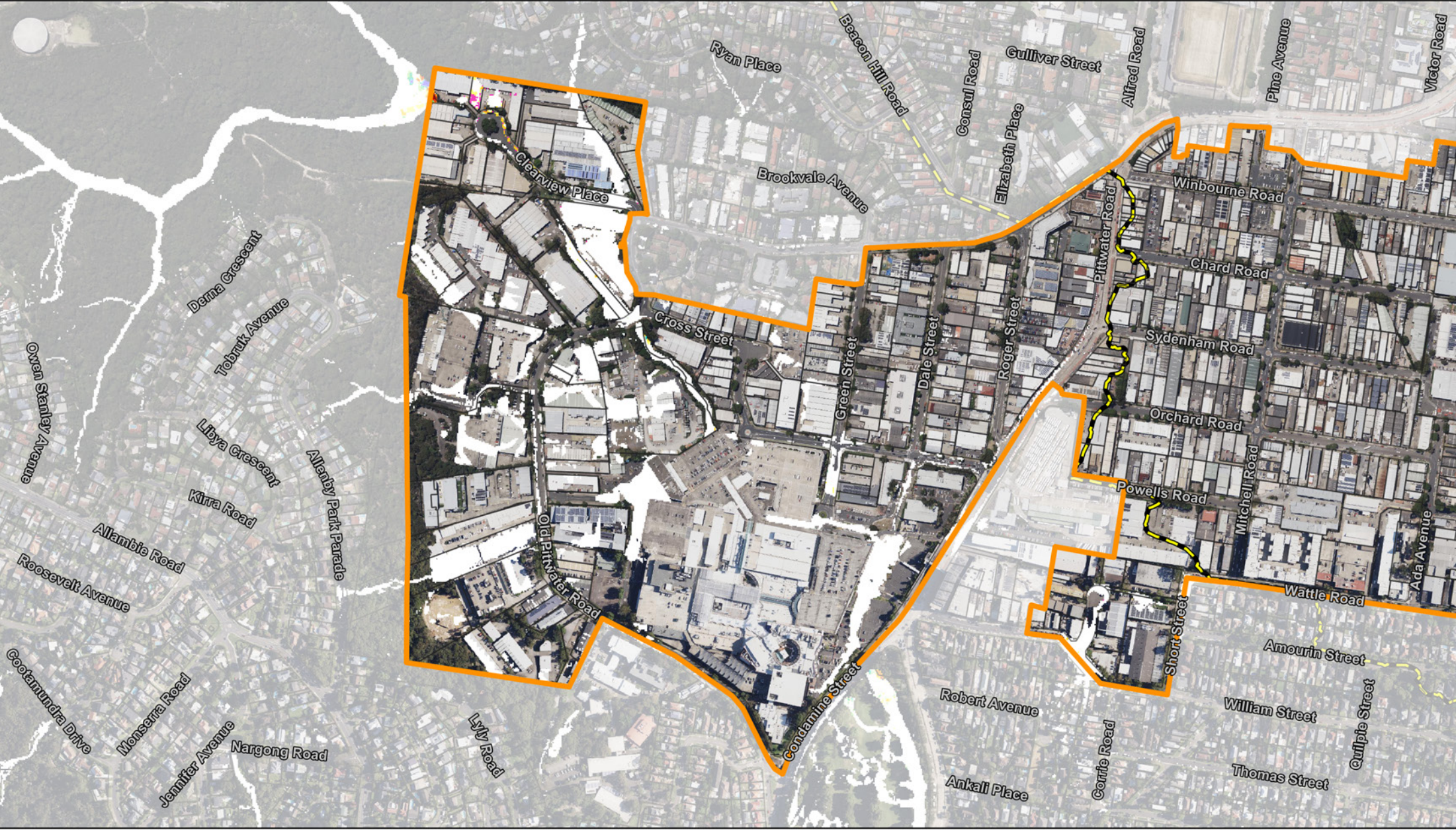
0 100 200 m



FIGURE B10
Levee - 50% Blockage Scenario - PMF
Difference - Flood Level

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01

- 0.01 - 0.01
- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- Previously wet now dry
- Previously dry now wet

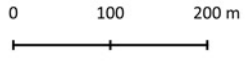
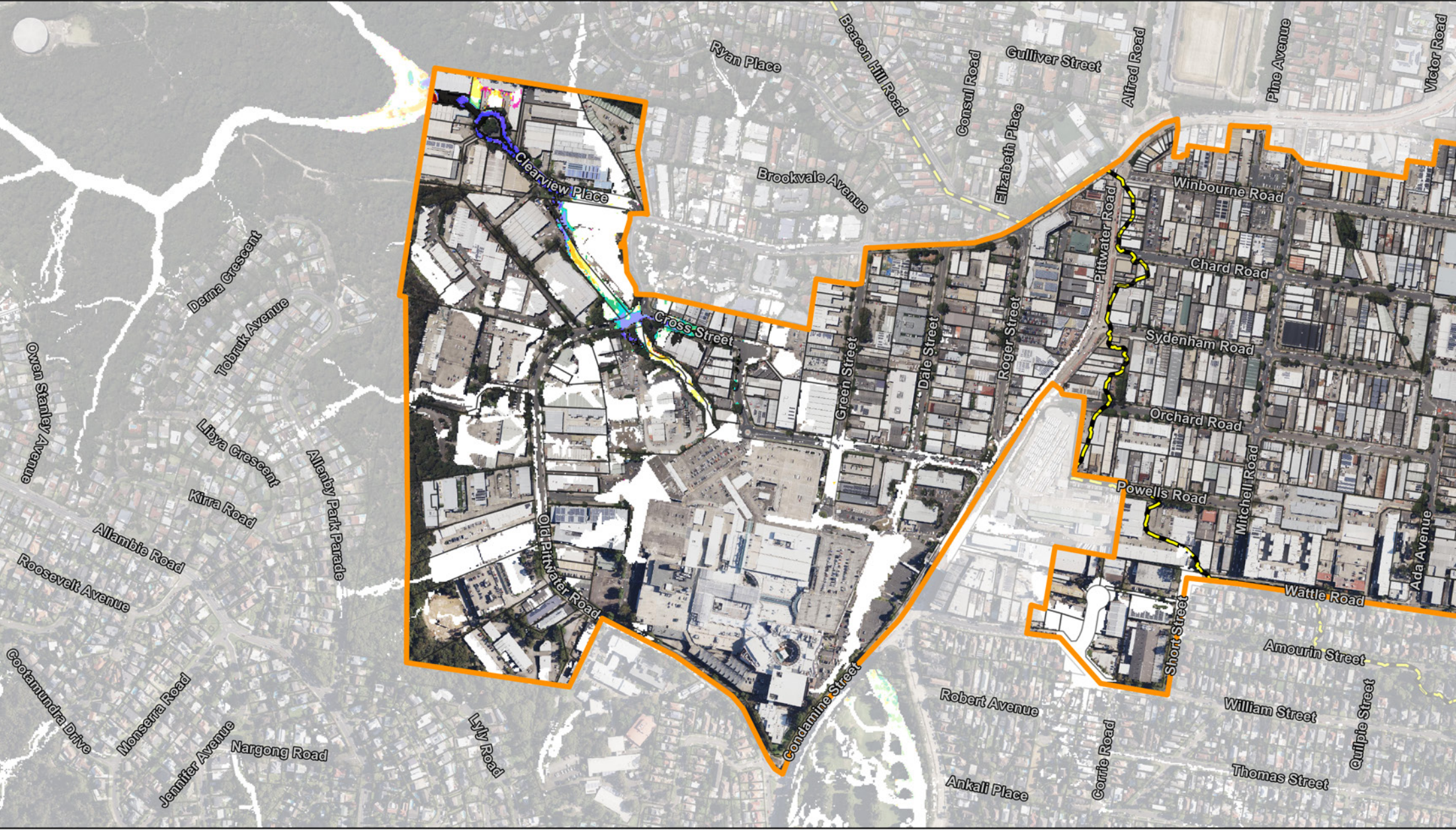
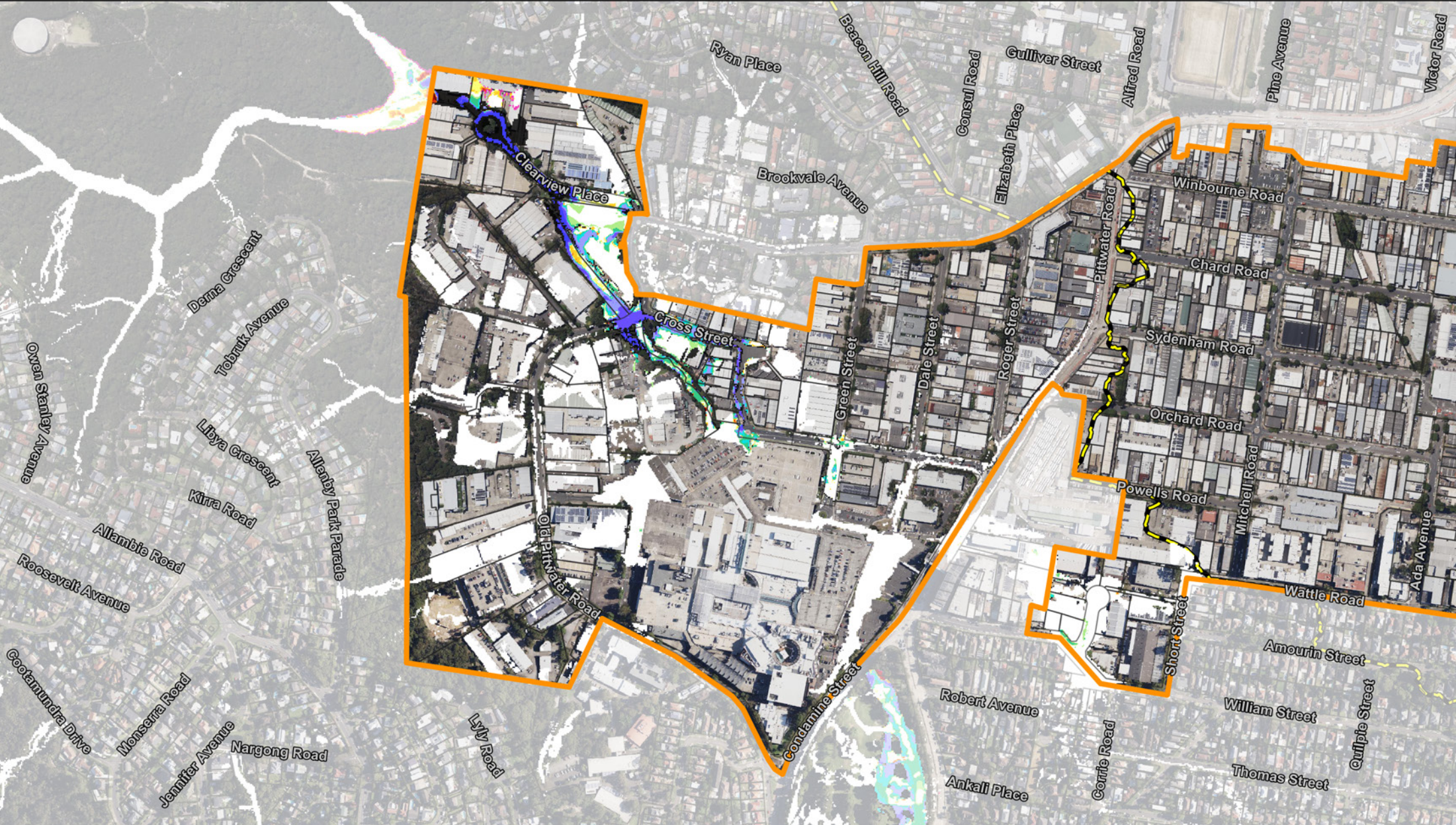


FIGURE B11
Levee - 50% Blockage Scenario - 20% AEP
Difference - Flood Velocity





LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent

Change in flood velocity (m/s)

	<= -0.5
	-0.5 - -0.2
	-0.2 - -0.1
	-0.1 - -0.05
	-0.05 - -0.02
	-0.02 - -0.01

	-0.01 - 0.01
	0.01 - 0.02
	0.02 - 0.05
	0.05 - 0.1
	0.1 - 0.2
	Previously wet now dry
	Previously dry now wet

FIGURE B13
Levee - 50% Blockage Scenario - 1% AEP
Difference - Flood Velocity

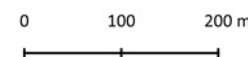
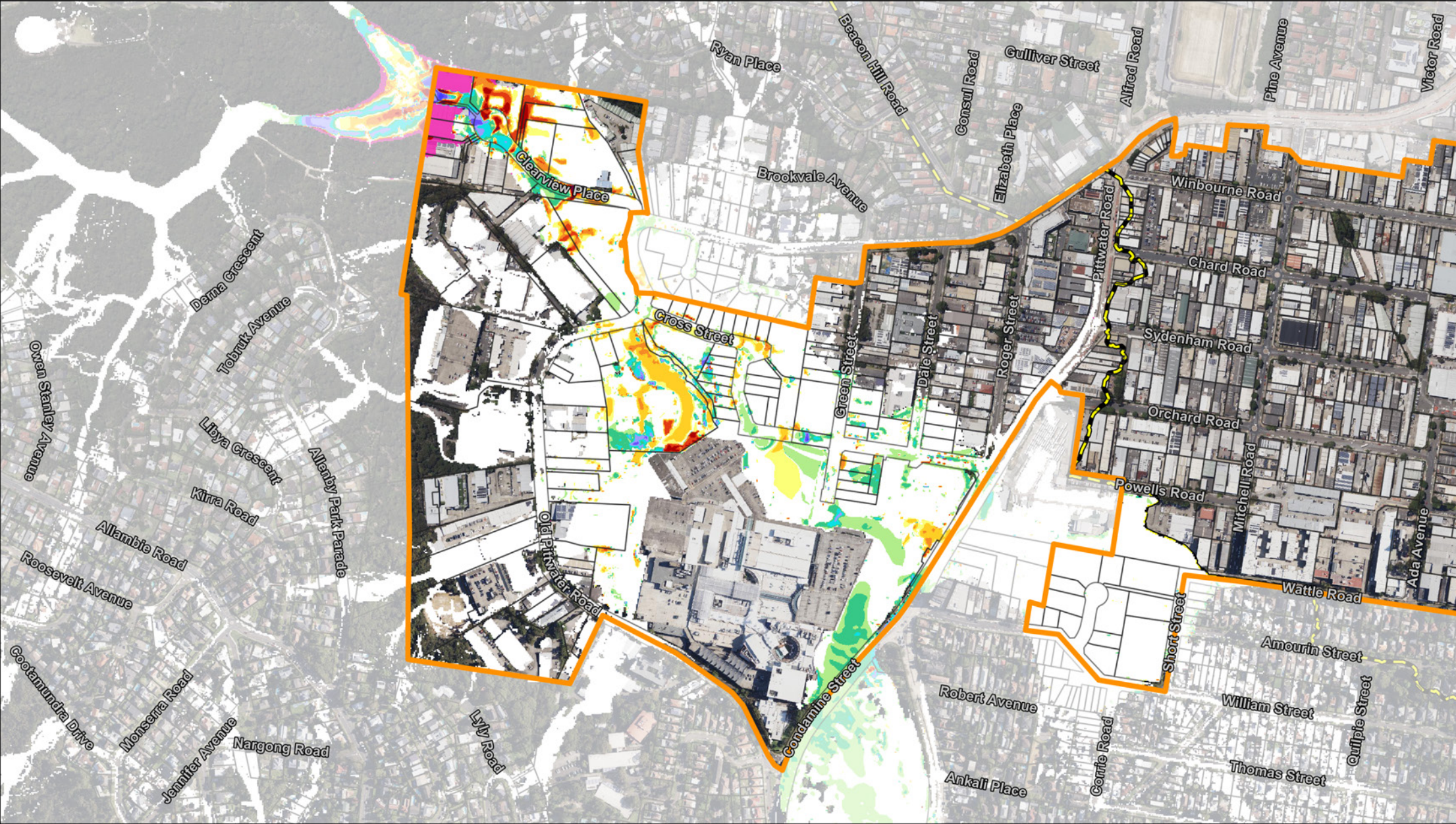
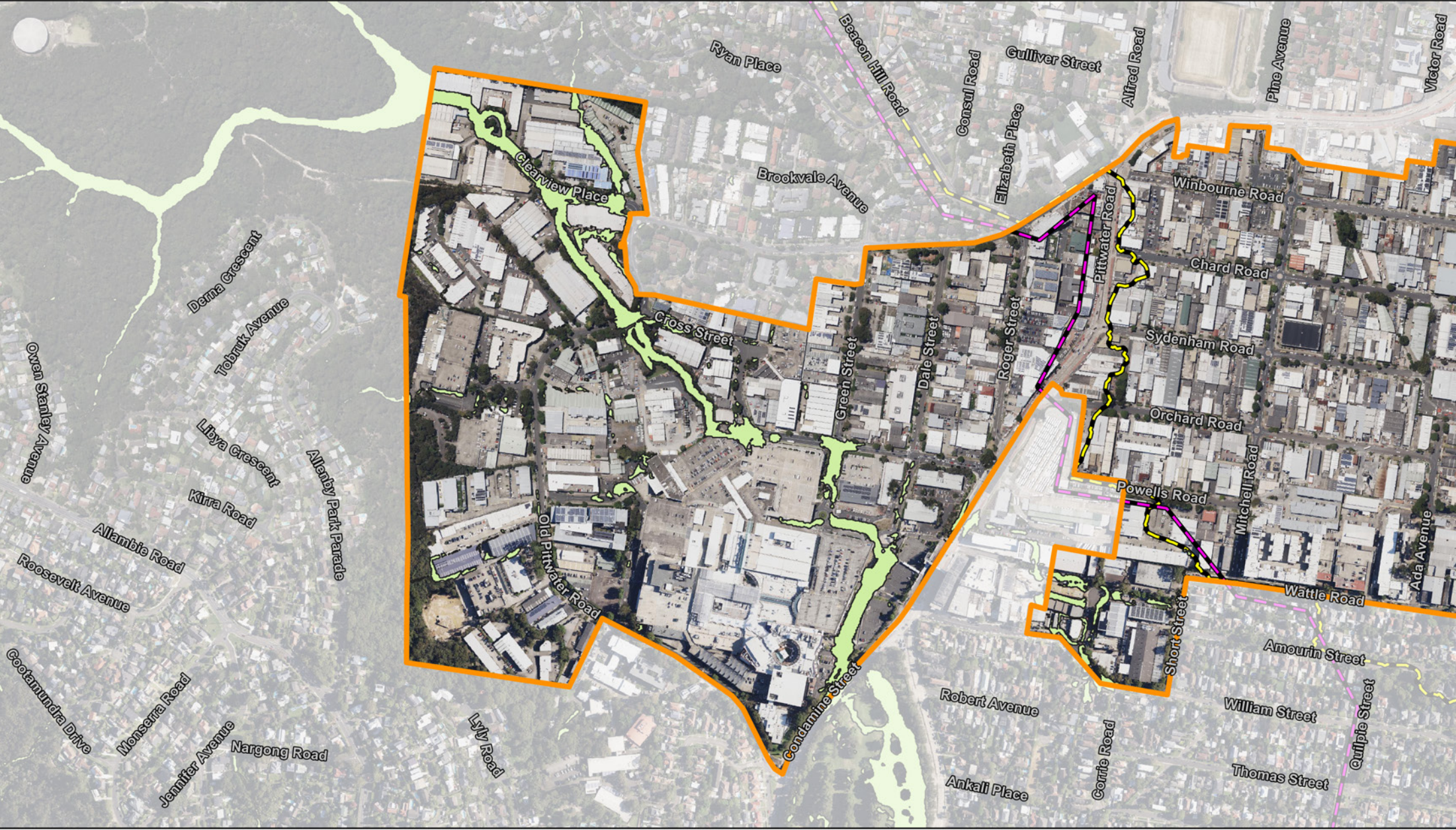


FIGURE B14
Levee - 50% Blockage Scenario - PMF
Difference - Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

Structure Plan study area

Greendale Creek model extent

Flood Mapping Category 1 (Northern Beaches Council) (DFE: 1% AEP)

Manly Lagoon model extent

FIGURE D01

Developed Scenario - 1% AEP

Flood Planning Category 1 (Northern Beaches Council)

Coordinates: GDA94 MGA Zone 56

Created: 9/4/2026

Scale: 1:7,800 (A4)

Originator: AN

Checked: PW

Approved: SH

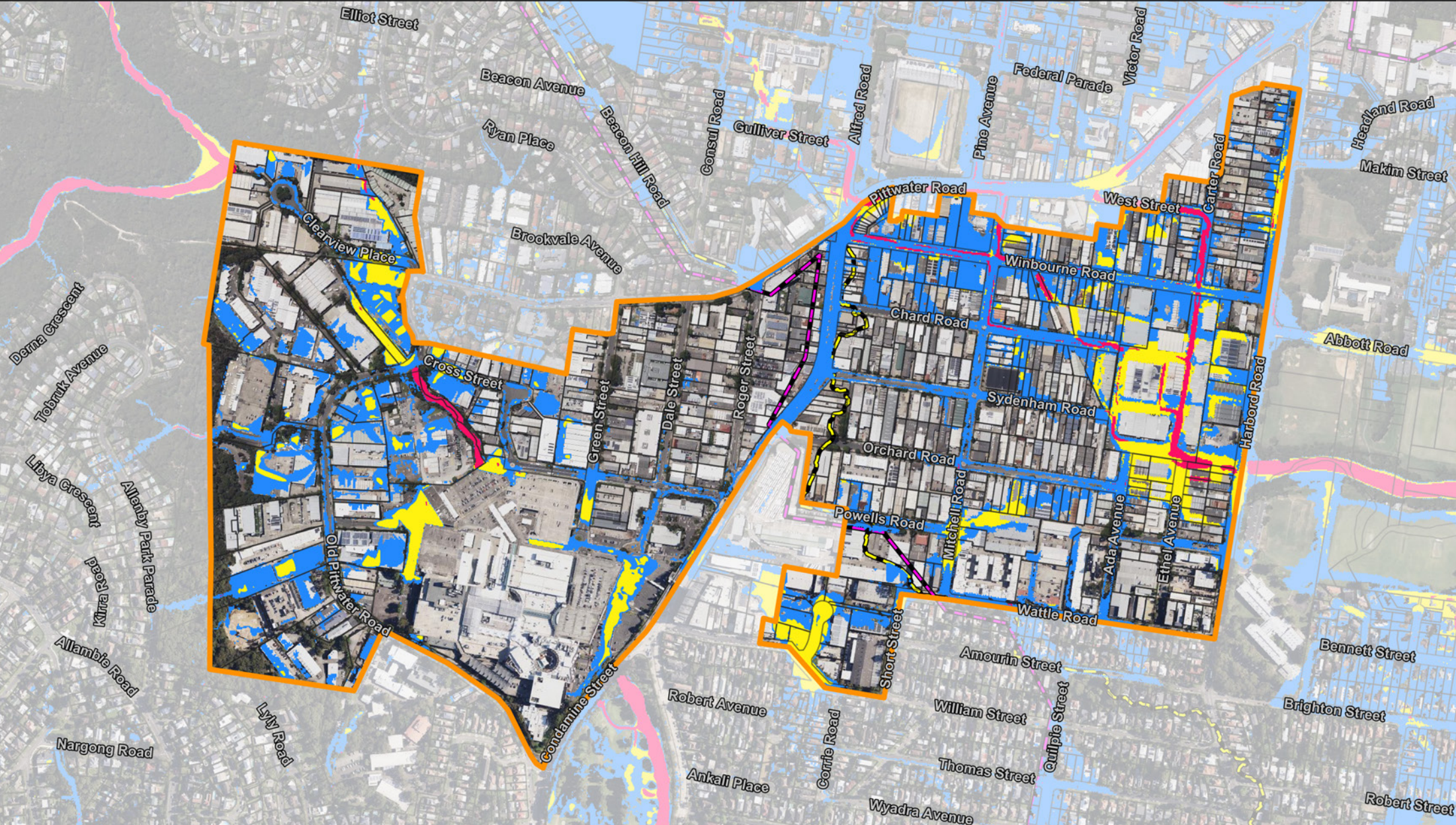


LEGEND

 Structure Plan study area	 Greendale Creek model extent	 Flood Mapping Category 1 (Northern Beaches Council) (DFE: 1% AEP+Climate Change)
 Manly Lagoon model extent		

FIGURE D02
Developed Scenario - 1% AEP+CC
Flood Planning Category 1 (Northern Beaches Council)

Coordinates: GDA94 MGA Zone 56	Originator: AN
Created: 9/4/2026	Checked: PW
Scale: 1:7,800 (A4)	Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

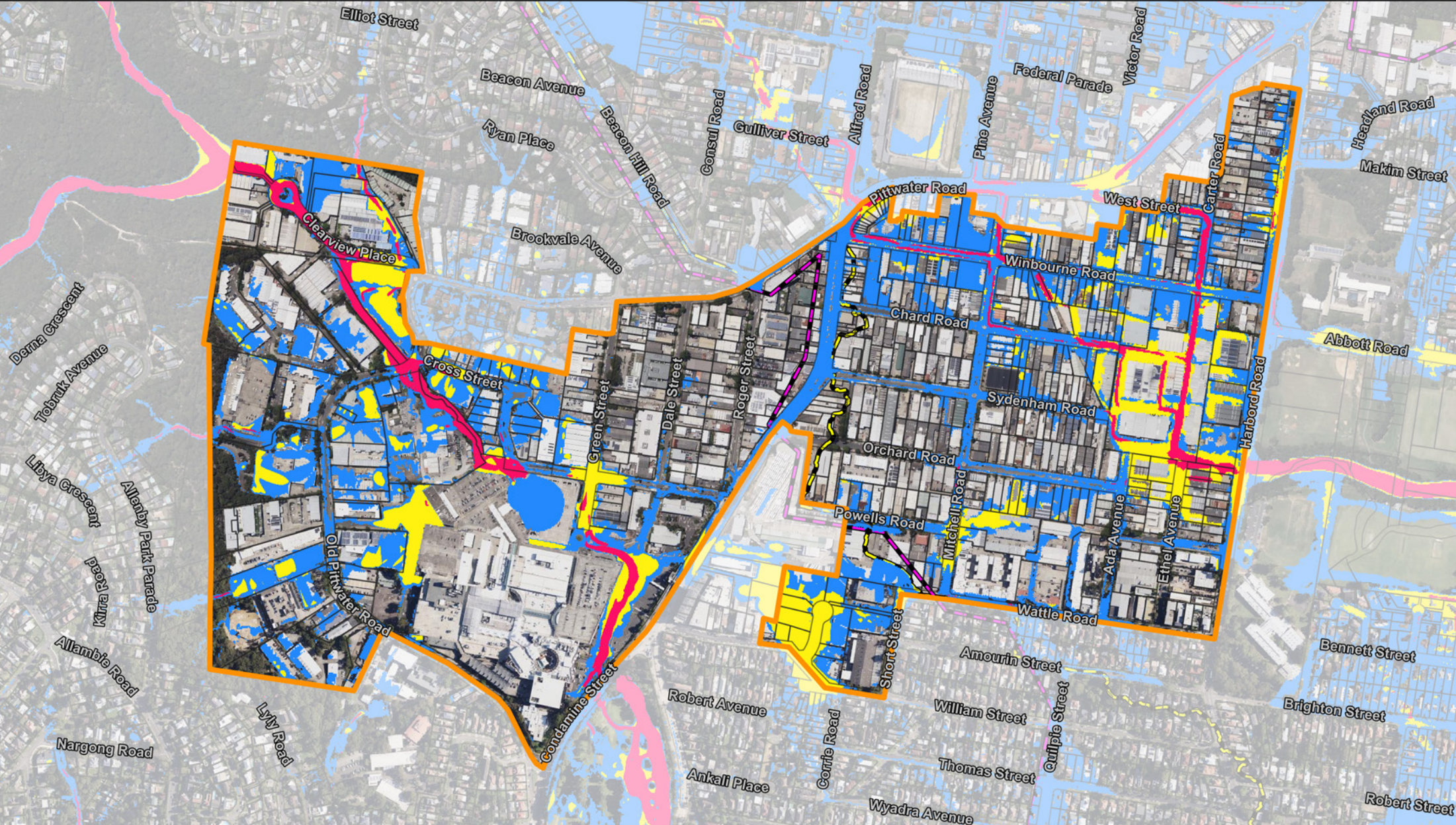
Flood function

- Floodway:
- Flood storage:
- Flood fringe:

Velocity x Depth (VD) > 0.3 m2/s
VD <= 0.3 m2/s + Depth (D) > 0.3 m
VD <= 0.3 m2/s



FIGURE E01
Developed Scenario - 1% AEP
Flood Function



LEGEND

- Structure Plan study area
- Lots
- Mainly Lagoon model extent
- Greendale Creek model extent

Flood function

- Floodway: Velocity x Depth (VD) > 0.3 m²/s
- Flood storage: VD <= 0.3 m²/s + Depth (D) > 0.3 m
- Flood fringe: VD <= 0.3 m²/s

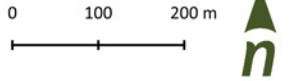
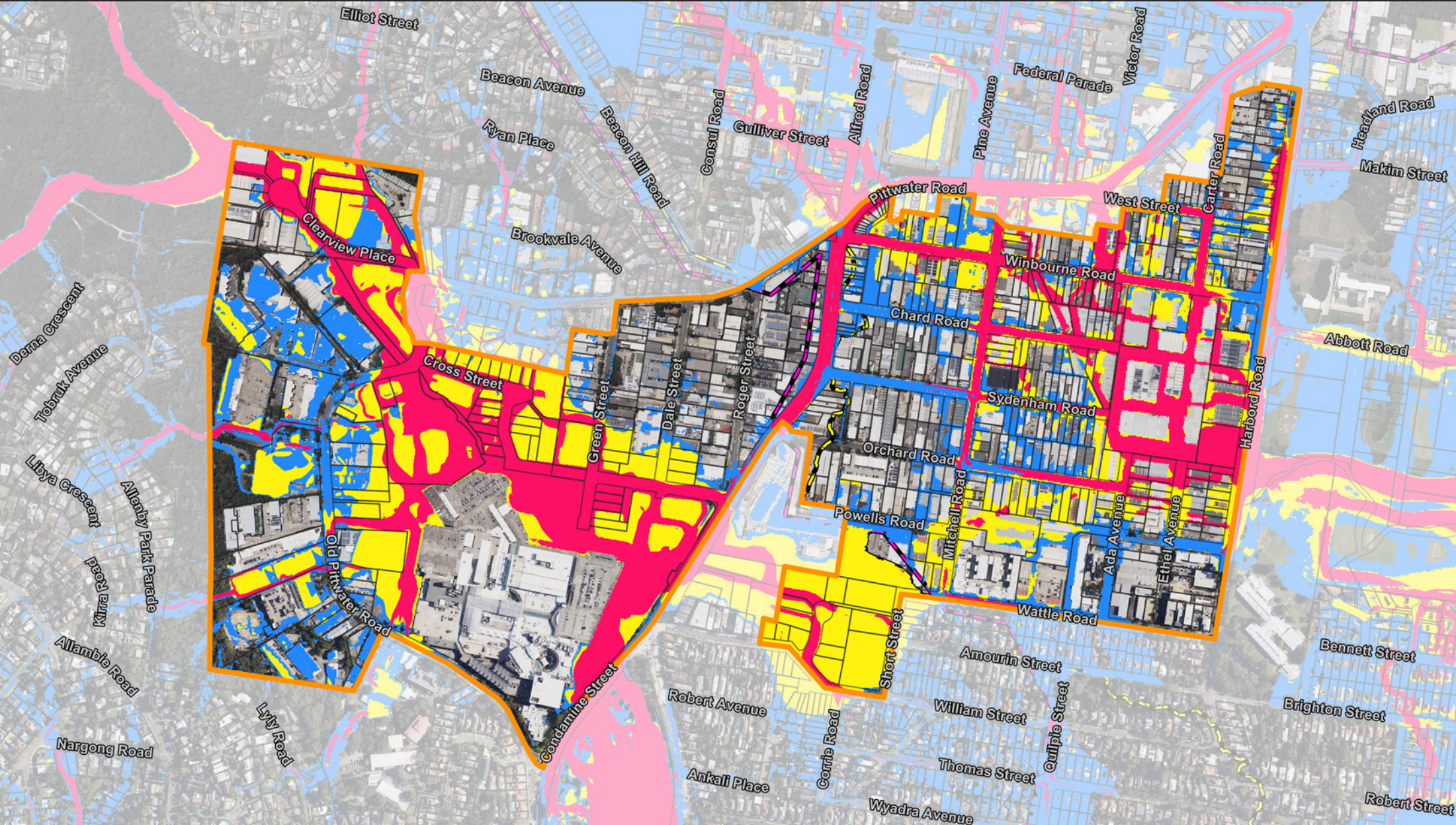


FIGURE E02
Developed Scenario - 1% AEP+CC
Flood Function



LEGEND

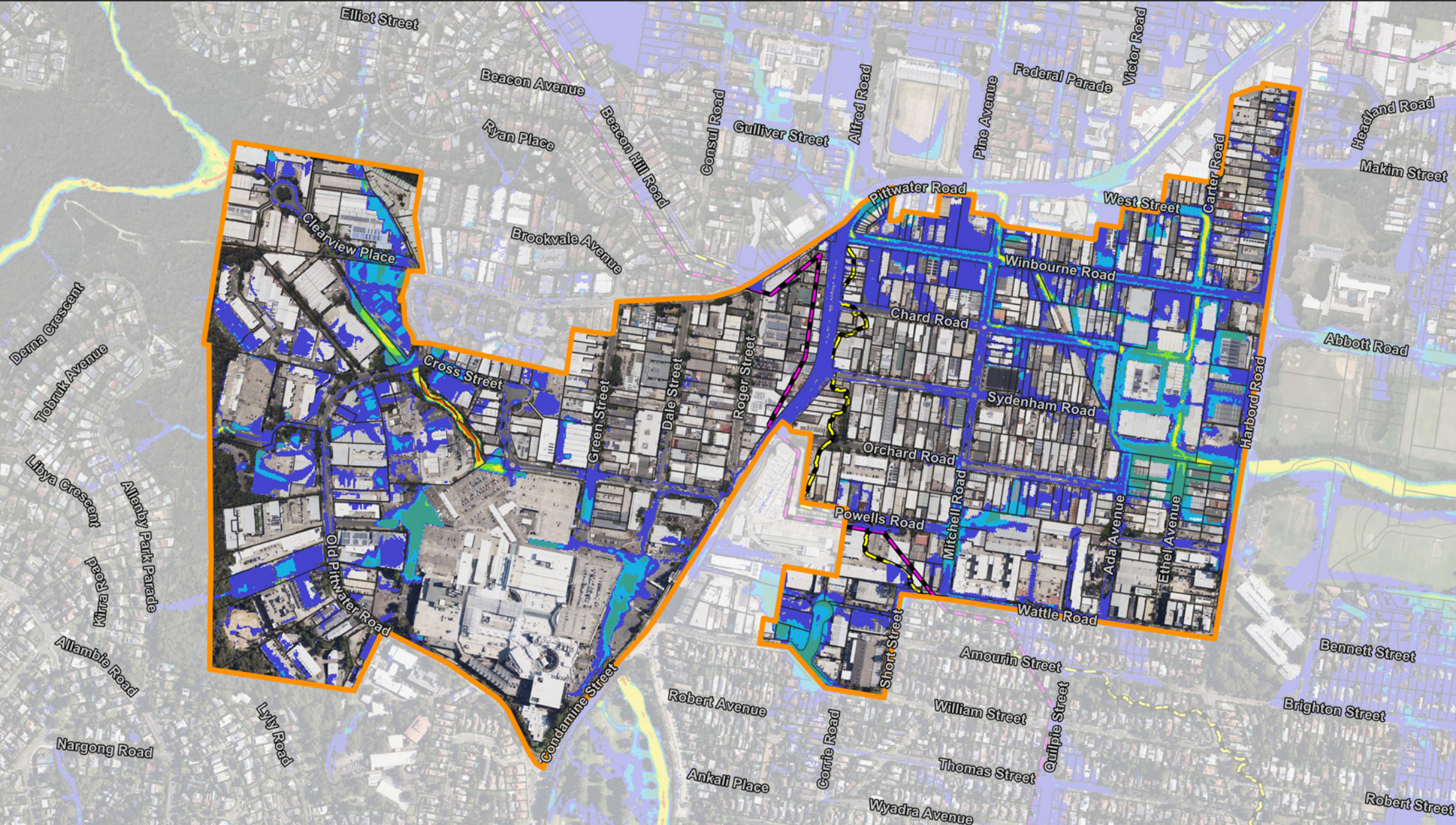
- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Flood function

- Floodway: Velocity x Depth (VD) > 0.3 m²/s
- Flood storage: VD <= 0.3 m²/s + Depth (D) > 0.3 m
- Flood fringe: VD <= 0.3 m²/s



FIGURE E03
Developed Scenario - PMF
Flood Function



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

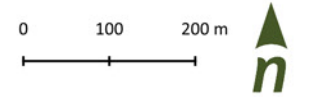
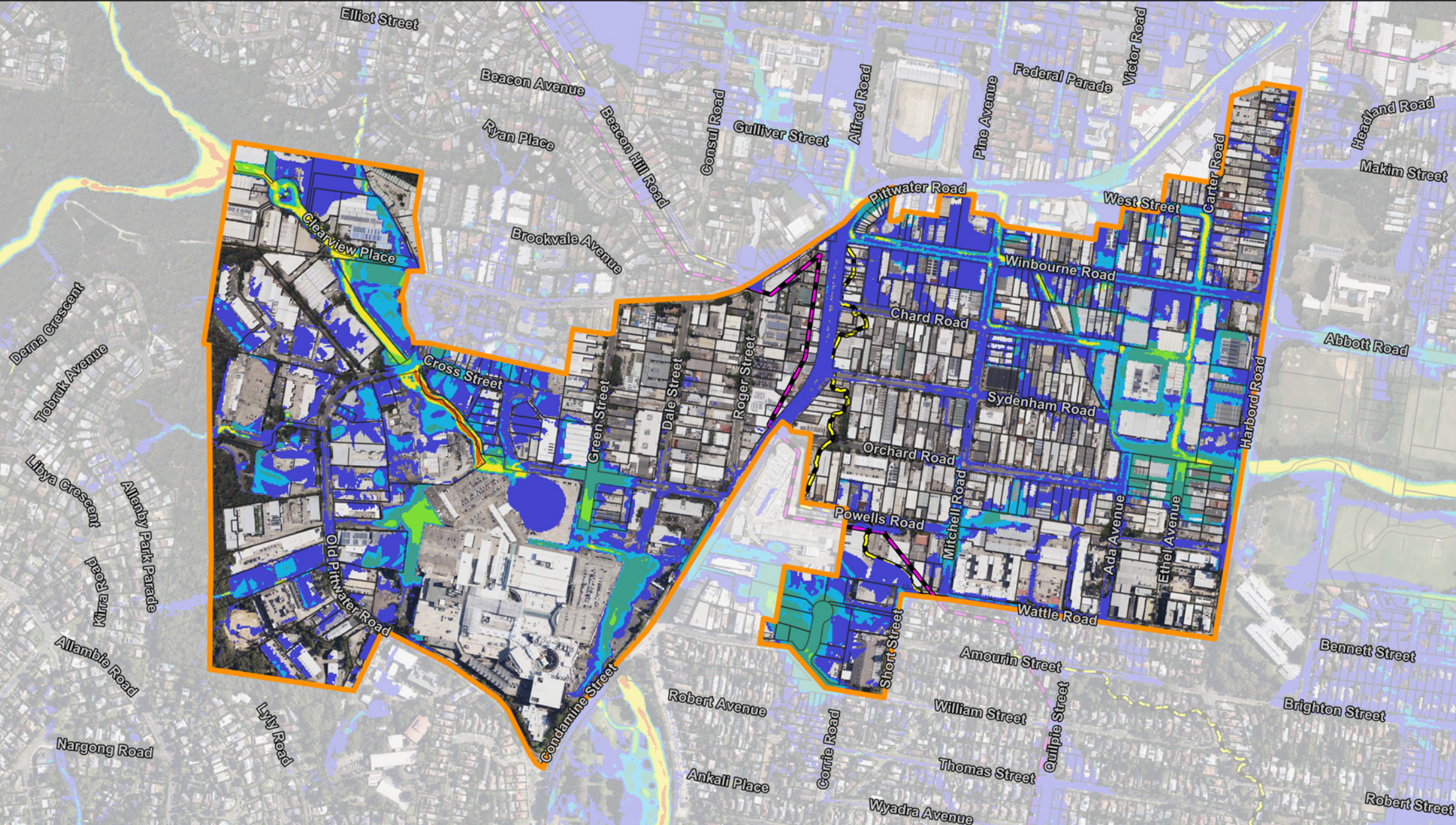


FIGURE E04
Developed Scenario - 1% AEP
Peak Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6



FIGURE E05
Developed Scenario - 1% AEP+CC
Peak Hazard



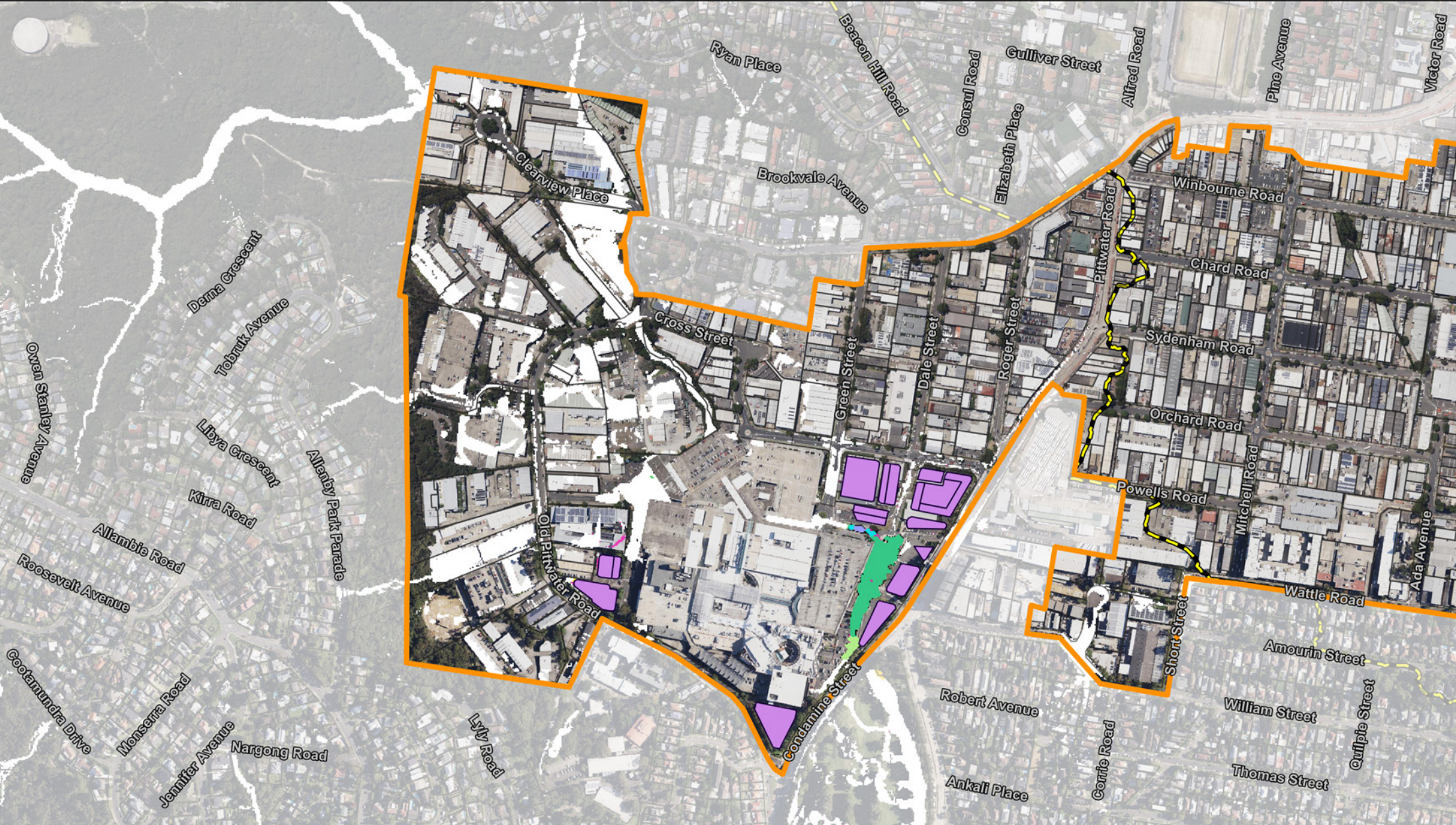
LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Greendale Creek model extent

Peak flood hazard (ZAEM1)

- H1
- H2
- H3
- H4
- H5
- H6

FIGURE E06
Developed Scenario - PMF
Peak Hazard



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood level (m)

<= -0.5
-0.5 - -0.2
-0.2 - -0.1
-0.1 - -0.05
-0.05 - -0.02
-0.02 - -0.01
-0.01 - 0.01

0.01 - 0.02
0.02 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
> 0.5
Previously wet now dry
Previously dry now wet

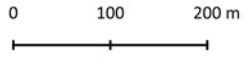
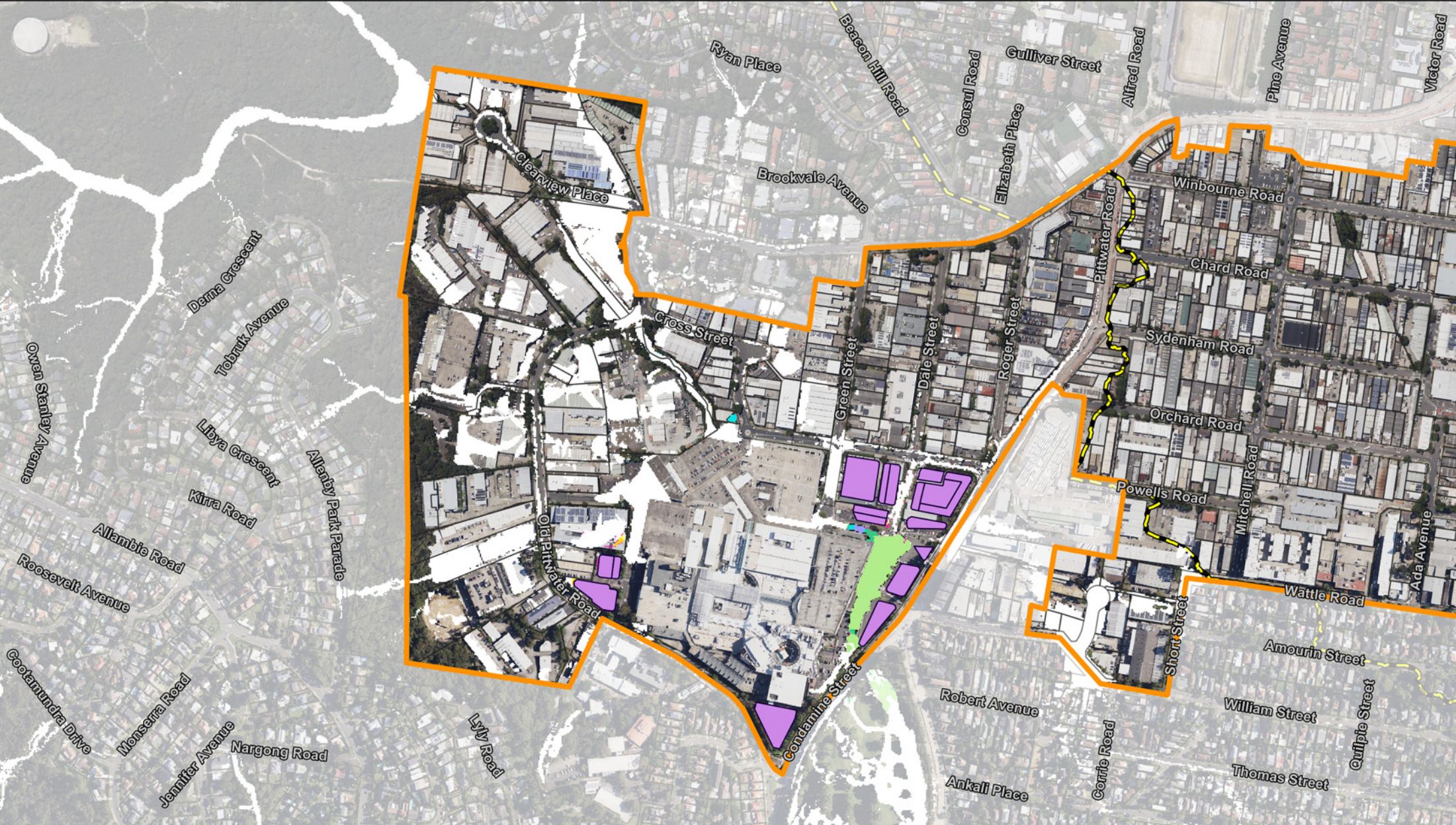


FIGURE F01
Mitigation - Drainage (M03) Scenario - 20% AEP
Difference - Flood Level



LEGEND

- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Adjusted building footprints
- Change in flood level (m)**
- <= -0.5
 - 0.5 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - -0.02
 - 0.02 - -0.01
 - 0.01 - 0.01
 - 0.01 - 0.02
 - 0.02 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.5
 - > 0.5
 - Previously wet now dry
 - Previously dry now wet

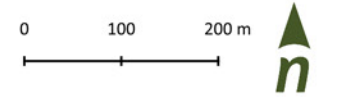
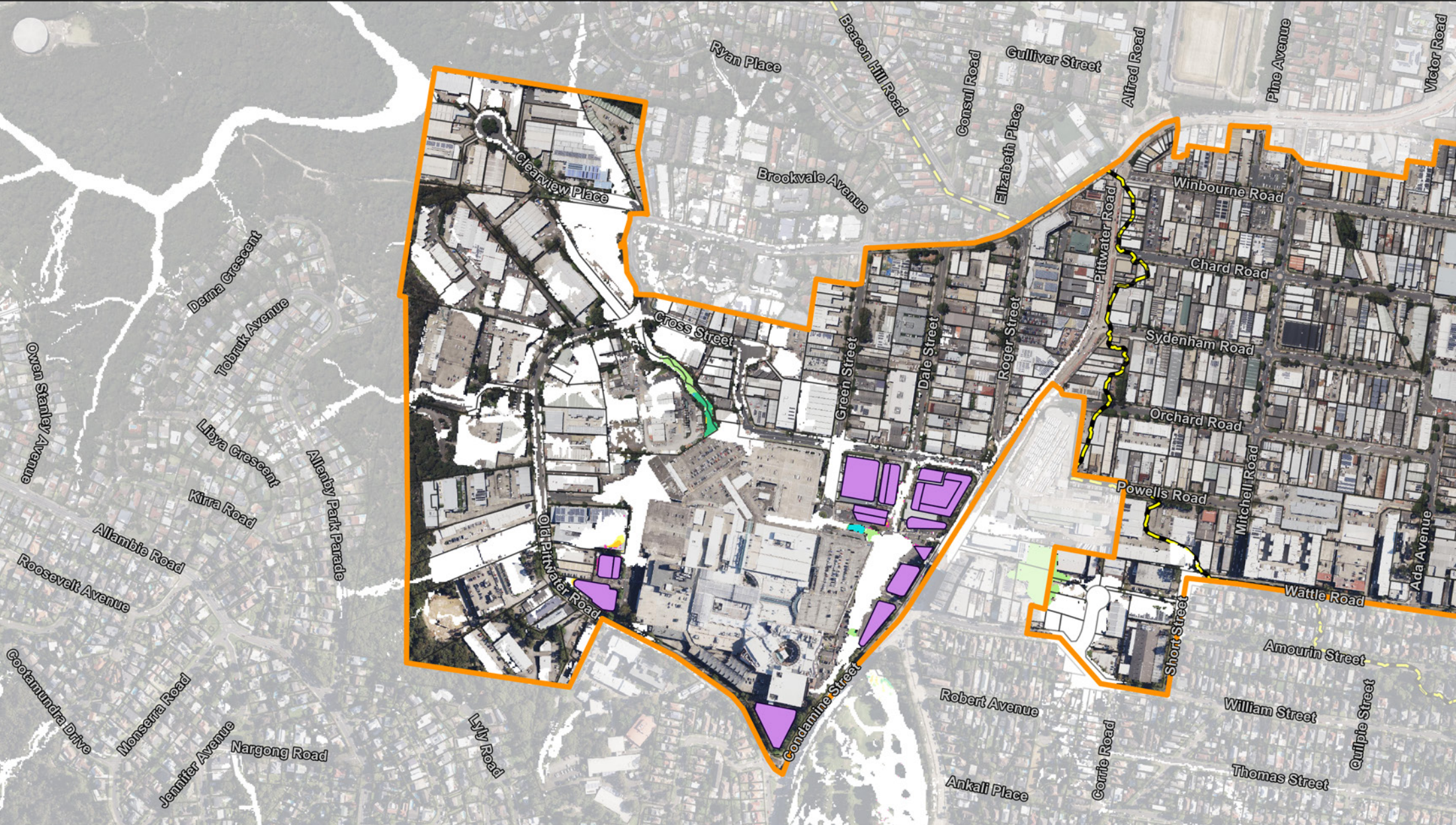


FIGURE F02
Mitigation - Drainage (M03) Scenario - 5% AEP
Difference - Flood Level

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood level (m)	
<= -0.5	
-0.5 - -0.2	
-0.2 - -0.1	
-0.1 - -0.05	
-0.05 - -0.02	
-0.02 - -0.01	
-0.01 - 0.01	

0.01 - 0.02	
0.02 - 0.05	
0.05 - 0.1	
0.1 - 0.2	
0.2 - 0.5	
> 0.5	
Previously wet now dry	
Previously dry now wet	

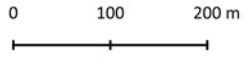
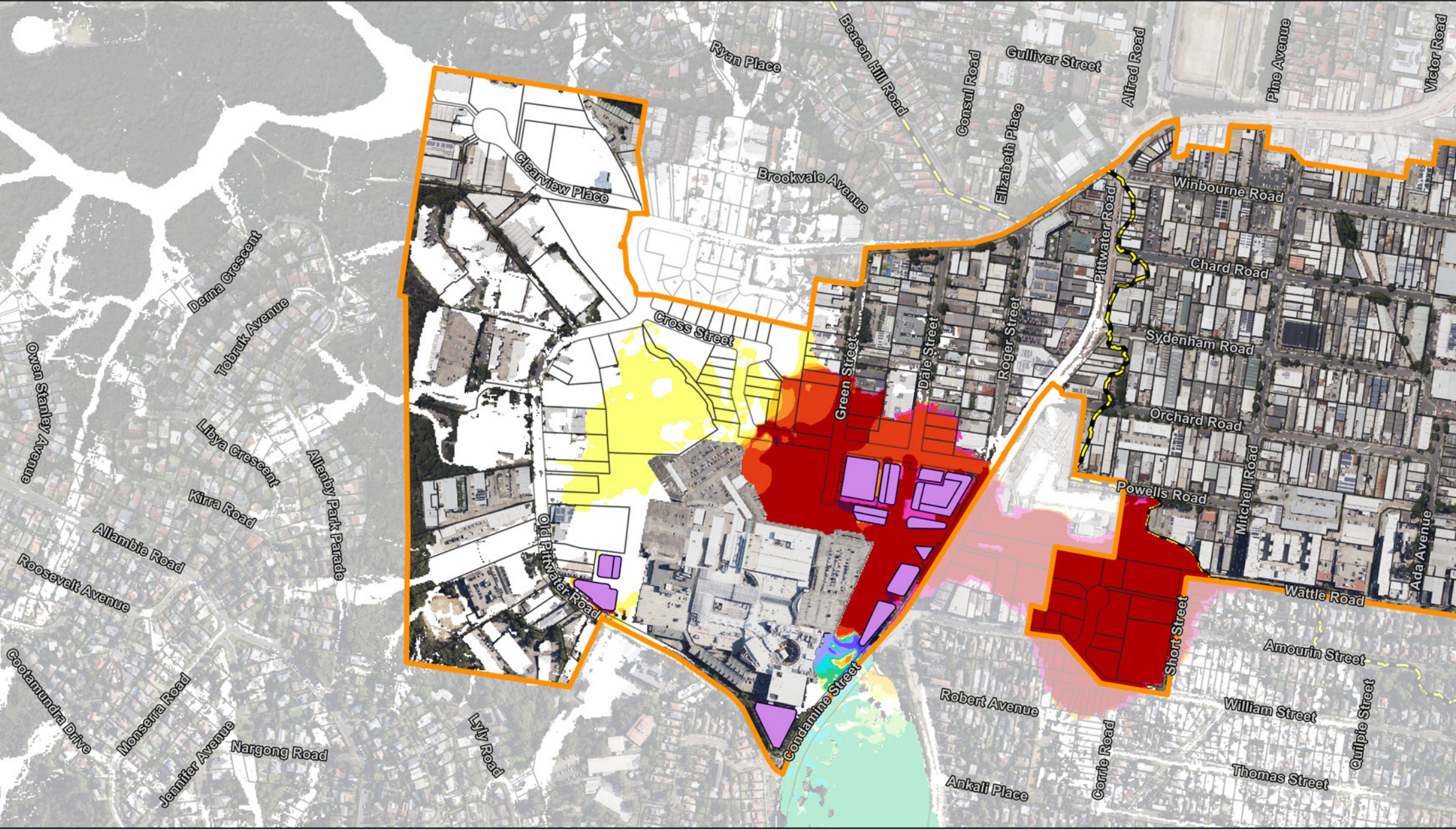


FIGURE F03
Mitigation - Drainage (M03) Scenario - 1% AEP
Difference - Flood Level



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood level (m)	
<= -0.5	
-0.5 - -0.2	
-0.2 - -0.1	
-0.1 - -0.05	
-0.05 - -0.02	
-0.02 - -0.01	
-0.01 - 0.01	

0.01 - 0.02	
0.02 - 0.05	
0.05 - 0.1	
0.1 - 0.2	
0.2 - 0.5	
> 0.5	
Previously wet now dry	
Previously dry now wet	

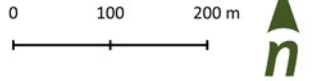
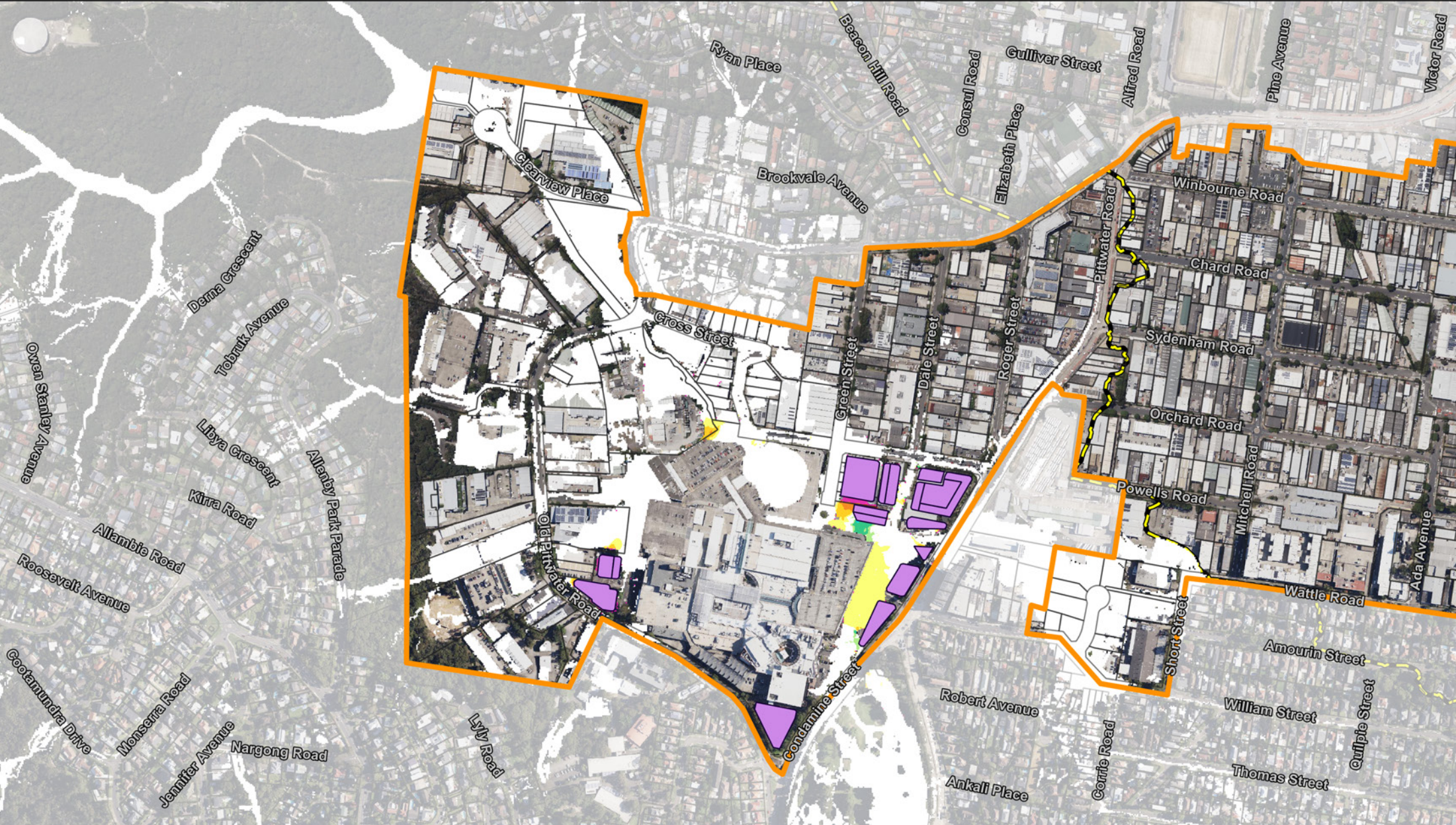


FIGURE F04
Mitigation - Drainage (M03) Scenario - PMF
Difference - Flood Level



LEGEND

- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Adjusted building footprints
- Change in flood level (m)**
- <= -0.5
 - 0.5 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - -0.02
 - 0.02 - -0.01
 - 0.01 - 0.01
 - 0.01 - 0.02
 - 0.02 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.5
 - > 0.5
 - Previously wet now dry
 - Previously dry now wet

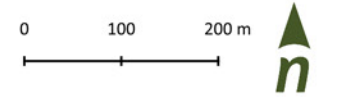
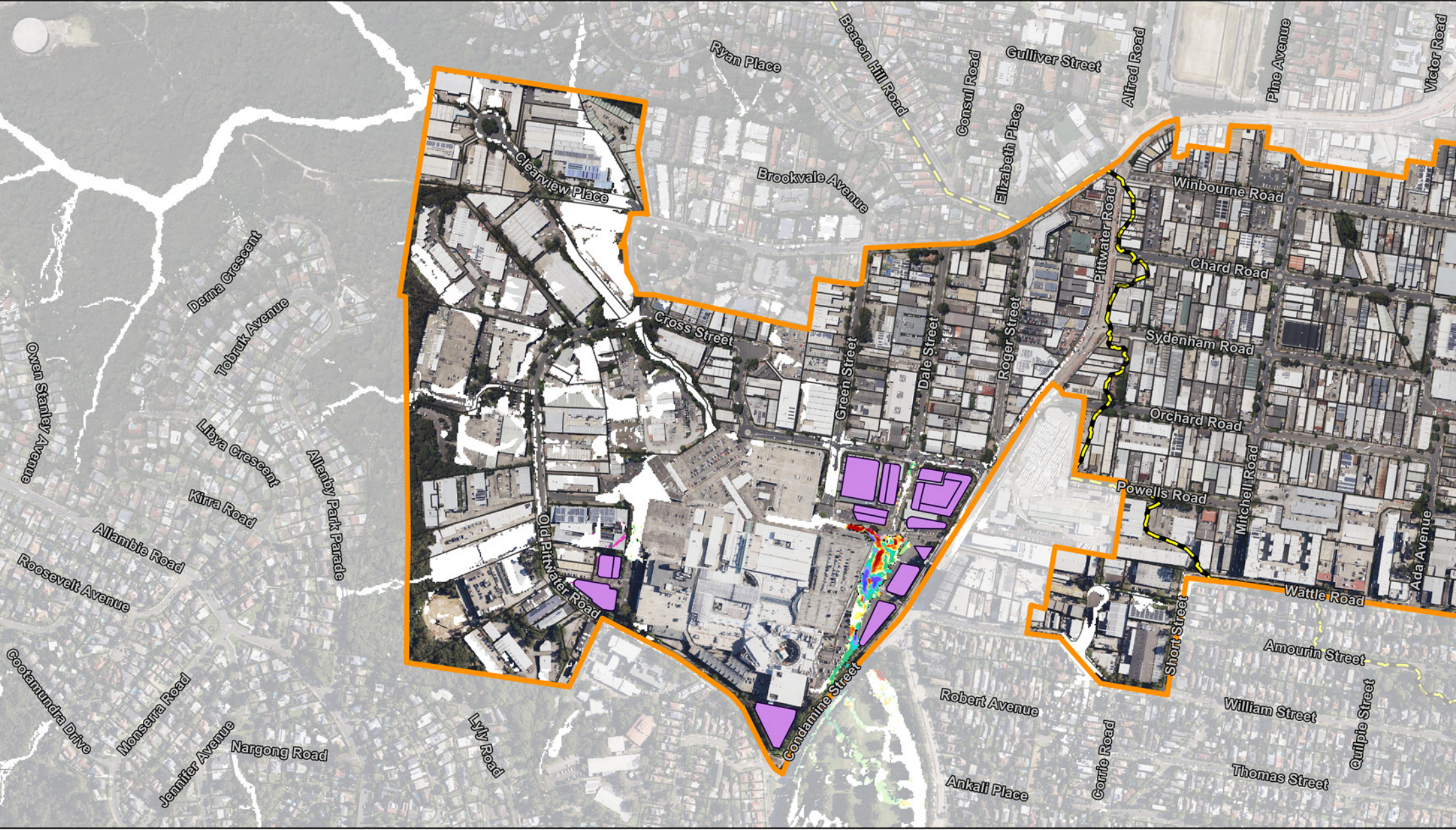


FIGURE F05
Mitigation - Drainage (M03) Scenario - 1% AEP+CC
Difference - Flood Level



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5
- Previously wet now dry
- Previously dry now wet

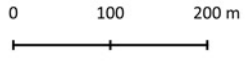
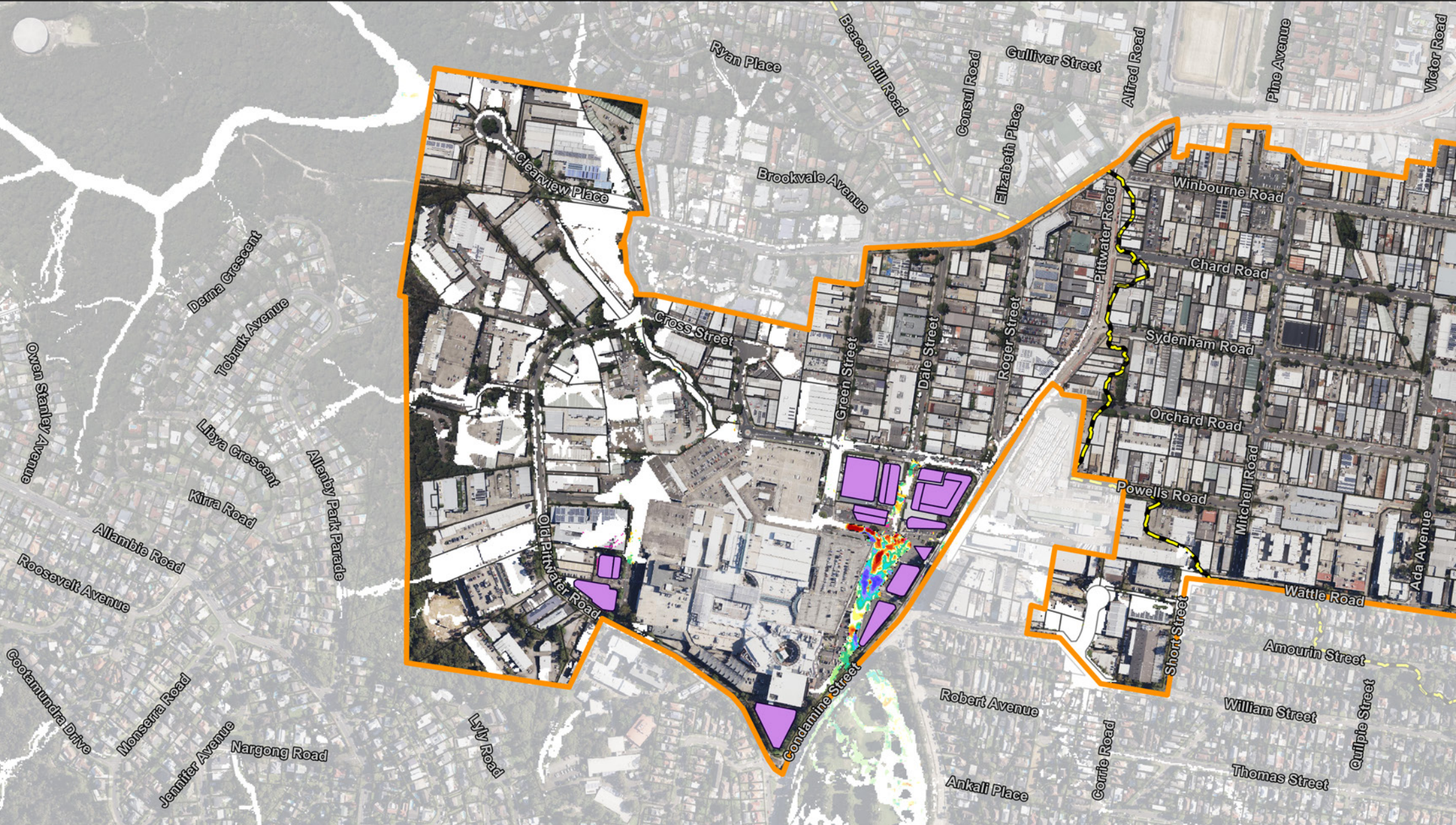


FIGURE F06
Mitigation - Drainage (M03) Scenario - 20% AEP
Difference - Flood Velocity



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

<= -0.5
-0.5 - -0.2
-0.2 - -0.1
-0.1 - -0.05
-0.05 - -0.02
-0.02 - -0.01
-0.01 - 0.01

0.01 - 0.02
0.02 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
> 0.5
Previously wet now dry
Previously dry now wet

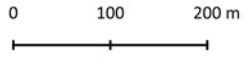
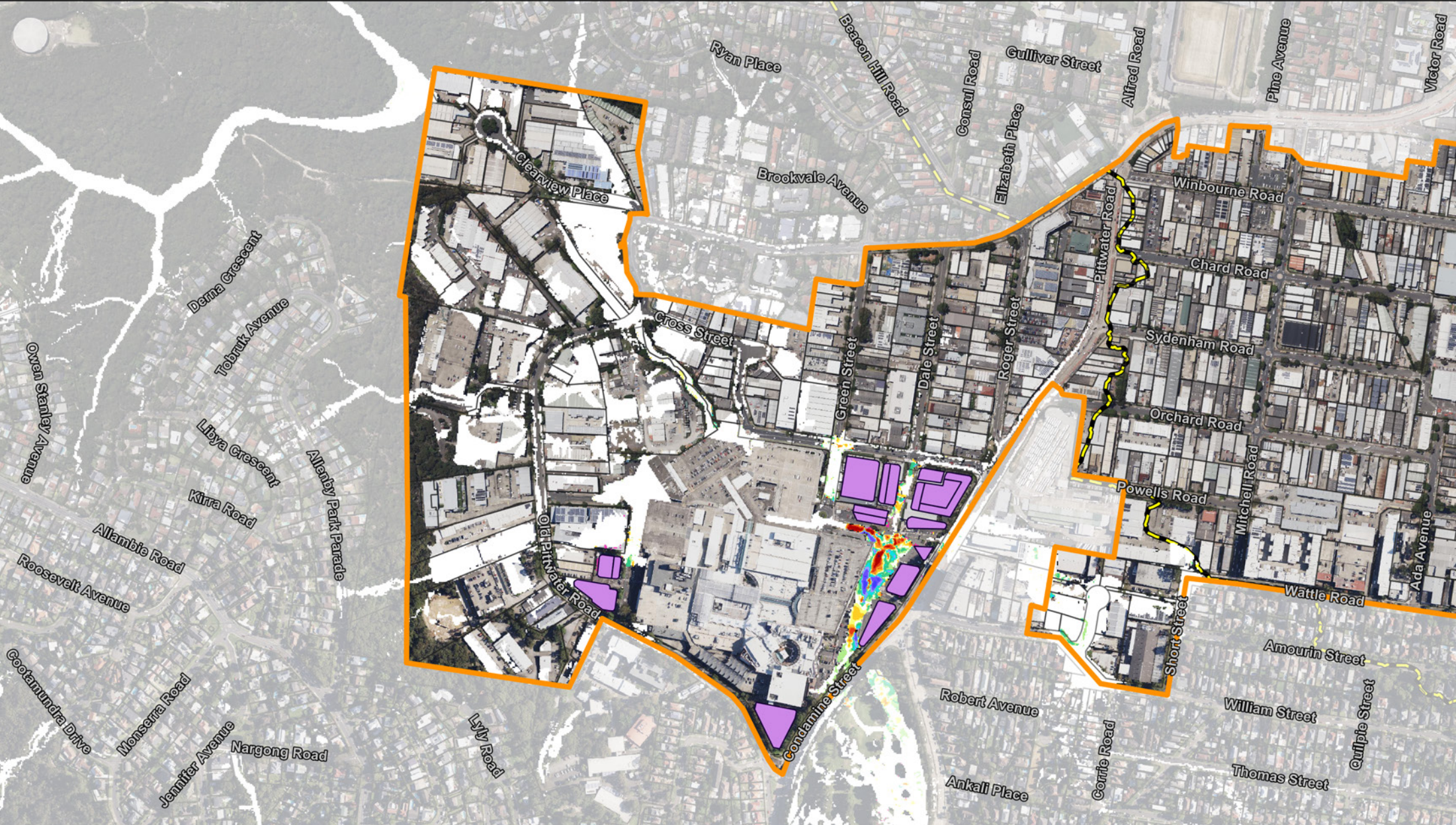


FIGURE F07
Mitigation - Drainage (M03) Scenario - 5% AEP
Difference - Flood Velocity



LEGEND

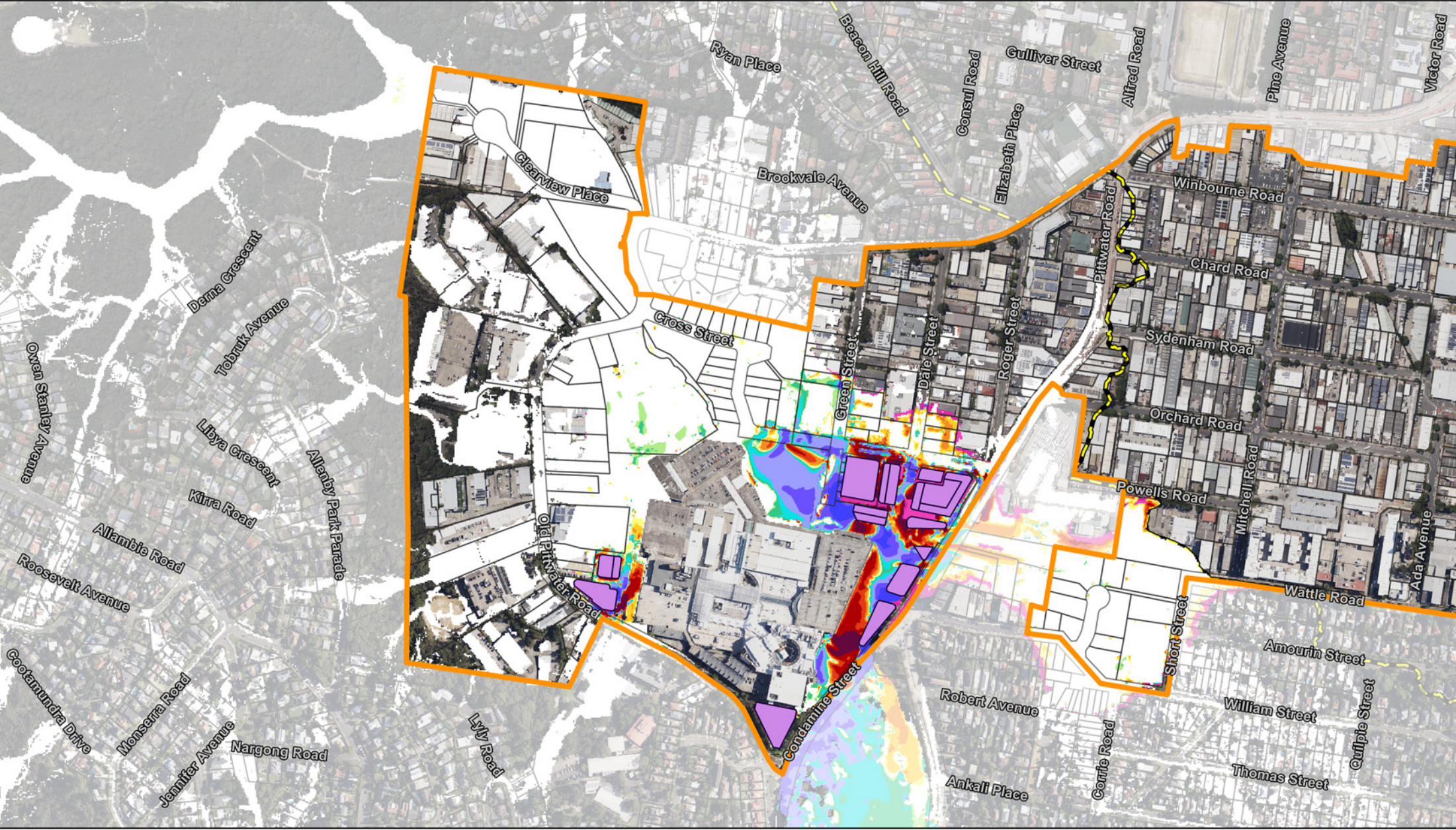
- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5
- Previously wet now dry
- Previously dry now wet

FIGURE F08
Mitigation - Drainage (M03) Scenario - 1% AEP
Difference - Flood Velocity



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5
- Previously wet now dry
- Previously dry now wet

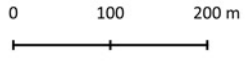
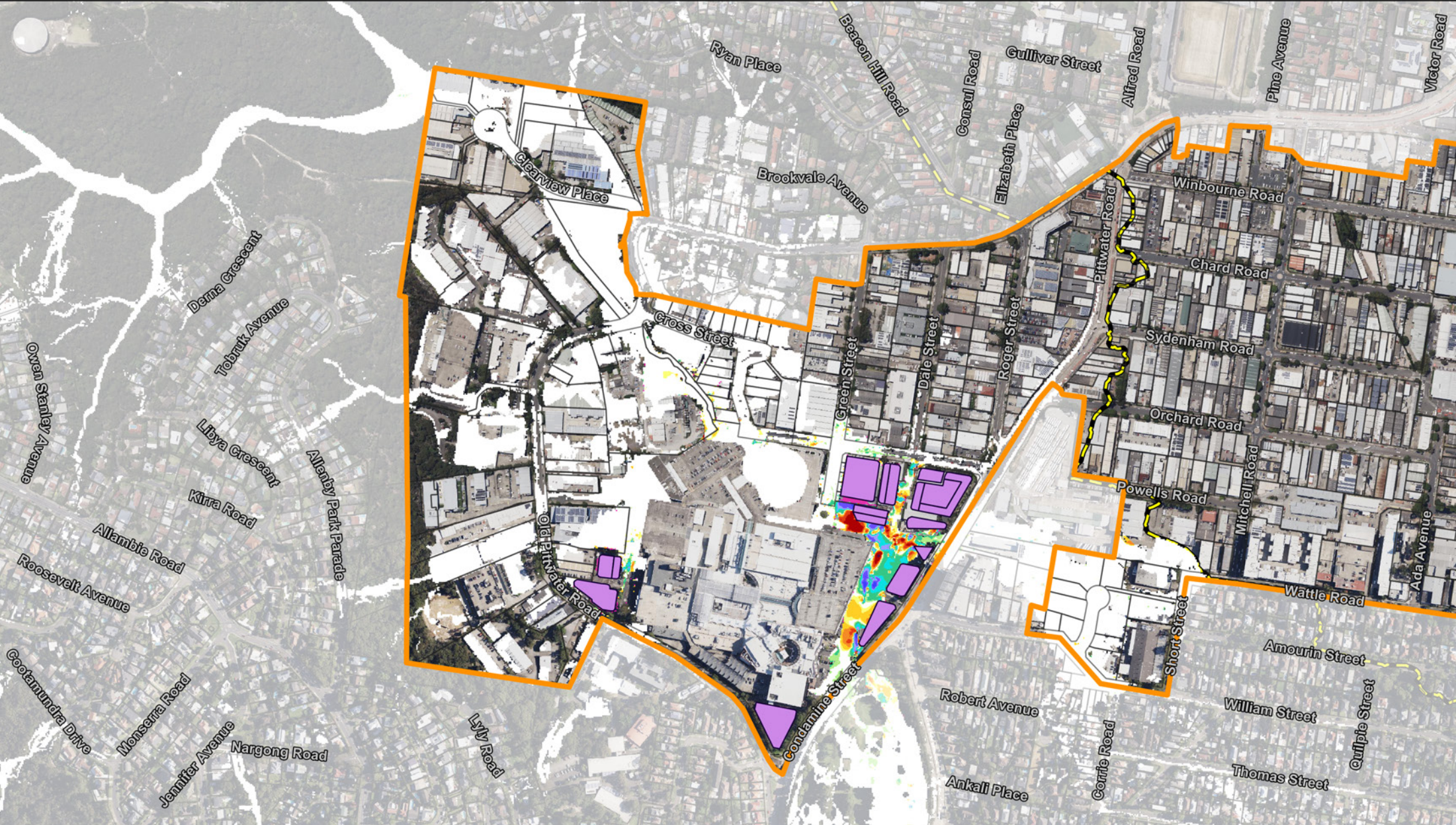


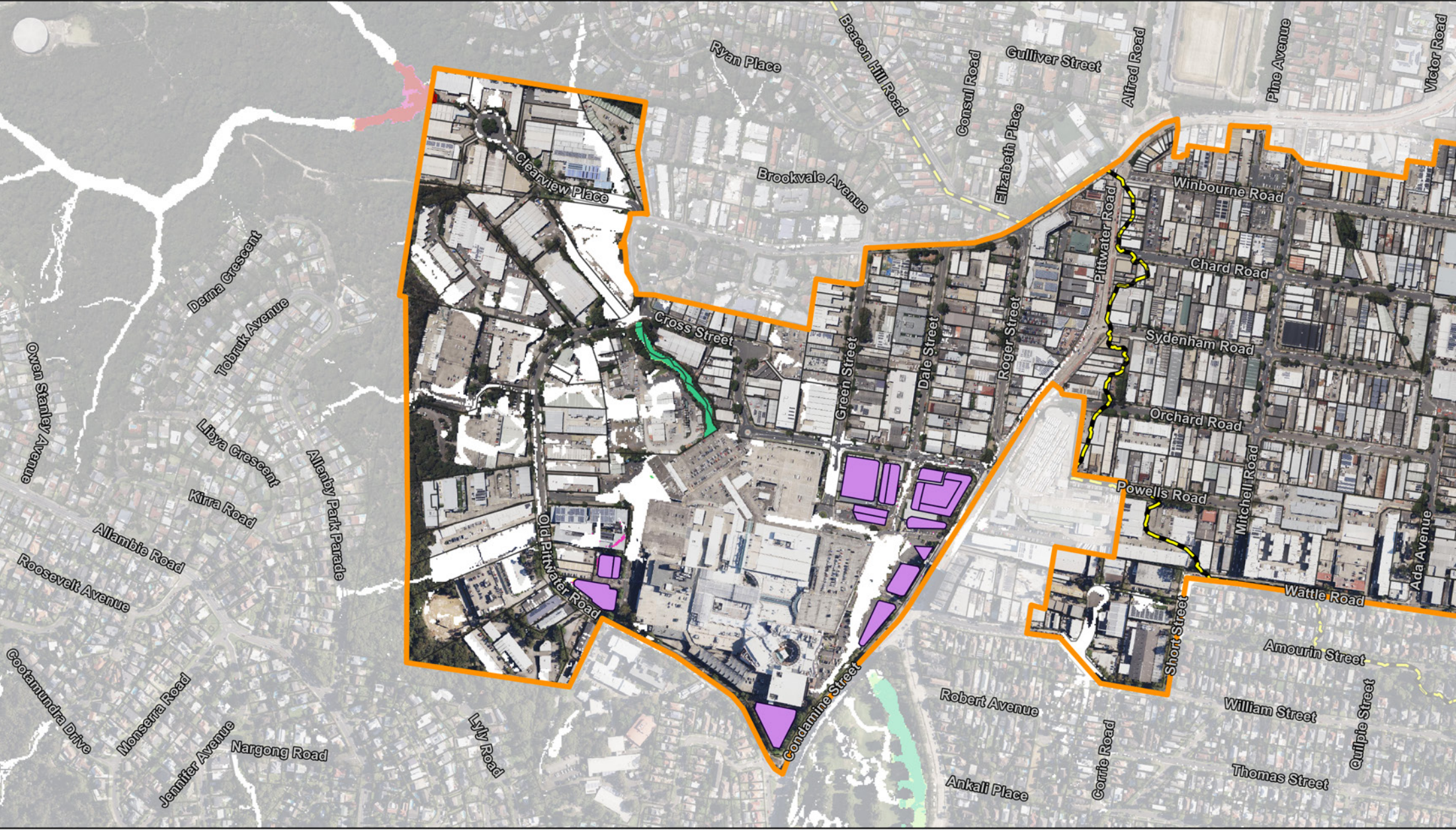
FIGURE F09
Mitigation - Drainage (M03) Scenario - PMF
Difference - Flood Velocity



LEGEND

- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Adjusted building footprints
- Change in flood velocity (m/s)
- <= -0.5
 - 0.5 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - -0.02
 - 0.02 - -0.01
 - 0.01 - 0.01
 - 0.01 - 0.02
 - 0.02 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.5
 - > 0.5
 - Previously wet now dry
 - Previously dry now wet

FIGURE F10
Mitigation - Drainage (M03) Scenario - 1% AEP+CC
Difference - Flood Velocity



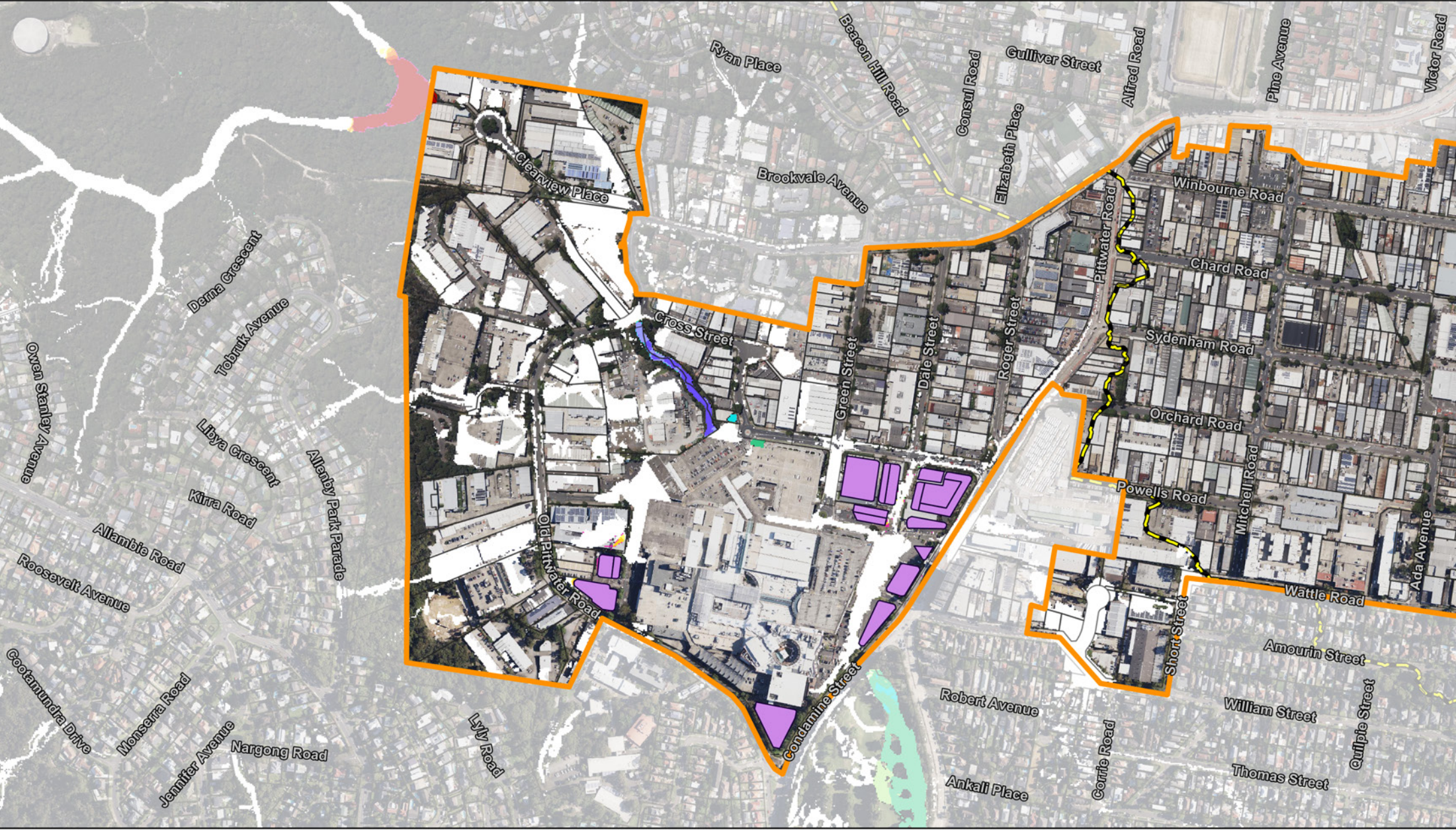
LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood level (m)	
<= -0.5	
-0.5 - -0.2	
-0.2 - -0.1	
-0.1 - -0.05	
-0.05 - -0.02	
-0.02 - -0.01	
-0.01 - 0.01	

0.01 - 0.02	
0.02 - 0.05	
0.05 - 0.1	
0.1 - 0.2	
0.2 - 0.5	
> 0.5	
Previously wet now dry	
Previously dry now wet	

FIGURE G01
Mitigation - Flood Gates (M04) Scenario - 20% AEP
Difference - Flood Level



LEGEND

- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Adjusted building footprints
- Change in flood level (m)**
- <= -0.5
 - 0.5 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - -0.02
 - 0.02 - -0.01
 - 0.01 - 0.01
 - 0.01 - 0.02
 - 0.02 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.5
 - > 0.5
 - Previously wet now dry
 - Previously dry now wet

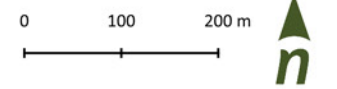
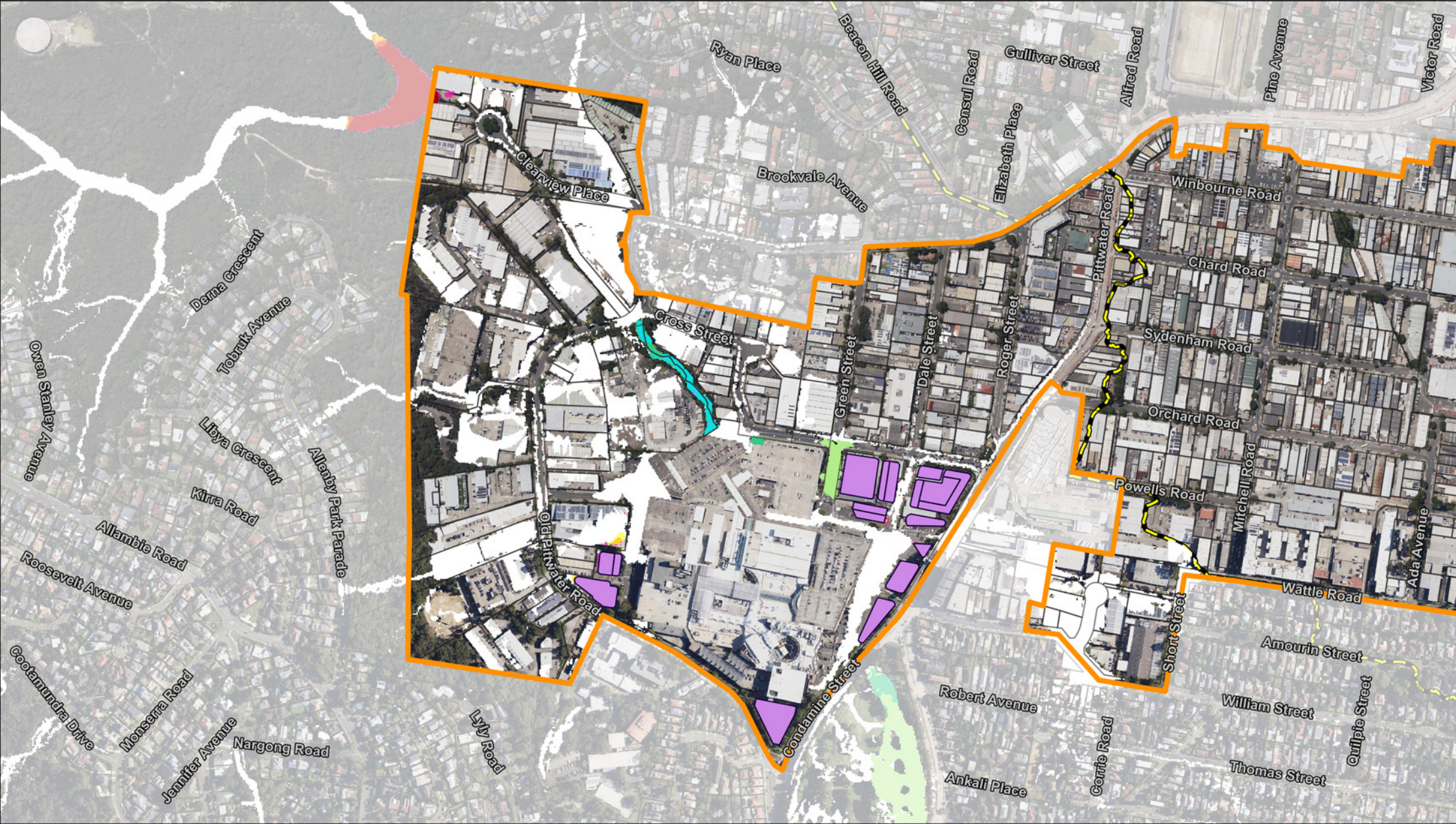


FIGURE G02
Mitigation - Flood Gates (M04) Scenario - 5% AEP
Difference - Flood Level



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood level (m)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5

- Previously wet now dry
- Previously dry now wet

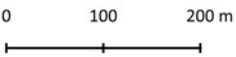
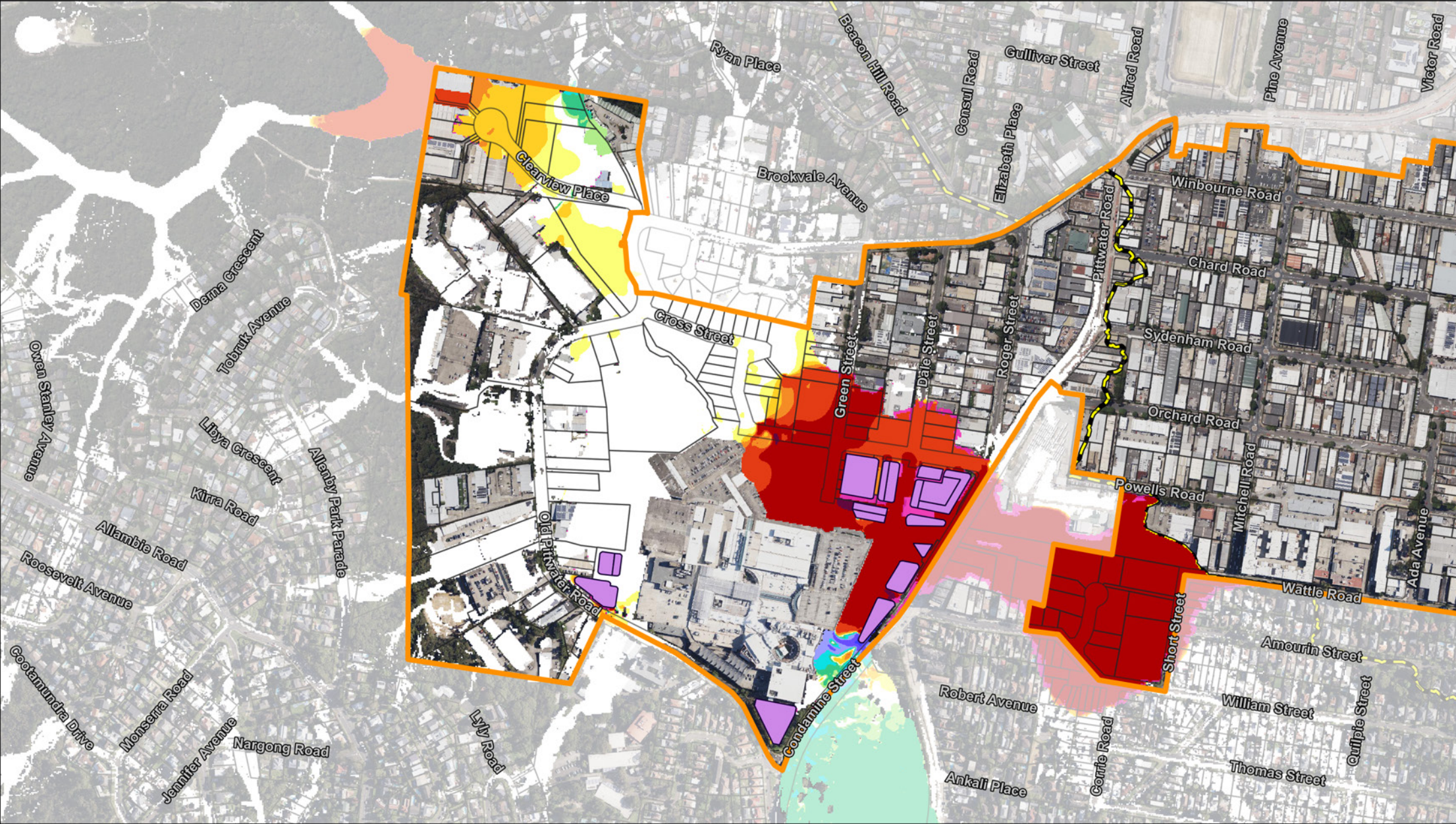


FIGURE G03
Mitigation - Flood Gates (M04) Scenario - 1% AEP
Difference - Flood Level

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood level (m)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5

- Previously wet now dry
- Previously dry now wet

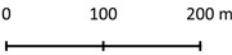


FIGURE G04
Mitigation - Flood Gates (M04) Scenario - PMF
Difference - Flood Level

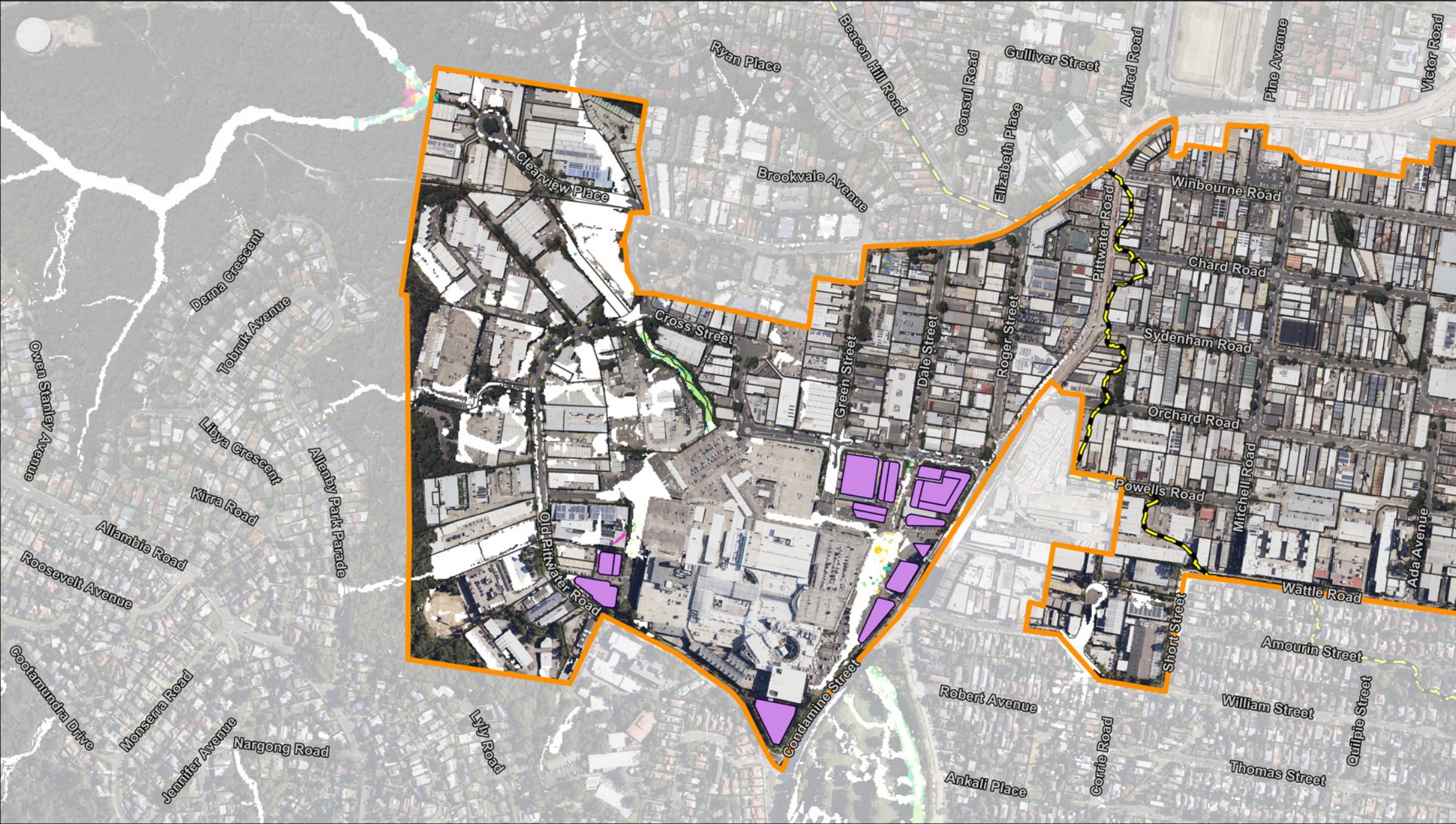
Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Adjusted building footprints
- | Change in flood level (m) | |
|---------------------------|------------------------|
| <= -0.5 | 0.01 - 0.02 |
| -0.5 - -0.2 | 0.02 - 0.05 |
| -0.2 - -0.1 | 0.05 - 0.1 |
| -0.1 - -0.05 | 0.1 - 0.2 |
| -0.05 - -0.02 | 0.2 - 0.5 |
| -0.02 - -0.01 | > 0.5 |
| -0.01 - 0.01 | Previously wet now dry |
| | Previously dry now wet |



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5
- Previously wet now dry
- Previously dry now wet

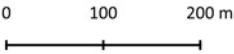
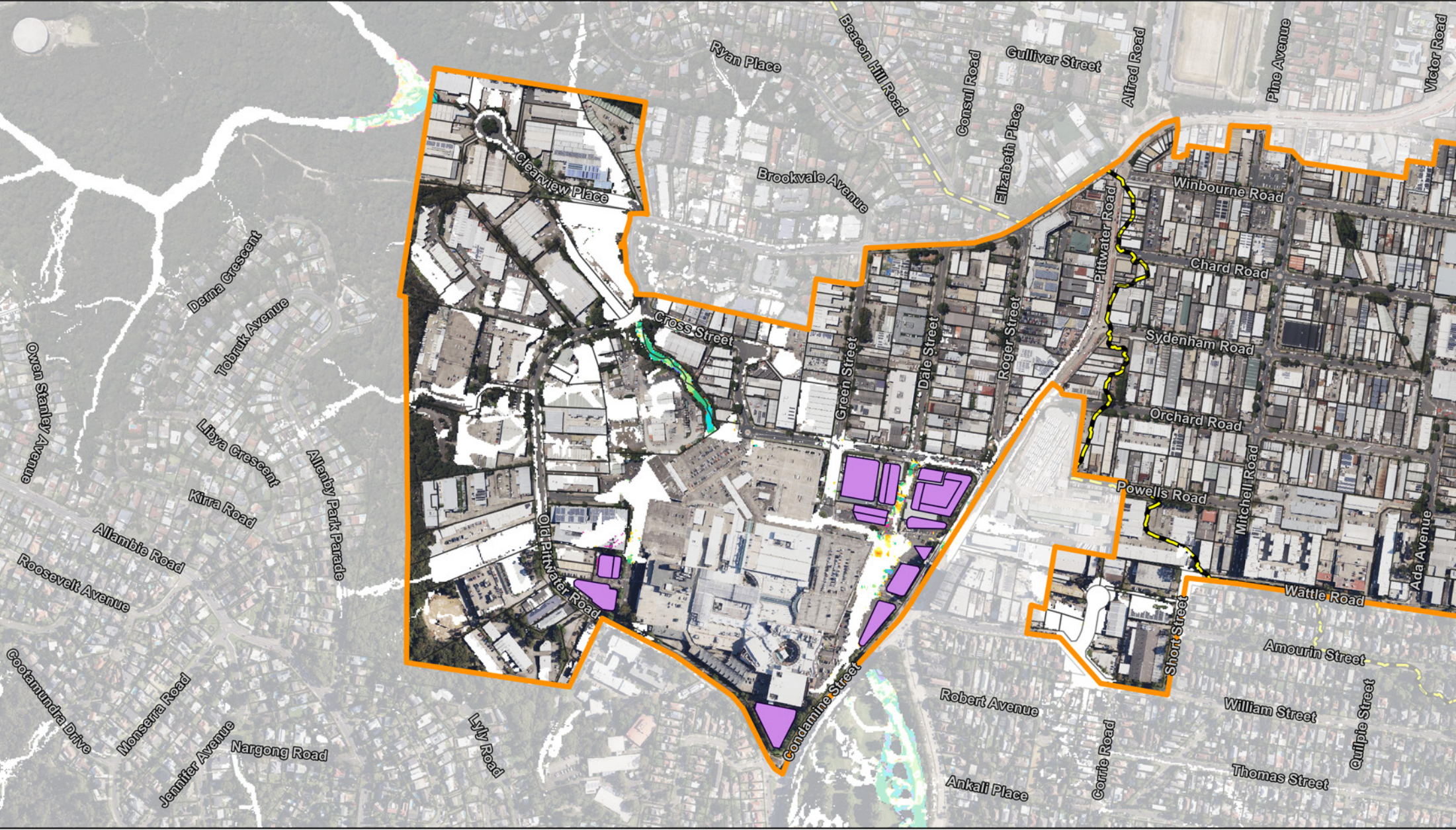


FIGURE G06
Mitigation - Flood Gates (M04) Scenario - 20% AEP
Difference - Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

0.01 - 0.02

0.02 - 0.05

0.05 - 0.1

0.1 - 0.2

0.2 - 0.5

> 0.5

Previously wet now dry

Previously dry now wet

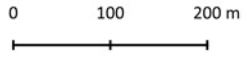
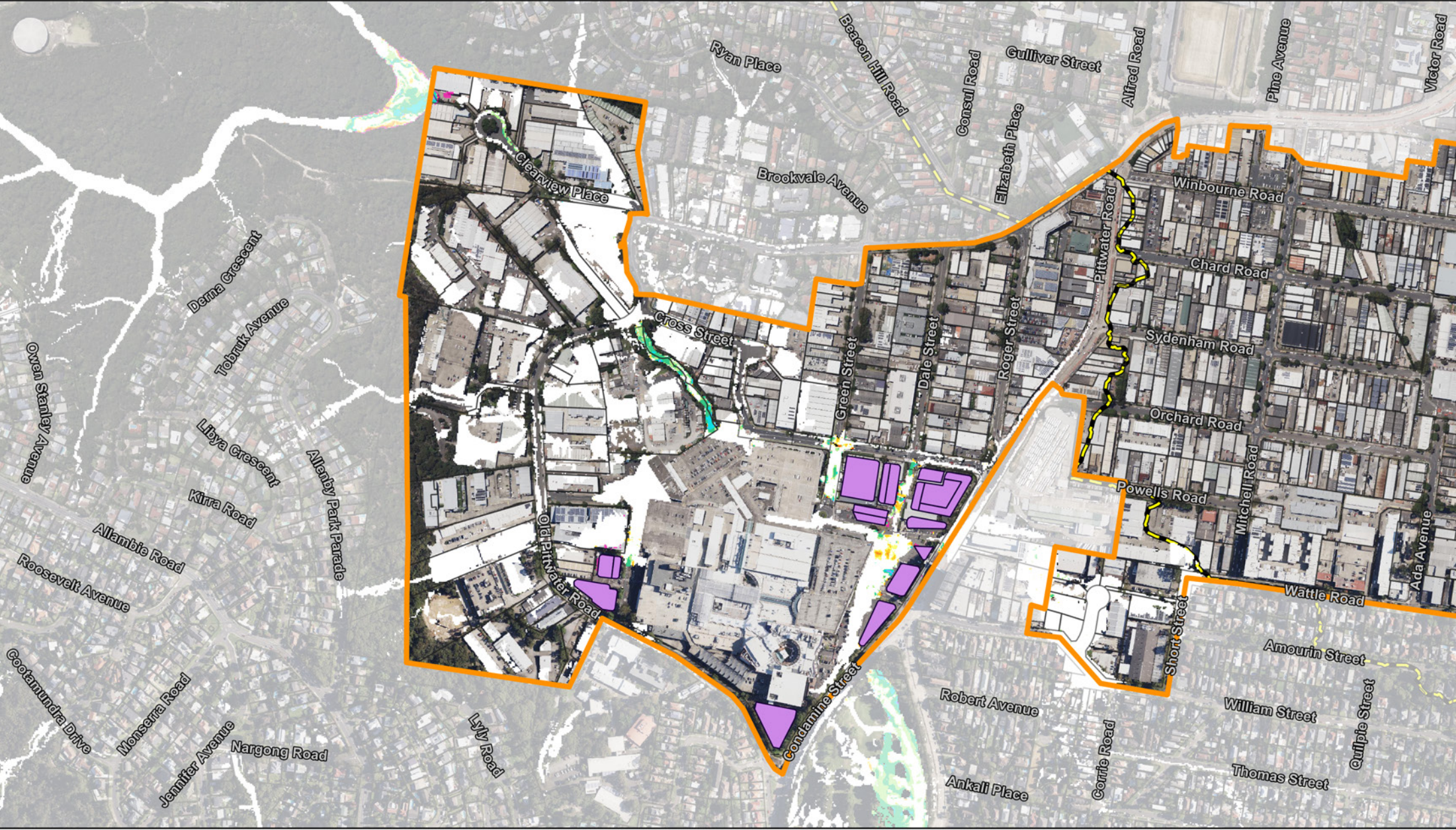


FIGURE G07
Mitigation - Flood Gates (M04) Scenario - 5% AEP
Difference - Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5

- Previously wet now dry
- Previously dry now wet

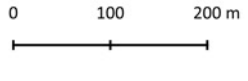
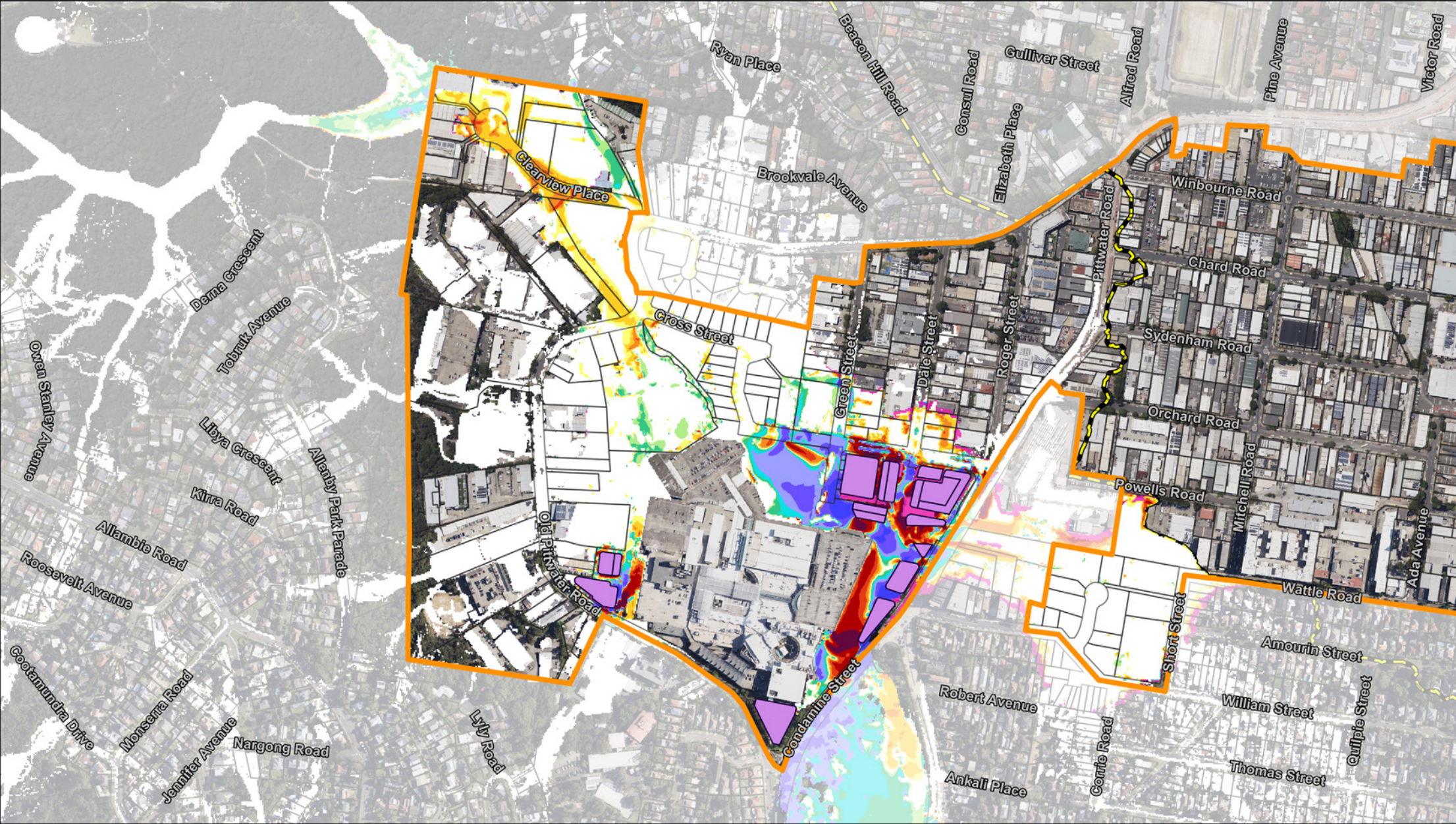


FIGURE G08
Mitigation - Flood Gates (M04) Scenario - 1% AEP
Difference - Flood Velocity



LEGEND

- Structure Plan study area
- Lots
- Manly Lagoon model extent
- Adjusted building footprints

Change in flood velocity (m/s)

- <= -0.5
- 0.5 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - -0.02
- 0.02 - -0.01
- 0.01 - 0.01

- 0.01 - 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- > 0.5
- Previously wet now dry
- Previously dry now wet

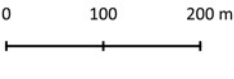
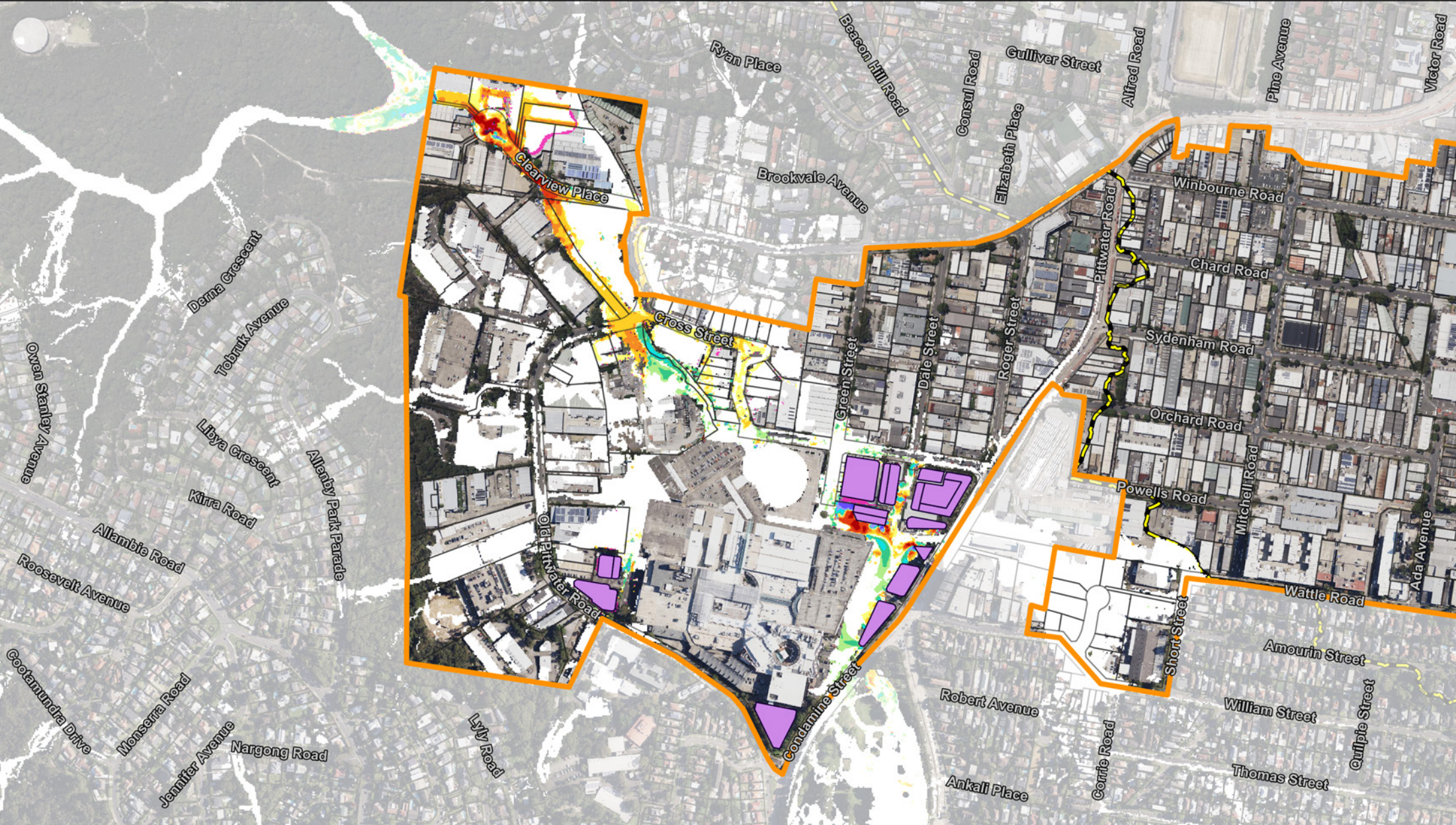


FIGURE G09
Mitigation - Flood Gates (M04) Scenario - PMF
Difference - Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



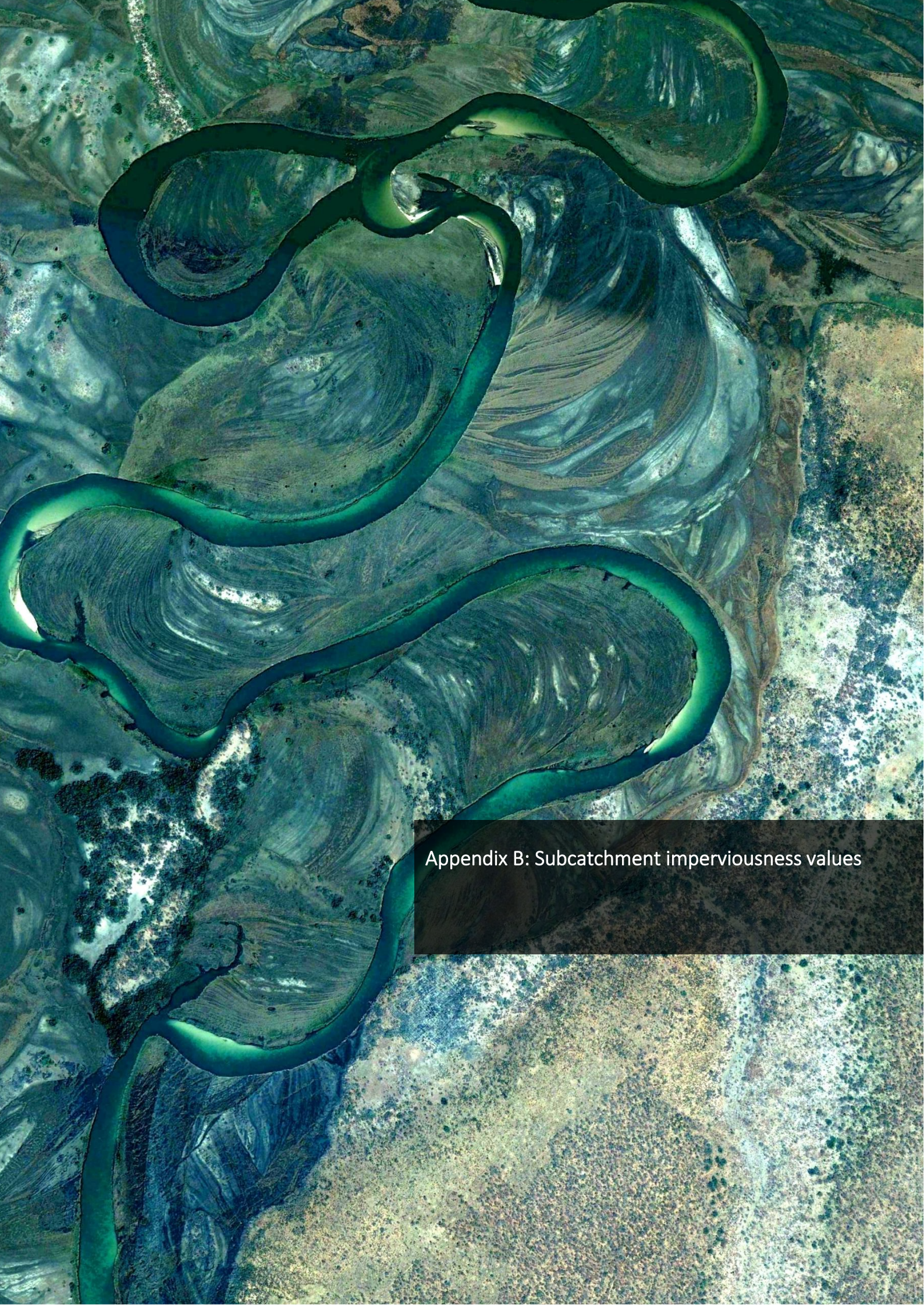
LEGEND

- Structure Plan study area
 - Lots
 - Manly Lagoon model extent
 - Adjusted building footprints
- Change in flood velocity (m/s)**
- <= -0.5
 - 0.5 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - -0.02
 - 0.02 - -0.01
 - 0.01 - 0.01
 - 0.01 - 0.02
 - 0.02 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.5
 - > 0.5
 - Previously wet now dry
 - Previously dry now wet

FIGURE G10
Mitigation - Flood Gates (M04) Scenario - 1% AEP+CC
Difference - Flood Velocity

Coordinates: GDA94 MGA Zone 56
Created: 9/4/2026
Scale: 1:7,800 (A4)

Originator: AN
Checked: PW
Approved: SH



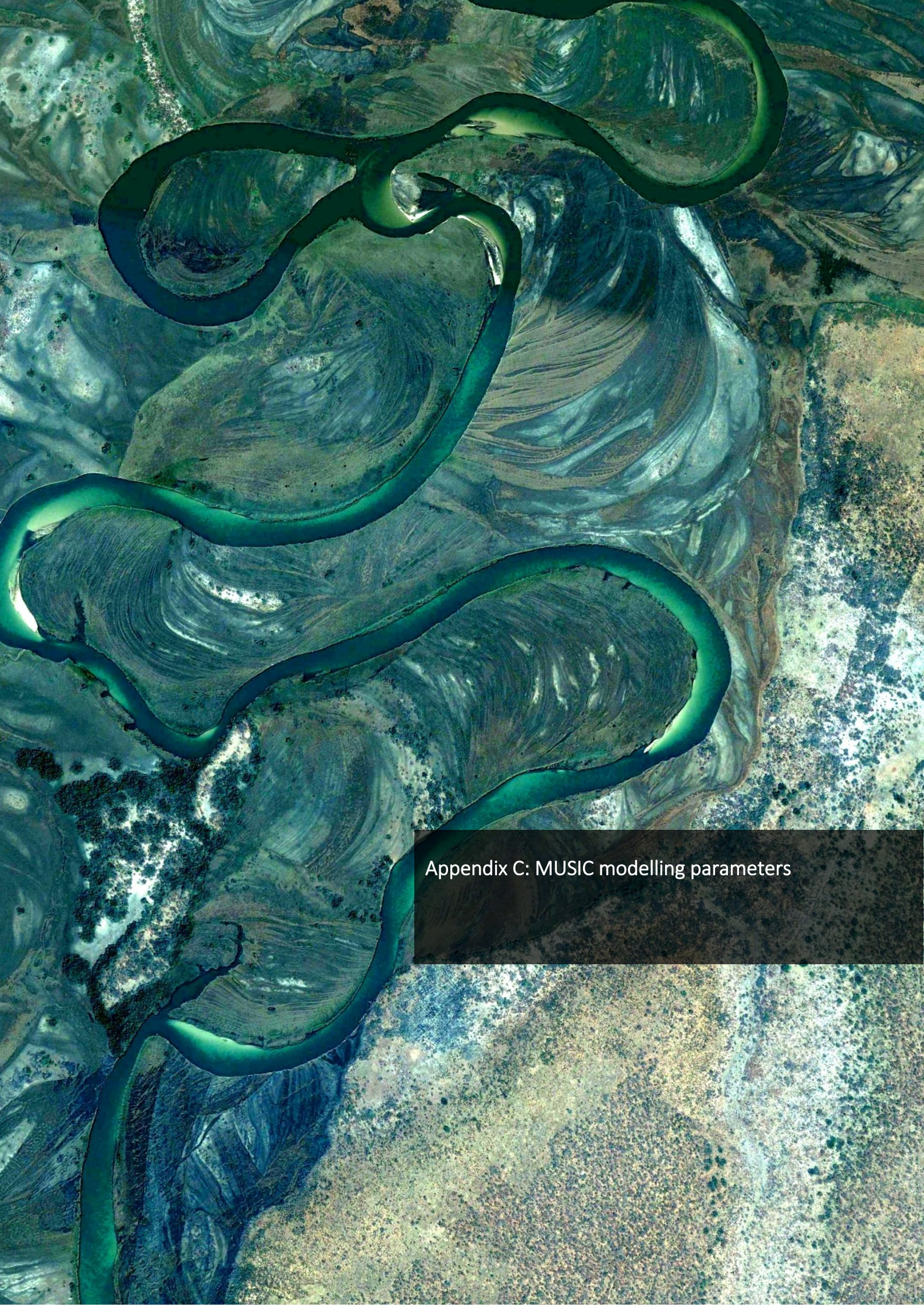
Appendix B: Subcatchment imperviousness values

Table 42. Adopted fraction imperviousness area by sub-catchment

Sub-catchment	Structure plan land use	Existing area (ha)	Proposed area (ha)	Fraction impervious (FI)	Proposed effective impervious area (ha) – Area x FI
SC 8	Industrial/Commercial	2.95	2.95	76	2.24
	Nature conservation	0.03	0.03	0	0
	Roads	0.62	0.62	40	0.25
	Sub-total	3.6	3.6		2.49
SC 9	Industrial/Commercial	3.45	3.45	76	2.62
	Nature conservation	2.72	2.72	0	0
	Roads	1.35	1.35	40	0.54
	Urban Residential	3.76	3.76	39	1.47
	Sub-total	11.28	11.28		4.63
SC 10	Industrial/Commercial	5.21	5.21	76	3.96
	Nature conservation	1.23	1.23	0	0
	Public service	0.19	0.19	24	0.05
	Roads	2.15	2.15	40	0.86
	Urban Residential	4.62	4.62	39	1.8
	Sub-total	13.4	13.4		6.67
SC 51	Industrial/Commercial	6.46	6.46	76	4.91
	Roads	1.43	1.43	40	0.57
	Urban Residential	0.66	0.66	39	0.26
	Sub-total	8.55	8.55		5.74
SC 52	Industrial/Commercial	2.55	2.55	76	1.94
	Roads	0.24	0.24	40	0.1
	Urban Residential	0.38	0.38	39	0.15
	Sub-total	3.17	3.17		2.19
SC 53	Industrial/Commercial	5.22	5.22	76	3.97
	Nature conservation	0.92	0.92	0	0
	Roads	1.08	1.08	40	0.43
	Urban residential	1.26	1.26	39	0.49
	Sub-total	8.48	8.48		4.89

Sub-catchment	Structure plan land use	Existing area (ha)	Proposed area (ha)	Fraction impervious (FI)	Proposed effective impervious area (ha) – Area x FI
SC 55	Industrial/commercial	1.65	1.65	76	1.25
	Roads	2.29	2.29	40	0.92
	Urban residential	4.93	4.93	39	1.92
	Sub-total	8.87	8.87		4.09
SC 56	Industrial/commercial	7.2	7.2	76	5.47
	Recreation	0.01	0.01	12	0
	Roads	0.57	0.57	40	0.23
	Urban residential	0.02	0.02	39	0.01
	Sub-total	7.8	7.8		5.71
SC 57	Industrial/commercial	5.11	4.88	76	3.71
	Mixed use	0	0.23	63	0.14
	Public service	2.79	2.79	24	0.67
	Roads	2.76	2.76	40	1.1
	Urban residential	5.11	5.11	39	1.99
	Sub-total	15.77	15.77		7.61
SC 81	Industrial/commercial	10.37	10.37	76	7.88
	Nature conservation	0.6	0.6	0	0
	Roads	1.12	1.12	40	0.45
	Urban residential	0.32	0.32	39	0.12
	Sub-total	12.41	12.41		8.45
SC 82	Industrial/commercial	3.35	2.24	76	1.7
	Mixed Use	0	1.11	63	0.7
	Roads	1.11	1.11	40	0.44
	Urban residential	0.03	0.03	39	0.01
	Sub-total	4.49	4.49		2.85
SC 84	Industrial/commercial	2.82	1.49	76	1.13
	Mixed use	0	1.7	63	1.07
	Recreation	0.28	0.28	12	0.03
	Roads	1.72	1.35	40	0.54

Sub-catchment	Structure plan land use	Existing area (ha)	Proposed area (ha)	Fraction impervious (FI)	Proposed effective impervious area (ha) – Area x FI
SC 110	Urban residential	0.05	0.05	39	0.02
	Sub-total	4.87	4.87		2.79
	Industrial/commercial	0.96	0.96	76	0.73
	Nature conservation	3.82	3.82	0	0
	Roads	1.41	1.41	40	0.56
	Urban residential	5.62	5.62	39	2.19
	Sub-total	11.81	11.81		3.48
SC 113	Industrial/commercial	2.87	2.87	76	2.18
	Recreation	0.25	0.25	12	0.03
	Roads	1.03	1.03	40	0.41
	Urban residential	1.62	1.62	39	0.63
	Sub-total	5.77	5.77		3.25
SC 114	Industrial/commercial	3.1	2.63	76	2
	Mixed use	0	0.47	63	0.3
	Recreation	0.01	0.01	12	0
	Roads	1.29	1.29	40	0.52
	Urban residential	1.17	1.17	39	0.46
	Sub-total	5.57	5.57		3.28
SC 115	Industrial/commercial	4.86	0.33	76	0.25
	Mixed use	0	4.52	63	2.85
	Public service	0.02	0.02	24	0
	Roads	2.82	2.82	40	1.13
	Urban Residential	0.11	0.11	39	0.04
	Sub-total	7.81	7.8		4.27
TOTAL		133.65	133.64		72.39



Appendix C: MUSIC modelling parameters

The sub-catchments to be modelled in the MUSIC model are highlighted in Figure 17, and are all catchments that contribute to the outlet point before the Brookvale Creek trash rack.

The rainfall, PET parameters and modelling period are taken from the WSUD & MUSIC Modelling Guidelines (NBC, 2016) and are detailed in Table 43 and Table 44. The model was run from 1/1/1981 and 31/12/1985, as this modelling period is representative of the long-term annual rainfall of the Northern Beaches and includes a mix of wet and dry years.

Table 43. Recommended Rainfall Data for MUSIC modelling

Purpose	Time step required	Rainfall station	Modelling period
Water Quality	6 minutes	066062 Sydney Observatory	1981-1985

Table 44. Monthly Evapotranspiration for Sydney Region

Month	J	F	M	A	M	J	J	A	S	O	N	D
PET (mm)	180	135	128	85	58	43	43	58	88	127	152	163

The adopted fraction impervious is shown in Table 42 for each land use category. The roads were delineated as a separate land use category using the NSW Land Use shapefile (SEED, 2017), rather than being incorporated into other land use categories.

For the soil properties of the MUSIC Source Nodes, per the NBC MUSIC modelling guidelines, a soil landscape map from the NSW eSPADE website was utilised, and it was determined that the catchment is mainly composed of sandy clay loam. Sub-catchments 57 and 55 are half composed of sandy soils, however within the model, sandy clay loam parameters are adopted. The adopted soil properties for the MUSIC sources nodes, derived from the WSUD & MUSIC Modelling Guidelines (NBC, 2016) are detailed in Table 45. It is assumed that the industrial/commercial, public service and urban residential land use categories take the 'roof' rainfall threshold since most of the impervious areas of that land use are rooftops. It is assumed that nature conservation, open water, recreation and road land uses take the 'roads/paths' rainfall threshold since most impervious areas for these land uses are roads or paths.

Table 45. Soil properties for MUSIC Source Nodes

Parameter	Unit	Value
Impervious area parameters		
Rainfall Threshold (mm)	mm	1.5 (for roads/paths etc.) 0.3 (for roofs)
Pervious area parameters (Sandy Clay Loam)		
Soil Capacity (mm)	mm	108
Initial storage (%)	%	30
Field Capacity (mm)	mm	73

Parameter	Unit	Value
Infiltration Capacity Coefficient a		250
Infiltration Capacity Coefficient b		1.3
Groundwater properties (Sandy Clay Loam)		
Initial Depth (mm)	mm	10
Daily Recharge Rate (%)	%	60
Daily Baseflow Rate (%)	%	45
Deep Seepage (%)	%	0

The pollutant generation parameters are shown in Table 46, and are based on the MUSIC land use categories from the WSUD & MUSIC Modelling Guidelines (NBC, 2016).

Table 46. Pollutant generation parameter for each land use

Structure plan land use	Adopted MUSIC land use		Log10 TSS (mg/L)		Log10 TP (mg/L)		Log10 TN (mg/L)	
			Storm flow	Base flow	Storm flow	Base flow	Storm flow	Base flow
Industrial/Commercial	Industrial, Commercial	Mean Std Dev	2.15 0.32	1.20 0.17	-0.60 0.25	-0.85 0.19	0.30 0.19	0.11 0.12
Nature conservation	Forest	Mean Std Dev	1.60 0.20	0.78 0.13	-1.10 0.22	-1.52 0.13	-0.05 0.24	-0.52 0.13
Open water	Forest	Mean Std Dev	1.60 0.20	0.78 0.13	-1.10 0.22	-1.52 0.13	-0.05 0.24	-0.52 0.13
Public service	General Urban	Mean Std Dev	2.15 0.32	1.20 0.17	-0.60 0.25	-0.85 0.19	0.30 0.19	0.11 0.12
Recreation	Landscape Areas	Mean Std Dev	2.15 0.32	1.20 0.17	-0.60 0.25	-0.85 0.19	0.30 0.19	0.11 0.12
Roads	Paved Road Areas	Mean Std Dev	2.43 0.32	---* ---*	-0.30 0.25	---* ---*	0.34 0.19	---* ---*
Urban residential	Residential	Mean Std Dev	2.15 0.32	1.20 0.17	-0.60 0.25	-0.85 0.19	0.30 0.19	0.11 0.12
Mixed Use	General Urban	Mean Std Dev	2.15 0.32	1.20 0.17	-0.60 0.25	-0.85 0.19	0.30 0.19	0.11 0.12

The layout of the model is such that each sub-catchment has a node for each of its land uses. The upstream sub-catchments are combined into one large sub-catchment, and the sum of the area of each land use was taken and input into the nodes for the combined sub-catchment.

Table 47. Treatment node assumptions – Vegetated swale assets

Node Type	SwaleNode
Node Name	Swale
Asset ID	Variation 1
Low Flow By-pass	0 m ³ /s
Length	100 m
Bed Slope	1.5 %
Base Width	1 m
Top Width	2.2 m
Depth	0.15 m
Vegetation Height	0.25 m
Exfiltration Rate	0 mm/hr
Number of CSTR Cells	10
Total Suspended Solids - k (m/yr)	8000 m/year
Total Suspended Solids - C* (mg/L)	20 mg/L
Total Suspended Solids - C** (mg/L)	14 mg/L
Total Phosphorus - k (m/yr)	6000 m/year
Total Phosphorus - C* (mg/L)	0.13 mg/L
Total Phosphorus - C** (mg/L)	0.13 mg/L
Total Nitrogen - k (m/yr)	500 m/year
Total Nitrogen - C* (mg/L)	1.4 mg/L
Total Nitrogen - C** (mg/L)	1.4 mg/L
Threshold Hydraulic Loading for C** (m/yr)	3500 m/year

Table 48. Treatment node assumptions – GPT (Humegard HG45 or similar)

Node Type	GPTNode
Node Name	GPT - Humegard HG45
Lo-flow bypass rate (cum/sec)	0
High Flow By-pass (cubic metres per sec)	1.96
GP Transfer Function - Input #1	0
GP Transfer Function - Output #1	0
GP Transfer Function - Input #2	15
GP Transfer Function - Output #2	1.5
TN Transfer Function - Input #1	0
TN Transfer Function - Output #1	0
TN Transfer Function - Input #2	0.5
TN Transfer Function - Output #2	0.5
TN Transfer Function - Input #3	5
TN Transfer Function - Output #3	4.3
TP Transfer Function - Input #1	0
TP Transfer Function - Output #1	0
TP Transfer Function - Input #2	0.5
TP Transfer Function - Output #2	0.5
TP Transfer Function - Input #3	1
TP Transfer Function - Output #3	0.85
TSS Transfer Function - Input #1	0
TSS Transfer Function - Output #1	0
TSS Transfer Function - Input #2	75
TSS Transfer Function - Output #2	75
TSS Transfer Function - Input #3	1000
TSS Transfer Function - Output #3	350

Table 49. Treatment node assumptions – Biofiltration assets

Node Type	BioRetentionNodeV4								
	Node Name	Bioretention Swale	Passively Irrigated Street Tree	Passively Irrigated Street Tree	Passively Irrigated Street Tree	Raingarden	Raingarden	Raingarden	Wicking lawn
	Asset ID	Variation 2	Variation 1	Variation 2	Variation 3	Variation 1	Variation 2	Variation 3	
Low Flow By-pass	0 m³/s								
High Flow By-pass	100 m³/s								
Extended Detention Depth	0.05 m	0.15 m	0.15 m	0.15 m	0.1 m	0.1 m	0.1 m	0 m	
Filter and Surface Area	10 m²	22.5 m²	1.5 m²	20 m²	3.2 m²	10.4 m²	6.4 m²	100 m²	
Unlined Media Perimeter	0.01								
Sat Hydraulic Conductivity	100 mm/hr								
Filter Depth	0.4 m	0.8 m	0.8 m	1 m	0.4 m	0.4 m	0.4 m	0.35 m	
TN Content of Filter Media	800 mg/kg								
Orthophosphate Content of Filter Media	40 mg/kg								
Exfiltration Rate	0	0	0	0	0	0	0	0	
Base Lined	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Vegetation Properties	Vegetated with Effective Nutrient Removal Plants								Vegetated with Ineffective Nutrient Removal Plants
Overflow Weir Width	1.2 m	1.2 m	1.2 m	1.2 m	1.2 m	1.2 m	1.2 m	1 m	
Underdrain Present	Yes								
Submerged Zone With Carbon Present	No	Yes	No	No	No	No	No	Yes	
Submerged Zone Depth	NA	0.3 m	NA	NA	NA	NA	NA	0.2 m	
Total Suspended Solids - k (m/yr)	8000 m/yr								
Total Suspended Solids - C* (mg/L)	20 mg/L								
Total Phosphorus - k (m/yr)	6000 m/yr								

Node Type	BioRetentionNodeV4							
Node Name	Bioretention Swale	Passively Irrigated Street Tree	Passively Irrigated Street Tree	Passively Irrigated Street Tree	Raingarden	Raingarden	Raingarden	Wicking lawn
Asset ID	Variation 2	Variation 1	Variation 2	Variation 3	Variation 1	Variation 2	Variation 3	
Total Phosphorus - C* (mg/L)	0.13 mg/L							
Total Nitrogen - k (m/yr)	500 m/yr							
Total Nitrogen - C* (mg/L)	1.4 mg/L							
Filter Media Soil Type	Loamy Sand							
Weir Coefficient	1.7							
Pet Scaling Factor	2.1							
Number of CSTR Cells	3							
Porosity of Filter Media	0.35							
Porosity of Submerged Zone	0.35							
Horizontal Flow Coefficient	3							

Table 50. Treatment node assumptions – Wicking (water demand) and stormwater harvesting assets

Node Type	RainWaterTankNode	
Node Name	Stormwater Harvesting	Wicking lawn
Asset ID	SWH	
Reuse Enabled	Yes	Yes
Annual Demand Enabled	Yes	Yes
Annual Demand Value (ML/year)	0.96115 ML/year	0.03886 ML/year
Annual Demand Distribution	Monthly	Monthly
Monthly Distribution Values	18.60;0.00;0.00;0.00;0.00;0.00;0.00;1.80;12.50;20.50;16.60;3	18.60;0.00;0.00;0.00;0.00;0.00;0.00;1.80;12.50;20.50;16.60;3
	0.00	0.00
Daily Demand Enabled	No	No
Daily Demand Value	NA	NA
Custom Demand Enabled	No	No

Node Type	RainWaterTankNode	
Node Name	Stormwater Harvesting	Wicking lawn
Asset ID	SWH	
Custom Demand Time Series File	NA	NA
Custom Demand Time Series Units	ML/day	ML/day
Minimum Draw down height	0	1.67E-18
Low Flow By-pass	0 m ³ /s	0 m ³ /s
High Flow By-pass	100 m ³ /s	100 m ³ /s
NumTanks	1	1
Surface Area	20 m ²	100 m ²
Depth above overflow	0.5 m	0.35 m
Volume below overflow pipe	60 kL	8 kL
Initial Volume	0	0
Overflow Pipe Diameter	450 mm	150 mm
Orifice Discharge Coefficient	0.6	0.6
Number of CSTR Cells	2	2
Total Suspended Solids - k (m/yr)	400 m/year	
Total Suspended Solids - C* (mg/L)	12 mg/L	
Total Suspended Solids - C** (mg/L)	0 mg/L	
Total Phosphorus - k (m/yr)	300 m/year	
Total Phosphorus - C* (mg/L)	0.13 mg/L	
Total Phosphorus - C** (mg/L)	0 mg/L	
Total Nitrogen - k (m/yr)	40 m/year	
Total Nitrogen - C* (mg/L)	1.4 mg/L	
Total Nitrogen - C** (mg/L)	0 mg/L	
Threshold Hydraulic Loading for C** (m/yr)	0 m/year	