CRC for
Water Sensitive Cities

Brisbane infill integrated water management study

Part B – Technical reports

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Brisbane infill integrated water management study
Part B – Technical reports

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1. Introduction

This report by the CRC for Water Sensitive Cities (CRCWSC) investigates synergies between infill development and integrated water management (IWM). It is based on a case study undertaken by the CRCWSC and Brisbane City Council (BCC) in the Norman Creek area, Greenslopes. The report comprises two parts:

- Part A summarises the planning implications, identifies possible strategies for implementation and provides a brief commentary on the reasons for these ideas.
- Part B (this document) contains the technical investigations that underpin the ideas presented in Part A.

The purpose of the work was to better understand the impacts of a water sensitive cities (WSC) approach to infill development. The analysis includes:

- options for alternative development typologies
- bio-physical comparisons between current, business-as-usual and new, alternative typologies
- an economic comparison between current, business-as-usual and new, alternative typologies.

The results are preliminary, and more detailed work is needed to gain a higher degree of certainty about the outcomes.

The work was completed by a team led by Anne Simi and Phil Young, from BCC's Natural Environment and Sustainability (NEWS) Branch:

- Chris Vos, Civil Engineer, BCC
- Niloo Tara, Civil Engineer, BCC
- Nick Morgan, Senior Planning Officer, BCC
- Nigel Bertram, Practice Professor of Architecture, Monash University
- Sayed Iftekhar, Senior Lecturer, Griffith University
- Chris Tanner, Regional Manager Queensland, CRCWSC.

2. Background and purpose

Population growth in Brisbane local government area is considerable and expected to continue. Around 188,000 new dwellings are expected between 2016 and 2041 – 177,000 to be housing consolidation or infill development and the balance occurring in new greenfield areas. In 2016 there were about 460,000 dwellings in Brisbane, so this represents an increase of about 40%, overwhelmingly by way of infill development. The community seeks liveable places – reliable water supplies, effective sanitation, protection from flooding, healthy ecosystems, cool green landscapes, efficient use of resources, and beautiful urban and natural spaces. But while there is typically broad agreement about such high-level aspirations, decision makers face the challenge of determining how to most effectively drive the transformations needed to continue delivering these aspirations in the context of growth, climate change and complex governance arrangements.

A water sensitive city of the future is a place where people want to live and work. It is a place that:

- serves as a potential water supply catchment, providing a range of different water sources at a range of different scales, and for a range of different uses
- provides ecosystem services and a healthy natural environment, thereby offering a range of social, ecological, and economic benefits, and
- consists of water sensitive communities where citizens have the knowledge and desire to make wise choices about water, are actively engaged in decision making, and demonstrate positive behaviours such as conserving water at home.

Water is integral to almost every feature of an urban landscape. Our cities and towns are complex, ever evolving places, and the way we interact with other people constantly changes too. In a water sensitive city, we interact with the urban water (hydrological) cycle in ways that:

- provide the water security essential for economic prosperity through efficient use of diverse available resources
- enhance and protect the health of waterways and wetlands, the river basins that surround them, and the coast and bays
- mitigate flood risk and damage, and
- create public spaces that collect, clean, and recycle water.

A water sensitive city can also be described as one that is resilient, liveable, productive, and sustainable.

BCC has articulated its vision for Brisbane's future, in *Clean, Green and Sustainable 2016 to 2031* (BCC, 2017):

- a vision for Brisbane as a top 10 lifestyle city globally
- significant achievements: clean air, the richest biodiversity of any city in Australia, 35% natural habitat cover – on track to a target of 40%, carbon neutral status, and generous green spaces
- big challenges ahead as population growth brings new pressures, reflecting a need to use land, energy and water resources more wisely, generating less waste, and as the climate changes, to be prepared for natural threats including droughts, bushfires, storms and flooding.

Clean, Green and Sustainable includes chapters relevant to this study including:

- Chapter 6, WaterSmart City lists, among others, the following actions:

  Adopt WaterSmart practices that contribute to a liveable, resilient city
  - Locate, design and manage new and existing development, infrastructure and services to be resilient and adaptable to flood, drought and extreme weather events
  - Continue to develop water sensitive city measures suited to Brisbane's infill development pattern in accordance with the City Plan
  - Continue to explore innovative ways to reduce the impact of flood on people and property
  - Identify a diverse mix of fit-for-purpose water sources such as stormwater harvesting, grey water and rainwater tanks to improve the resilience of water supply systems to drought.

  Design with water in mind
  - Provide space for water to flow and to be retained in the landscape, reducing and slowing stormwater runoff
  - Use stormwater to green and cool the city, mitigating urban heat island impacts
  - Ensure waterways are a key element of the city form.

These actions reflect the aspirations of a water sensitive city, with further detail developed in this report about what it means and what needs to be done for Brisbane.

The CRCWSC program included a key integrated research project dealing with *Water sensitive outcomes for infill developments.* Most major cities in Australia expect significant infill development over the coming decades and, as noted above, Brisbane is no exception. Without significant intervention, 'business as usual' is expected to have considerable influence on the hydrology, resources efficiency, liveability and amenity of our cities. This research project developed and applied a performance framework to understand infill impacts, create design options and processes through case studies, and identify improved governance options and arrangements.

This case study investigates, analyses and understands the impacts of infill development delivered as a continuum of current practice, or alternatively, in ways that meet the aspirations of water sensitive cities and *Clean, Green and Sustainable*.

3. Existing, business as usual and water sensitive

The work was framed to compare the three development scenarios described below.

3.1 Framing the options

Existing development or EX is reasonably self explanatory: it is the development that is occurring now along with existing development stock, i.e. it represents the existing housing stock. Typical streetscapes and building developments are shown below and indicate mostly single houses with relatively generous greenspace around them and (in some places) strongly vegetated verges:

Business as usual or BAU is the development that could be expected to occur under current planning instruments, and generally in accordance with best practice. Examples of this are shown below, typically comprising low rise multi-unit development with little green space:

Water sensitive or WSC is typified by the type of development envisaged in the urban design developed in this project. Not only does the urban design change, but the way we deal with water in the landscape and for servicing development is also different. It is development that would satisfy the vision for a water sensitive city.

3.2 Scenario development

Using these options, the following scenarios were investigated:

	EX	BAU	WSC
Urban design	Existing	Development likely under current planning instruments	Typologies developed in this project
Urban heat	Existing	Minimal street trees installed and irrigation of open space is rarely supplied	• Street trees to provide continuous canopy, and to be self watering trees unless irrigation is supplied • Public open space and street verges are moderately well irrigated • Private open space has continuous tree canopy and moderate irrigation • Fraction impervious of development is effectively 50% or less (e.g. could be achieved with green roofs)
Water balance	Existing	A very low uptake of integrated water management is assumed Only occasional development with rainwater tanks, active demand management and active implementation of stormwater reuse for irrigation or similar Stormwater quality meets the minimum requirement of the State Planning Policy (SPP)	High uptake of integrated water management Active water demand management Stormwater reuse for all non drinking water demand, supplemented by potable supply. Stormwater quality meets no net change criteria.
Overland flow	Existing	As would occur under current planning instruments Probably results in a slight improvement in impacts as new development is designed 'around' overland flows in a piecemeal fashion	A coordinated approach to drainage line setback, combined with new building forms reduces impacts while achieving high standard development outcomes, and meeting growth targets

4. Methodology

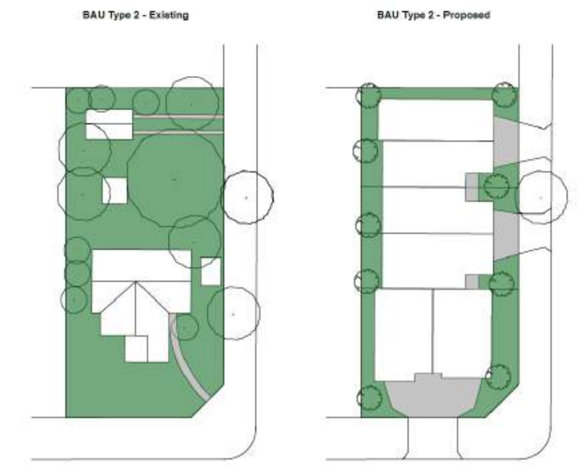
The study methodology is outlined below.

4.1 Framing the options

The land use options were developed as follows:

- EX: the existing situation was based on aerial mapping and BCC database records describing the current land uses
- BAU: land use allocations were provided by Monash University for the business-as-usual (BAU) typologies and are presented in Table 1, along with the land use allocation distributions for each typology. Two typologies were developed based on two typical examples of how infill development is currently occurring within the Norman Creek catchment.

Table 1: Monash percentage allocations (BAU)

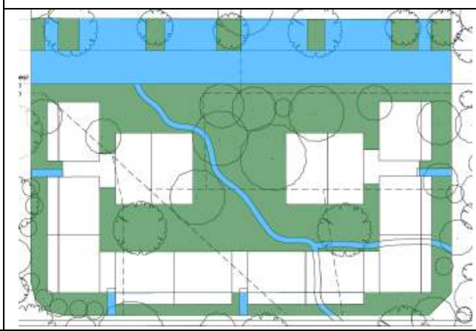
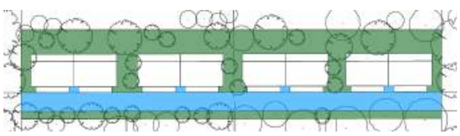
<table>
<tr><td></td><td colspan="2">BAU1</td><td colspan="2">BAU2</td></tr>
<tr><td></td><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td></td><td>Existing</td><td>Proposed</td><td>Existing</td><td>Proposed</td></tr>
<tr><td>Roof</td><td>31</td><td>58</td><td>25</td><td>66</td></tr>
<tr><td>Garden</td><td>62</td><td>22</td><td>72</td><td>21</td></tr>
<tr><td>Concrete</td><td>7</td><td>20</td><td>3</td><td>13</td></tr>
</table>

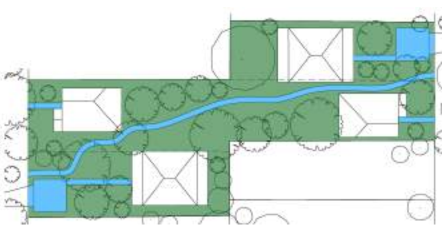
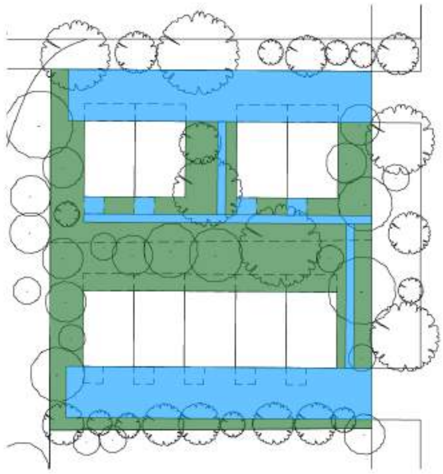
These two example typologies were spatially assigned across the entire Norman Creek catchment based on the existing lot size. This distribution is presented in Figure 1.

Figure 1: BAU design typology distributions

- WSC: land use allocations were provided by Monash University for four water sensitive (WS) typologies and are presented in Table **2,** along with the land use allocation distributions for each typology.

Table 2: Monash percentage allocations (WSC)

	WSC-A	WSC-B1
		
Roof	37	34
Garden	43	44
Permeable paving	20	22

	WSC-B2	WSC-C
		
Roof	23	30
Garden	65	38
Permeable paving	12	32

These four typologies were spatially assigned across the entire Norman Creek catchment based on the existing lot size. This distribution is presented in Figure 2.

Figure 2: WSC design typology distribution

4.2 Catchment scale land use change

The catchment wide land use changes derived from the above distributions are presented in Figure 3 and the associated change in population across scenarios is presented in Figure 4.

Scenario	Fraction impervious (%)
EX	61%
BAU	64%
WSC	55%

Figure 3: Catchment scale land use change

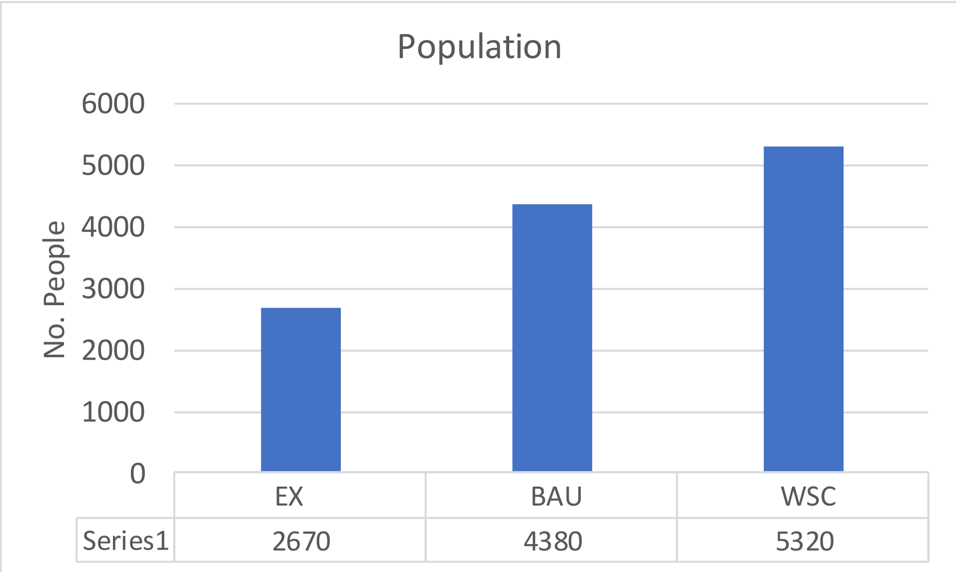


Figure 4: Change in population

4.3 Subsidiary studies

The work was completed in four separate subsidiary studies described below:

Urban design

The Norman Creek infill study design applies the principles developed in the CRCWSC's Integrated Research Project 4 (IRP4) for high amenity medium density housing that also improves overall hydrological and environmental performance.

A selection of housing types from the IRP4 Typologies Catalogue (London et al., 2020) were adapted and sited to suit the Norman Creek allotments and also respond to the natural topography. We have proposed one 'walk-up' (2–3-storey) apartment type, two 'townhouse' types, and one freestanding 'dividable house': distributed in the suburb in response to neighbouring conditions and street hierarchy. For example, apartment types are located on larger blocks along main pedestrian/commercial streets such as Denman St opposite the hospital; townhouses are located in more purely residential infill sites. Freestanding single level types are used in the 'character' residential zones (pre-1946 housing stock) and are intended as a variation (or renovation) of the traditional Queensland raised house – with a second entrance enabling subdivision into two smaller single-bedroom dwellings.

The first principle of site arrangement was to leave room on the ground plane for water (particularly for those existing housing sites located in overland flow path) and increase the number of canopy trees over time by providing ample deep root soil zones. Working also with the slope of the land, this leads to open, multipurpose ground level designs that can accommodate flexible carparking, workshop spaces and recreation space, with an emphasis on improving landscape quality and overall site permeability. Ground level parking spaces/ workshops can be either open or secured, and have storage and basic wet areas to allow them to function as home-office / home-workshop / studio spaces that activate the ground plane. These spaces are intended to be constructed from resilient materials to allow them to be inundated in extreme events.

Above the ground plane, the townhouse types have open warehouse-type living spaces with raised decks, with bedrooms above this and a roof terrace on top. The verticality is possible in this infill context due to steep topography and the raised nature of existing largely timber building stock. External staircases and balconies use the amenity of large canopy trees. All dwellings are well oriented and have full cross-ventilation.

The walk-up apartments are fully accessible with elevators attached to each stairwell, and use a 'stair hall' circulation type rather than gallery/corridor access. This means each stair hall has a distinct identity to the street, with up to 6 dwellings being accessed from each entrance. The apartments have a two-storey street frontage, with a set-back third level keeping the street scale low and maintaining pedestrian amenity and solar access. The internal areas are arranged around large courtyards, which can house proper canopy trees. Parking is provided at grade along the rear boundary, with through-block access from both sides. This design provides efficient vehicle circulation and prevents car spaces from dominating the site and primary frontages. Where overland flow path crosses apartment sites in Denman St, the ground floor dwellings are removed to provide pedestrianised covered porches linking street and courtyard. Ground level tenancies in this condition would be well suited to offices, small retail or allied health businesses supporting the hospital.

Overall, the infill dwelling types and urban design aim to provide this part of Norman Creek with a substantial increase in both population and dwelling diversity, while also increasing long term tree canopy, improving site permeability and increasing pedestrian amenity.

Urban heat and water balance

The performance of alternative infill scenarios for the study area were evaluated using the approach described in the Infill Performance Evaluation Framework (Renouf et al., 2020). Steps followed were:

- Creation of site-plans for dwelling typologies that represent the existing (EX) case, the business-as-usual (BAU) infill case and alternative water sensitive (WSC) infill cases. Design parameters are defined for each. These scenarios were previously documented as NOW, NEW and NEXT.
- Creation of precinct plans for various development scenarios in the study area, including the existing (EX) development case (at 2019), expected infill development under business-as-usual (BAU) conditions, and alternative infill development scenarios based on water sensitive (WS) city principles. Land uses within the study area under each development scenario were categorised into land use clusters (residential, vacant land, streets, etc.).
- Definition of water servicing assumptions for each development scenario
- Evaluation of the following aspects for each of the development scenarios:
    - Urban water flows were estimated for each development scenario using the Scenario Platform developed under the CRCWSC's Tool And Products (TAP) project (CRCWSC, 2020b). Previous iterations of the water cycle modelling were undertaken using the Aquacycle model (Mitchell et al., 2001)
    - The urban heat of the case study area under each development scenario was also modelled using the Scenario Platform (CRCWSC, 2020a).
    - Architectural and urban space qualities of each development scenario were developed by Monash University Architecture
- Generation of multiple performance indicators to rate and compare the performance of the BAU and WSC infill scenarios against the EX case.

Overland flow analysis

A hydrologic (XP-RAFTS) and hydraulic (TUFLOW) model were developed for stage one of the project. These models were modified to account for the changes in the next stage of the work. In the absence of historical catchment flood data, the XP-RAFTS model was suitably verified against the Rational Method (QUDM) and checked against TUFLOW model discharges.

Three catchment scenarios were simulated in the models for a range of flood magnitudes for two events: 39% annual exceedance probability (AEP) and 2% AEP. The four scenarios were:

- Now scenario – Existing catchment conditions: based on the current waterway conditions at the year 2020 (hydrology and hydraulic models)
- BAU scenario – Fully developed catchment conditions under current BCC City Plan guidelines (land use only): based on fully developed land use assumptions (hydrology model) for the whole of the catchment for selected land parcels, with BAU building footprints developed by Monash (hydraulic model)
- WSC scenario – Characterised by the type of development envisaged in the urban design scenarios developed for this project. It is the development that would satisfy the vision for a water sensitive city. From a hydrologic/hydraulic modelling perspective, this has been assessed as follows:
    - WSC typologies designed for the whole of catchment, with new typology building footprints within the overland flow conveyance corridor (hydraulic model), as per Appendix A
- WSC storage scenario – Characterised by the type of development envisaged in the urban design scenario developed for this project along with 10 kL storage tank for collecting rainwater for each dwelling.

Summary of scenarios

Scenario	Hydrology	Hydraulic		ARI
Existing	Existing catchment condition	Existing building footprints and catchment condition		39% AEP (2 year ARI) 2% AEP (50 year ARI)
BAU	335 lots throughout the catchment had increase in imperviousness	Existing building foot prints	BAU developed building footprints	39% AEP (2 year ARI) 2% AEP (50 year ARI)
WSC	405 lots has new typology building with reduced foot prints	Existing building foot prints	Developed typology building footprints	39% AEP (2 year ARI) 2% AEP (50 year ARI)
	WS +10 Kl	Developed typology building		

Results from the TUFLOW modelling were used to assess changes in flood depths, discharges, timing, flood hazard (depth x velocity product) and hazard safety classifications (Australian Emergency Management Institute (AEMI) Hazard Classification).

Economic analysis

An economic assessment of the outcomes was undertaken using the methods and tools developed under the CRCWSC's Integrated Research Project 2 (IRP2). A benefit–cost assessment (BCA) was completed with benefits determined through the above studies (urban design, water balance and urban heat and flood investigations), or using the Value Tool to determine benefits associated with intangible impacts e.g. property value increases associated with proximity to green areas. The BCA compared current BAU development with a 'water smart city' or WSC development scenario. The trial area contains 875 lots and a BAU development would create about 1,500 new dwellings that would have no rainwater tanks, lack flood resilience in architecture, have no (or minimal) street trees and have minimal water quality abatement. Water smart development would feature about 2,000 new dwellings that would address and mitigate all of these issues.

A number of critical assumptions were made in the assessment:

- The catchment is fully developed over a period of 25 years.
- Development margin is about 12% to 15%, and there is a bottom line increase of $8 million in the WSC scenario reflecting the higher number of dwellings in that scenario. Build cost estimates

were obtained from Total Estimating (https://www.totalestimatingservices.com.au/) for BAU and WSC typologies. These estimates indicated no appreciable difference in build costs, though the analysis added a 3% premium to the water sensitive typologies.

- Revenues and costs associated with development were based on a high level review of material available on the internet and the authors' experience. These figures require critical review.

Details of the methodologies used are presented in Attachments A to C.

5. Results

The studies demonstrate a WSC approach to urban design and architecture and water servicing infrastructure achieves a significantly increased population, helping to achieve Brisbane infill targets, while realising multiple bio-physical benefits (water use, runoff, flooding, heat) with strong economic performance. In summary these results are:

1. a significantly higher development yield:
    a. In the EX scenario, the study area population is estimated to be 2,670 people.
    b. Under BAU, the population increases to 4,380 people.
    c. In a WSC or WaterSmart city, the population increases to about 5,320 people.
2. lower impervious fraction (about 9% lower comparing BAU with WSC), with the result that:
    a. Urban heat island effects are reduced. This is shown in **Figure 5** which represents the change in the Urban Thermal Comfort Index and shows the proportion of outdoor areas above set threshold temperature. For example, BAU shows 57% of area between 40 and 42°C compared with 38% in the WSC scenario.
    b. Stormwater runoff is reduced so waterway health is improved (Table 3).
    c. There is more space for green infrastructure, more infiltration of rainwater to the ground helping to maintain green growth and more evapotranspiration. All these results reduce stormwater runoff quantities.
3. improved flood and overland flow outcomes. For a 50-year average recurrence interval (ARI) storm event, an estimated 34,100 m^2 of land is flooded in the EX scenario, compared with 31,000 m^2 in a WSC scenario (with stormwater harvesting/rainwater tanks) which is a decrease of 11%, and 37,500 m^2 for BAU which is a 10% increase. This means roughly 10 or 15 fewer properties are subject to flood in the WSC case when compared with BAU.
4. reduced per capita water demand (Table 3)
5. there is the opportunity for water source substitution from stormwater harvesting to irrigate green areas, street trees, verges etc., and this all improves property values and helps manage urban heat.

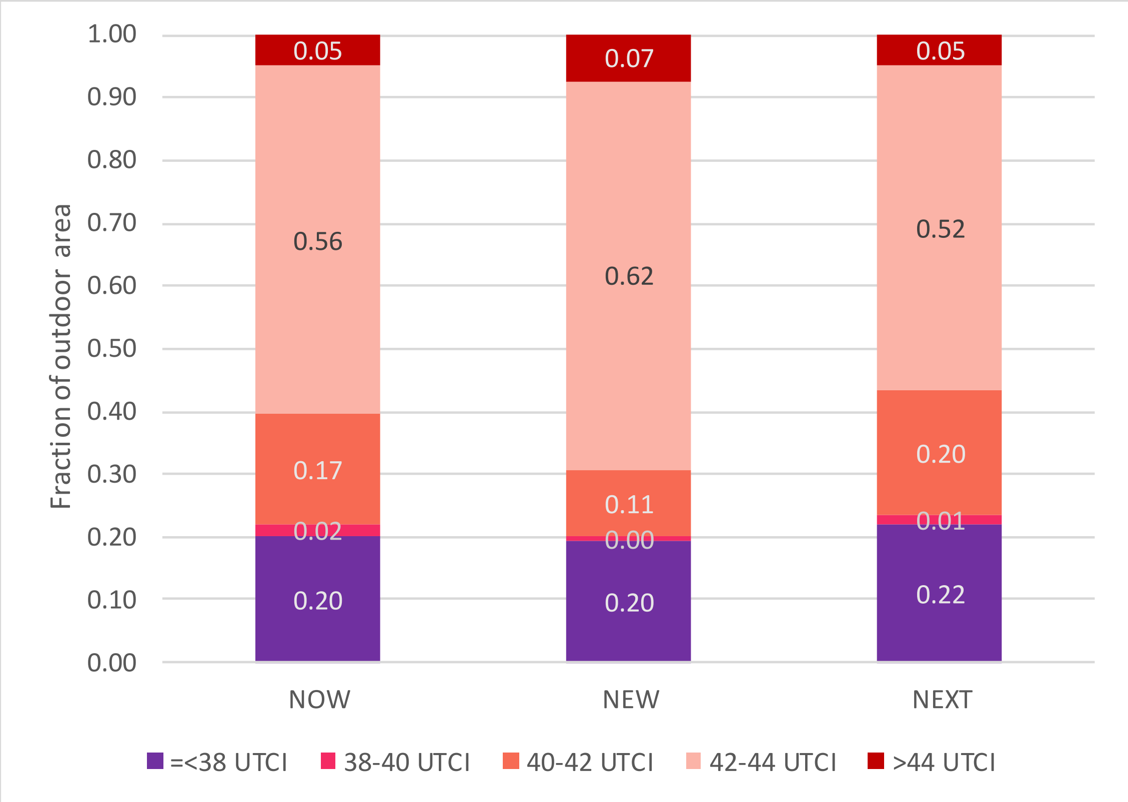


Figure 5: Proportion of outdoor areas meeting Urban Thermal Comfort Index (UTCI) thresholds

Table 3: Water cycle results

Scenario	Population	Water indicator (measured in megalitres/year)			
		Infiltration	Evapo-transpiration	Water demand	Stormwater runoff
EX	2,670	93.1	267.6	142.1	526.2
BAU	4,380	83.2	256.4	202.5	546.2
WSC (including stormwater harvesting or rainwater tank)	5,320	104.4	278.5	184	371.9

These results are shown in Figure 6 and Figure 7. On a total basis (i.e. without factoring in population growth) infiltration and evapotranspiration are relatively static, water demand increases and stormwater runoff decreases. When considered on a per capita basis, infiltration and evapotranspiration decrease, water demand decreases a small amount and stormwater runoff decreases significantly.

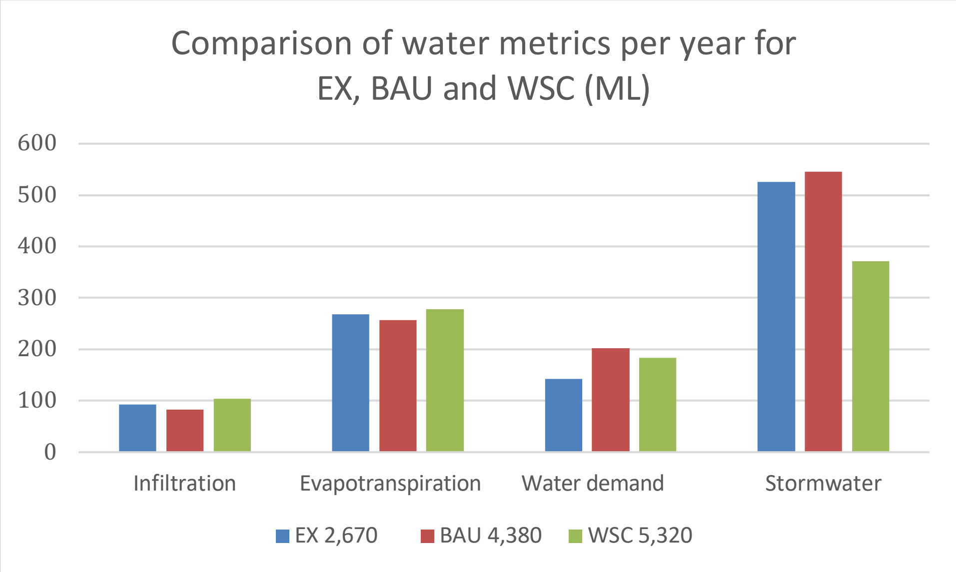


Figure 6: Total water cycle outcomes

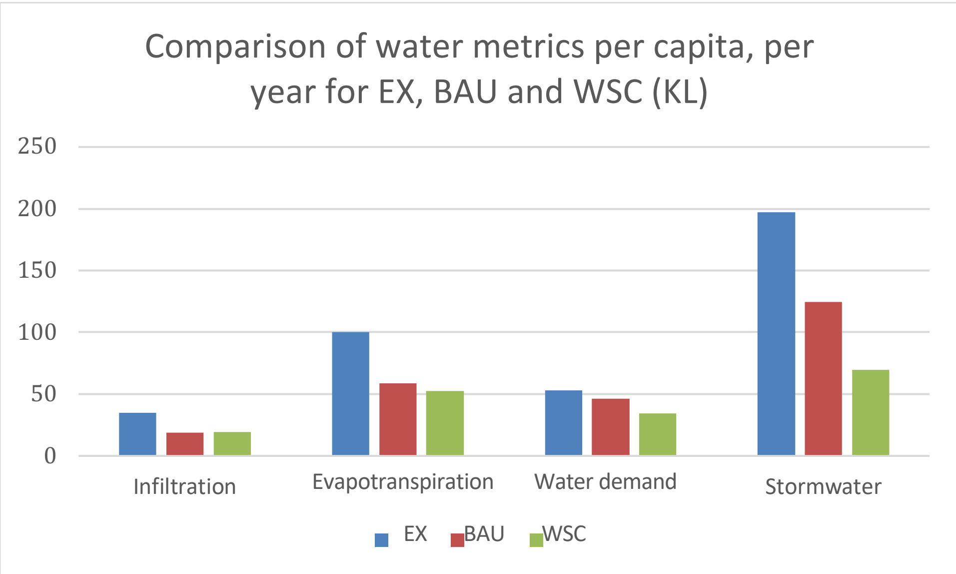


Figure 7: Per capita water cycle outcomes

Importantly, these results are achieved while accommodating a significantly increased population.

These results were incorporated into a benefit–cost assessment, which indicated:

- a positive benefit–cost ratio (BCR) of around 2 for the overall project, underpinned by a significant economic benefit accruing to the development industry
- a positive BCR of around 1.3 for BCC.

Further, development revenue would need to fall by 23% to produce an unfavourable BCR (i.e. less than 1).

Figure 8 illustrates analysis of the relative costs and benefits:

- Developer revenue dominates the benefits, primarily driven by the increased yield available in the WSC scenario. Nevertheless these results need to be used with caution until the results are tested with the development industry to provide greater confidence.
- The dominant costs result from an allowance made within the analysis for BCC and the utility cross-subsidising the costs of infrastructure works using revenue streams other than infrastructure charges. Infrastructure charges have been allowed for and assumed to be 100% allocated to the works associated with the development.
- Benefits associated with the elements of a water sensitive approach having a direct impact on water are significant. These benefits include reduced flood risk and reduced flood property damage, a significant reduction in stormwater runoff and entrained stormwater pollutants, savings on water supply and an uplift in property values associated with green and blue infrastructure. There is a small cost to the utility reflecting the reduction in water sales, which reduces the sales margin.
- Other benefits like reduced energy for cooling and reduced mortality resulting from a cooler temperatures were not included, but could be. In this regard more detailed analysis is needed.

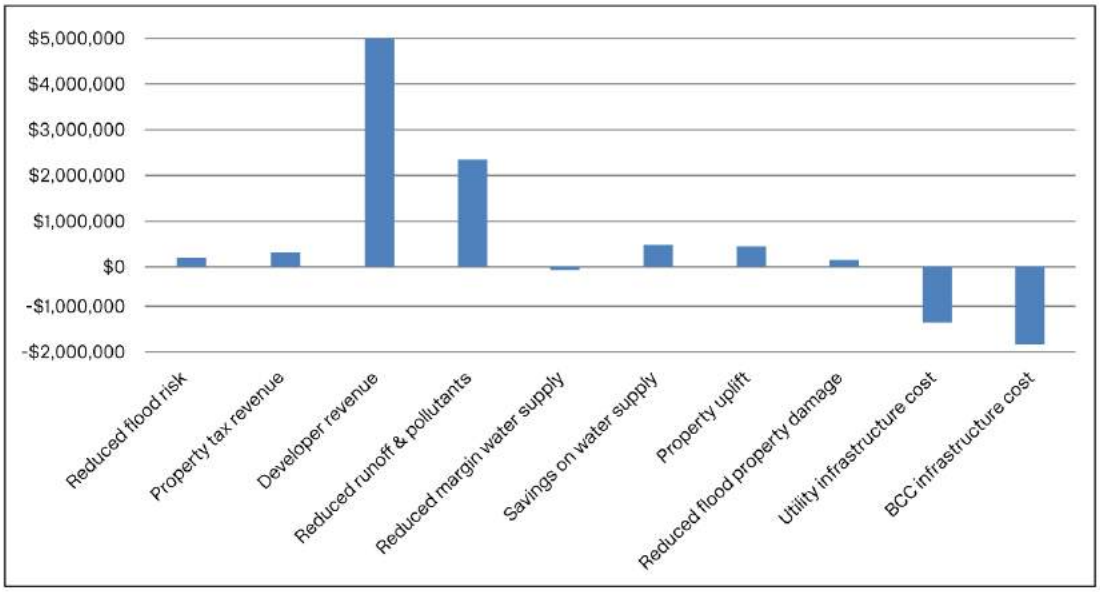


Figure 8: Breakdown of economic costs and benefits

These costs and benefits accrue to different parties as follows:

- Reduced flood risk and flood property damage, savings on water supply and property uplift accrue to households.
- Increased property tax revenue and reduced runoff benefit BCC.
- The development margin benefits developers.
- The reduced margin on water supply and utility infrastructure costs accrue to the utility.
- Other infrastructure costs accrue to BCC.

The benefit–cost assessment was undertaken using the CRCWSC's Benefit: Cost Analysis (BCA) Tool and Value Tool.

The results are positive and clearly provide a strong basis to support a WSC approach.

Nevertheless, the results need to be used with caution, and require a thorough review, particularly relating to the sensitivity and probability distributions. Further, to allow for only a partial buildout of WSC to all blocks available for development (as shown in the figures above) and to allow for uncertainty in the development revenue figures used in the analysis, a lower bound of –60% and upper bound of 0% has been used (others are at –30%/+30%) in the sensitivity analysis.

Detailed results are presented in the full reports at Attachments A to C.

6. Conclusions

This report presents a case study undertaken by the CRCWSC and BCC into infill development options for a water sensitive approach in the Norman Creek area, Greenslopes.

The purpose of the work was to better understand:

- the options for alternative development typologies that encourage water sensitive approaches
- the bio-physical comparisons between current, business-as-usual and new, alternative typologies
- an economic comparison between current, business-as-usual and new, alternative typologies.

The report and underlying work has delivered the following results:

- Proposed urban design and building (WSC) typologies for Brisbane infill development respond to the aspiration of a water sensitive or water smart city and meet many of the ideas included in BCC's *Clean, Green and Sustainable* document.
- When coupled with WSC building typologies, the case study demonstrates the significant bio-physical performance improvements of a water sensitive approach. This includes the metrics of urban heat, water demand and stormwater runoff.
- Similarly the WSC approach shows a strong benefit–cost ratio when compared with BAU.

The outcomes of this study are positive. Nevertheless, the analysis is based on a number of assumptions. It is recommended BCC undertake more detailed investigations to determine the benefits of a WSC approach to infill development with greater certainty. Assuming the outcomes from this study are ratified, BCC should pursue policies and guidelines for implementing a water smart approach to infill development.

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Attachment A – Technical report on urban design

Norman Creek Case Study

Presentation - 201022

Nigel Bertram, MADA

THE UNIVERSITY OF WESTERN AUSTRALIA

MONASH University MONASH ART DESIGN & ARCHITECTURE

CRC for Water Sensitive Cities

Scope Area Plan

Existing (EX)

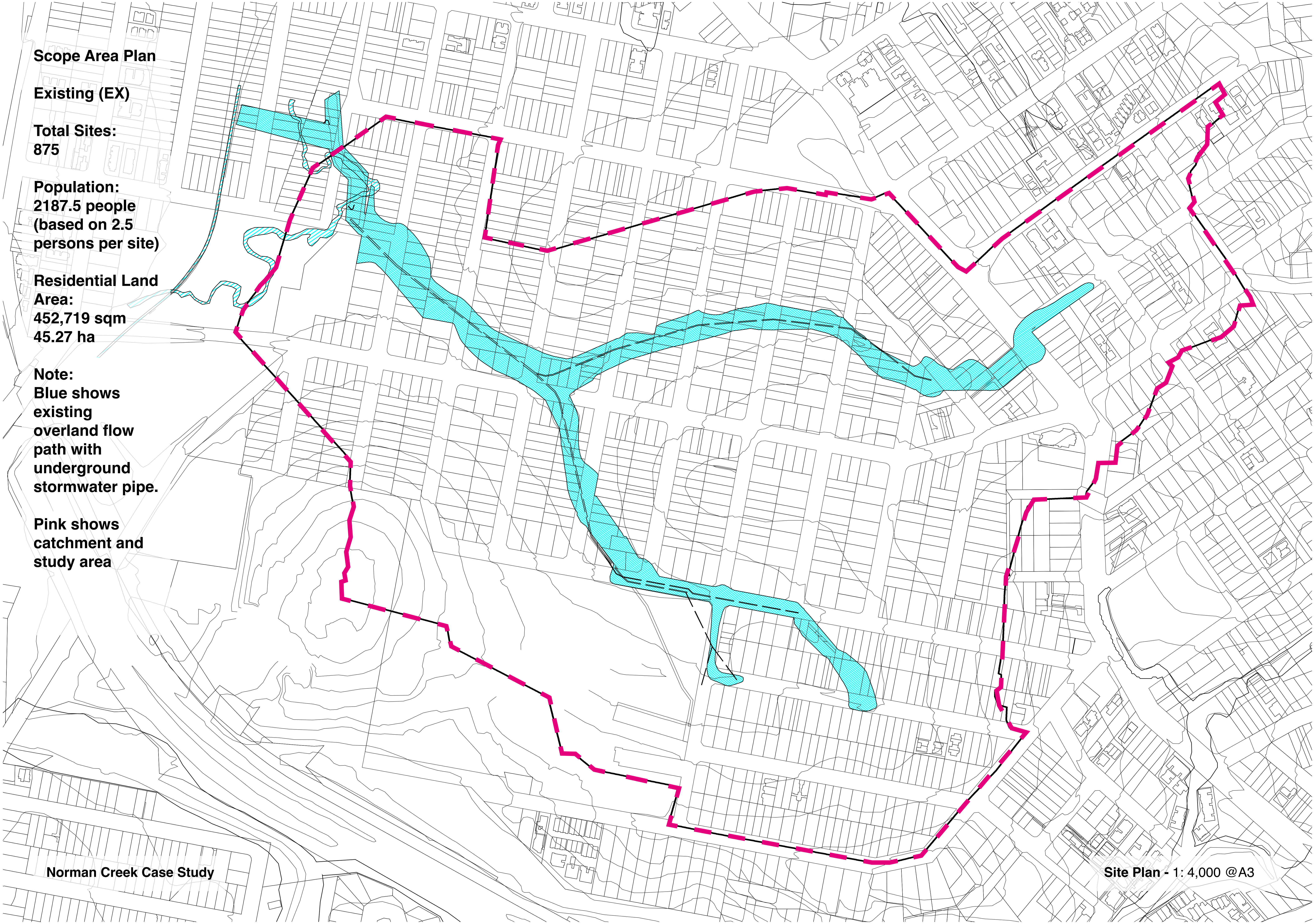
Total Sites:
875

Population:
2187.5 people
(based on 2.5
persons per site)

Residential Land
Area:
452,719 sqm
45.27 ha

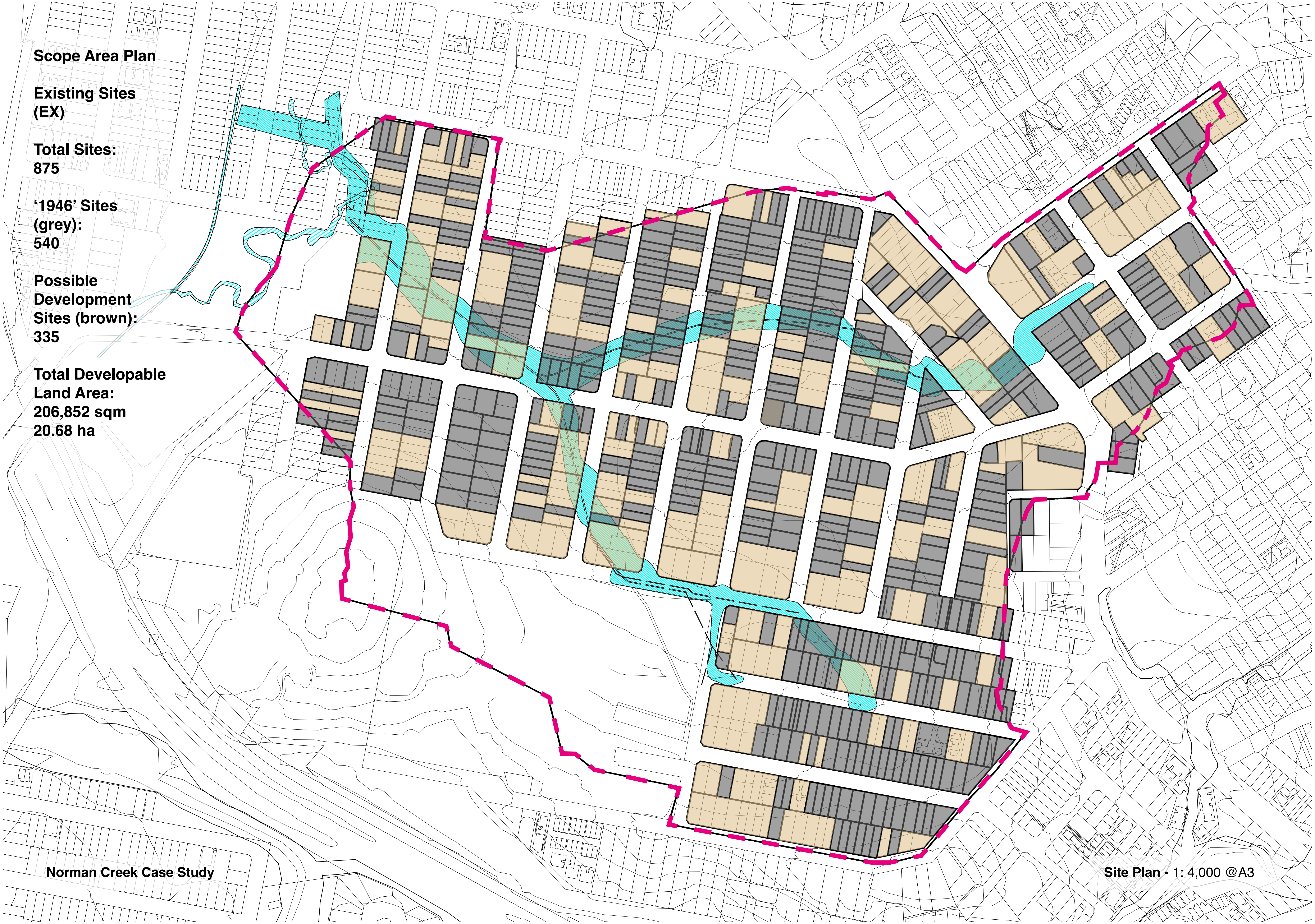
Note:
Blue shows
existing
overland flow
path with
underground
stormwater pipe.

Pink shows
catchment and
study area



Norman Creek Case Study

Site Plan - 1: 4,000 @A3


Scope Area Plan
Existing Sites (EX)
Total Sites: 875
'1946' Sites (grey): 540
Possible Development Sites (brown): 335
Total Developable Land Area: 206,852 sqm 20.68 ha
Norman Creek Case Study
Site Plan - 1: 4,000 @A3

Business As Usual Design (BAU)

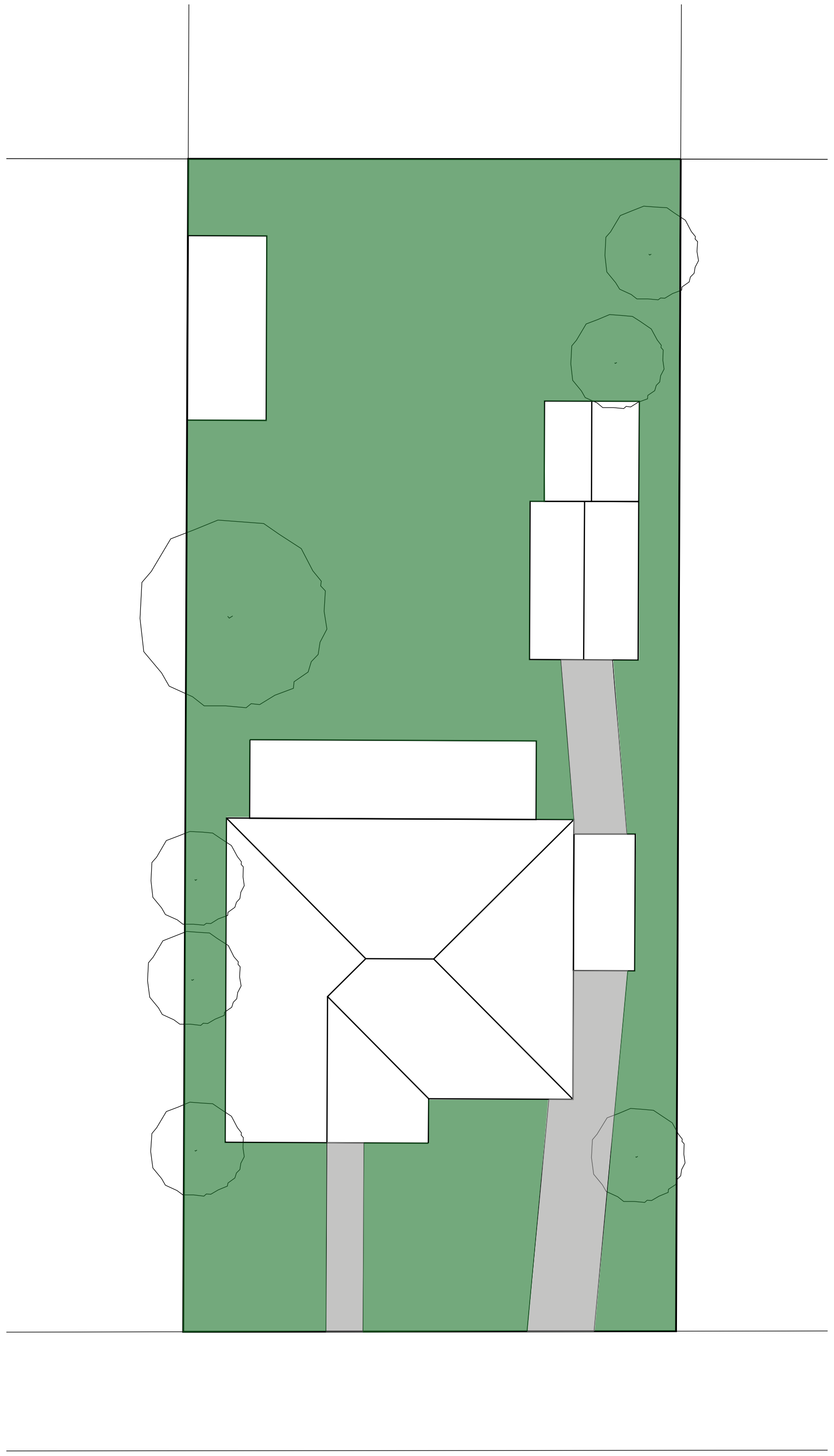
49 Headfort St

Type 1 - Existing
Site Area: 660 sqm
Roof: 204 sqm (31%)
Garden: 413 sqm (62%)
Concrete: 43 sqm (7%)

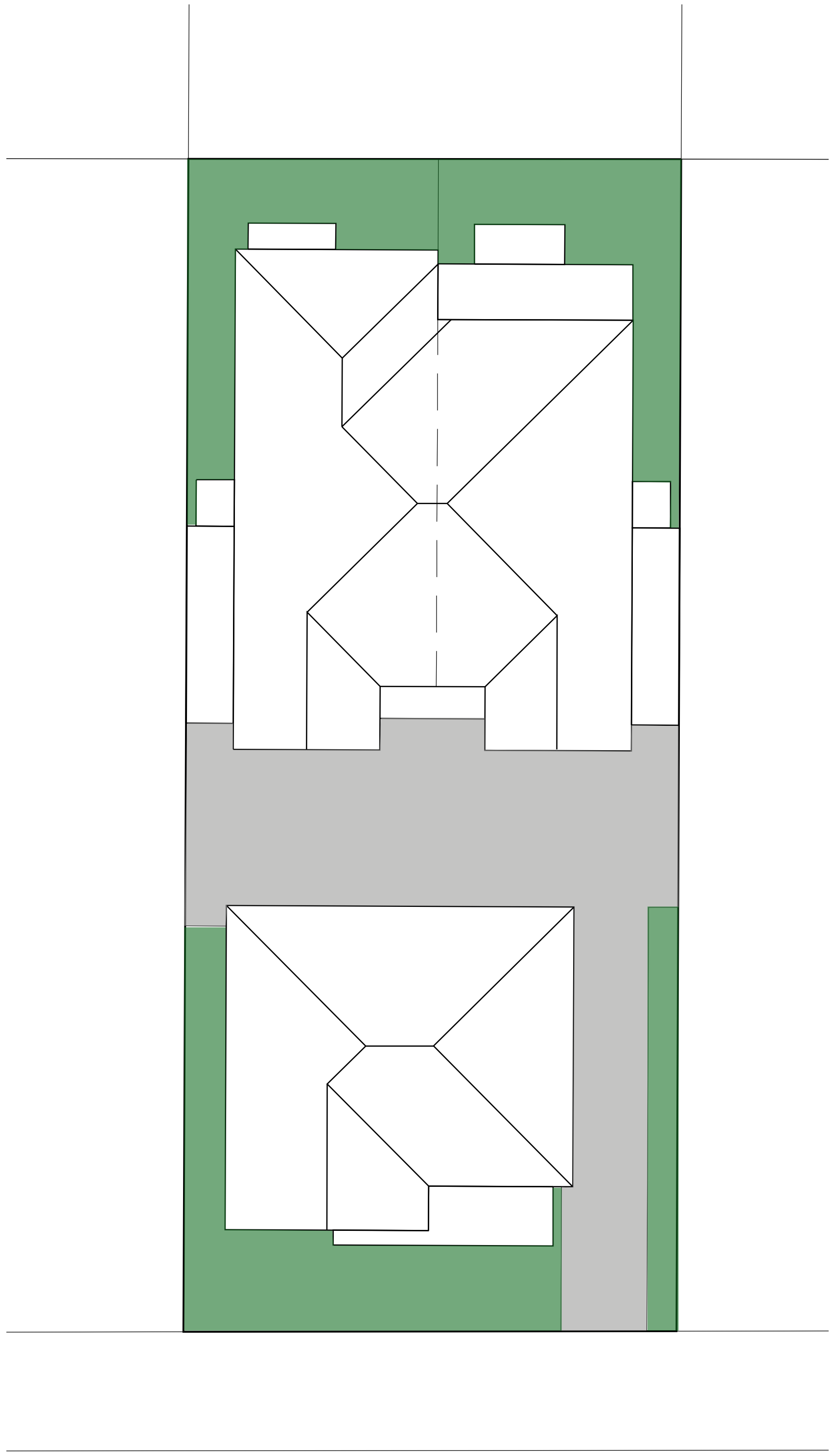
Type 1 - Proposed
Site Area: 660 sqm
Roof: 384 sqm (58%)
Garden: 143 sqm (22%)
Concrete: 133 sqm (20%)

1 **BAU Type 1**

BAU Type 1 - Existing



BAU Type 1 - Proposed



Business
As Usual
Design (BAU)

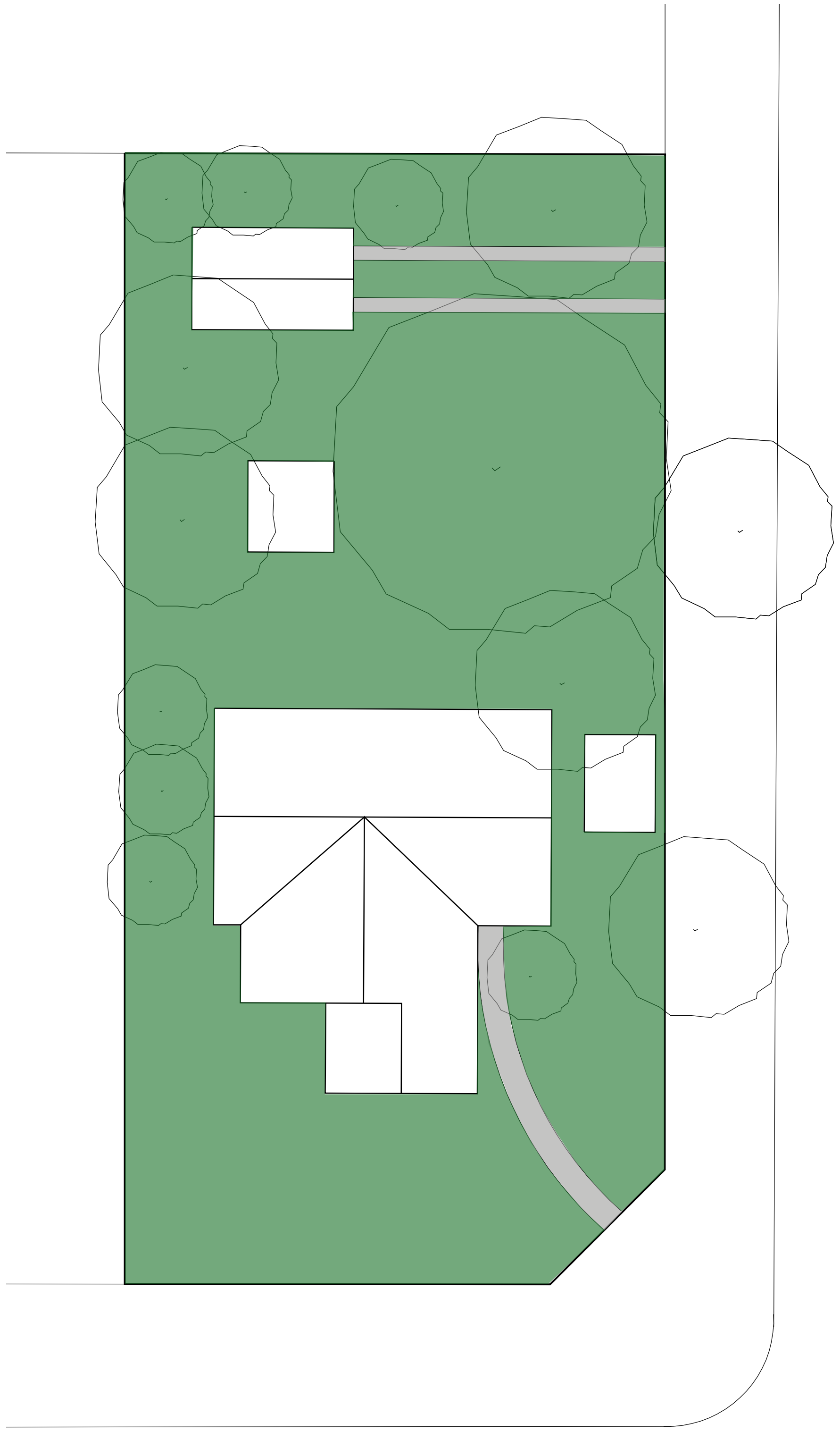
65 Denman St

Type 2 - Existing
Site Area: 660 sqm
Roof: 168 sqm (25%)
Garden: 472 sqm (72%)
Concrete: 20 sqm (3%)

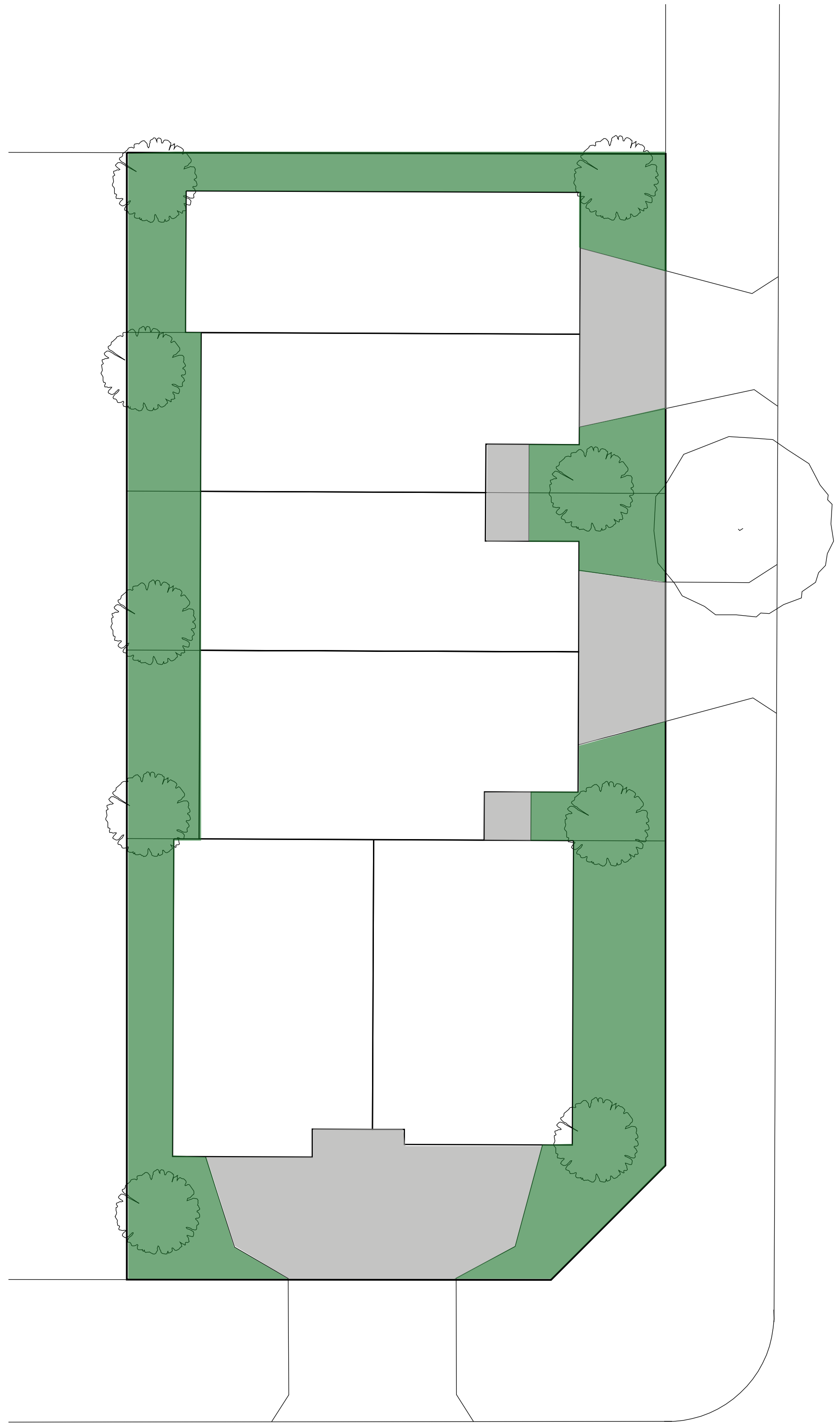
Type 2 - Proposed
Site Area: 660 sqm
Roof: 440 sqm (66%)
Garden: 138 sqm (21%)
Concrete: 82 sqm (13%)

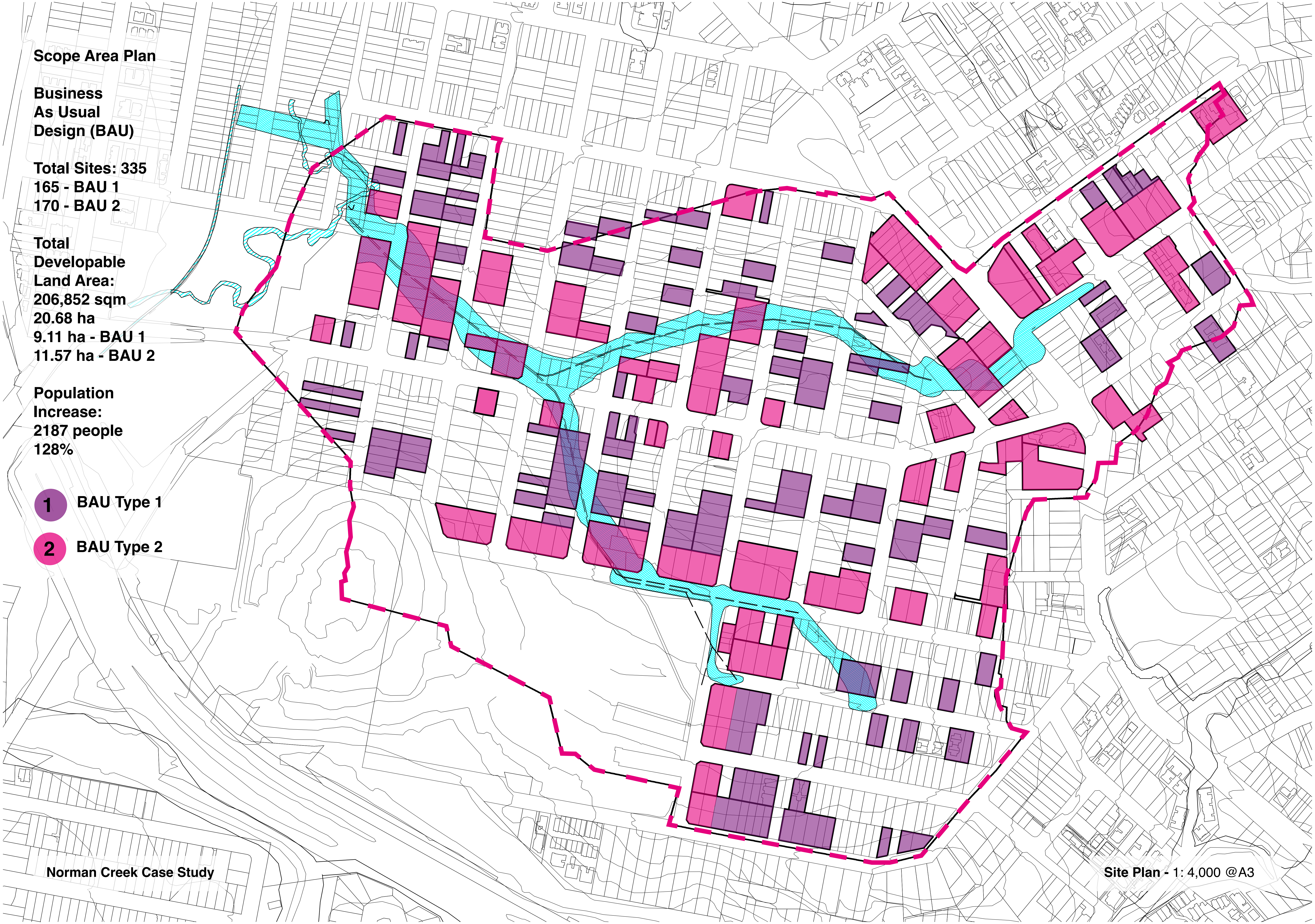
2 **BAU Type 2**

BAU Type 2 - Existing

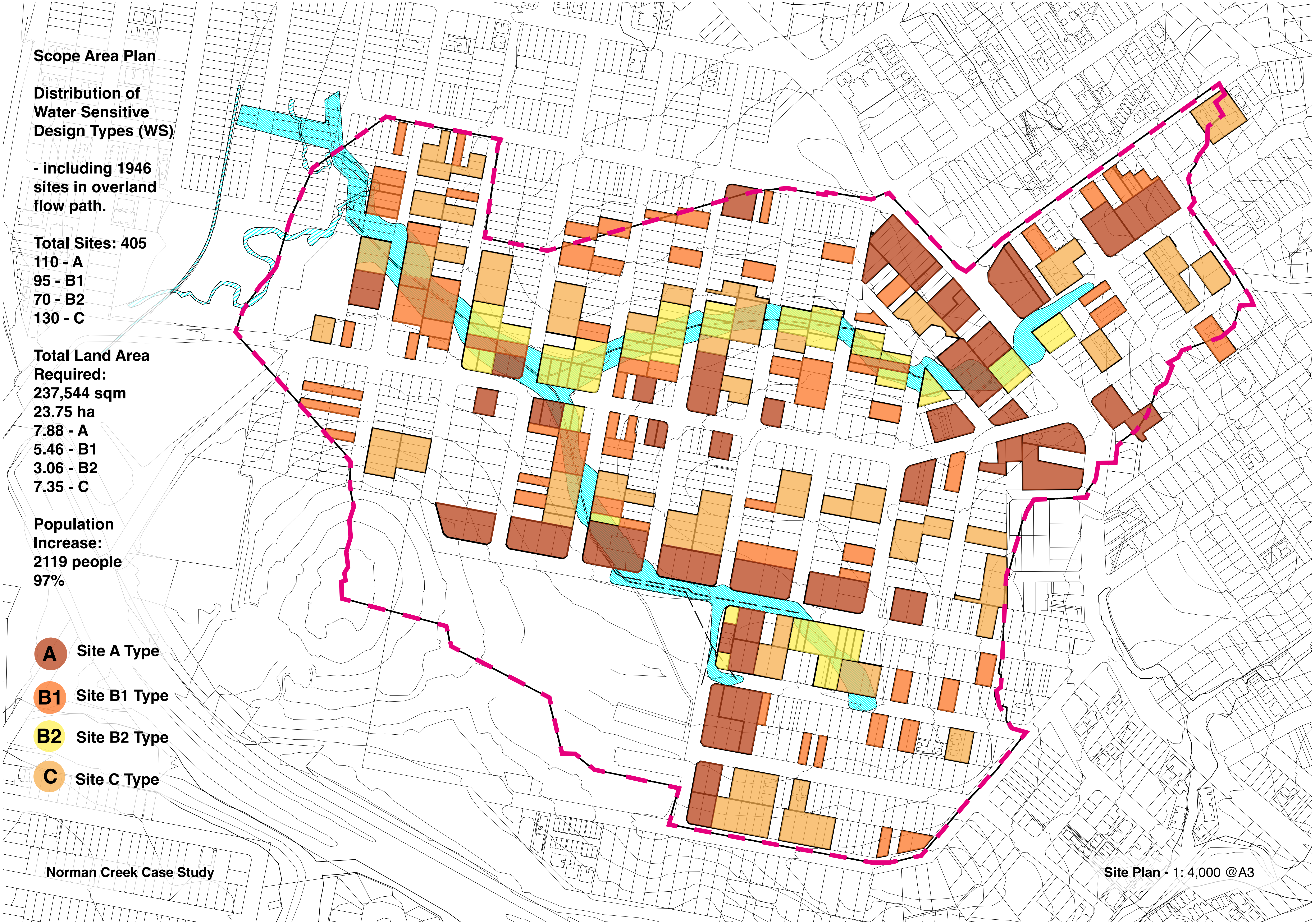


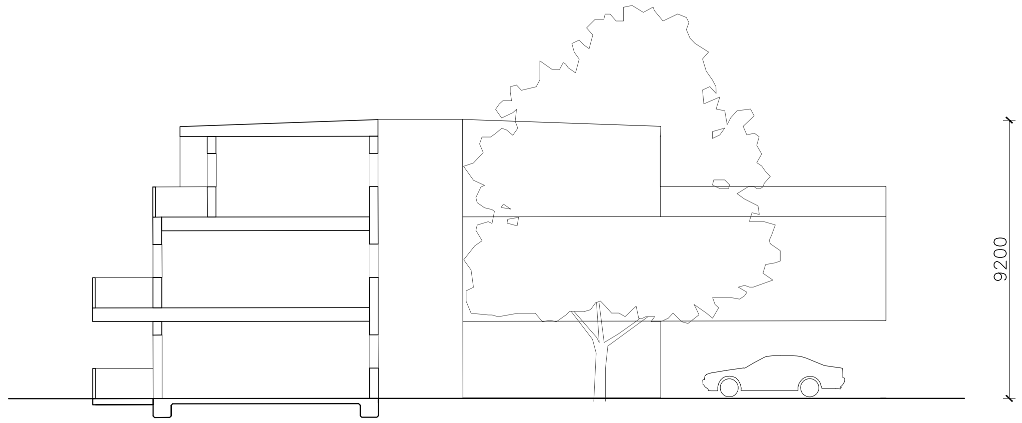
BAU Type 2 - Proposed

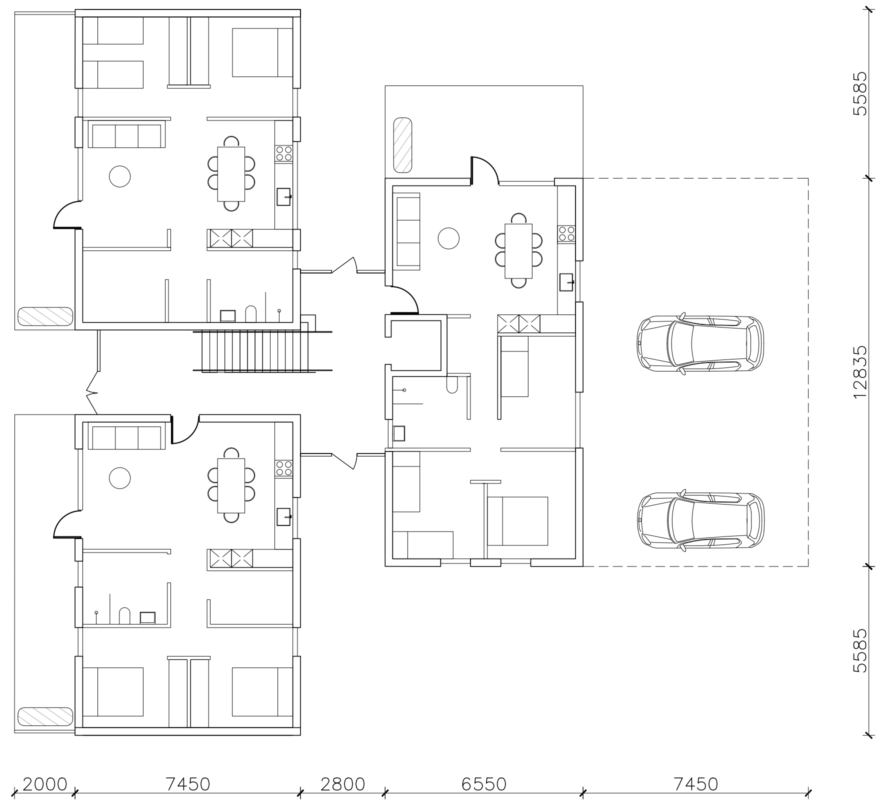




Scope Area Plan
Business
As Usual
Design (BAU)
Total Sites: 335
165 - BAU 1
170 - BAU 2
Total
Developable
Land Area:
206,852 sqm
20.68 ha
9.11 ha - BAU 1
11.57 ha - BAU 2
Population
Increase:
2187 people
128%
1 BAU Type 1
2 BAU Type 2
Norman Creek Case Study
Site Plan - 1: 4,000 @A3


Scope Area Plan
Distribution of Water Sensitive Design Types (WS)
- including 1946 sites in overland flow path.
Total Sites: 405
110 - A
95 - B1
70 - B2
130 - C
Total Land Area Required:
237,544 sqm
23.75 ha
7.88 - A
5.46 - B1
3.06 - B2
7.35 - C
Population Increase:
2119 people
97%
A Site A Type
B1 Site B1 Type
B2 Site B2 Type
C Site C Type
Norman Creek Case Study
Site Plan - 1: 4,000 @A3





Apartment Typology

Norman Creek Case Study

1: 250

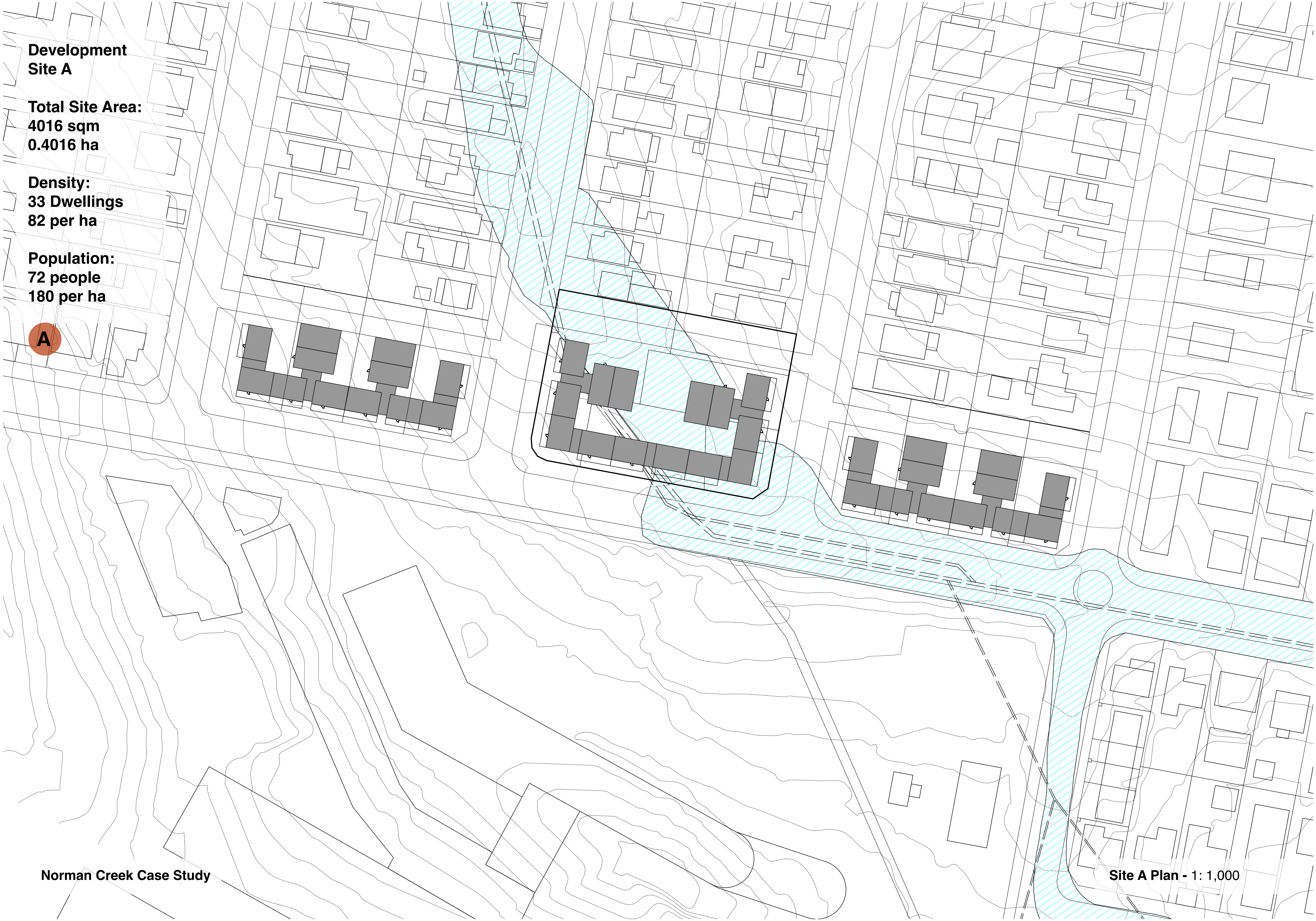

Norman Creek Case Study
Site A Plan - 1: 1,000

Development Site A

Total Site Area:
4016 sqm
0.4016 ha

Density:
33 Dwellings
82 per ha

Population:
72 people
180 per ha



Norman Creek Case Study

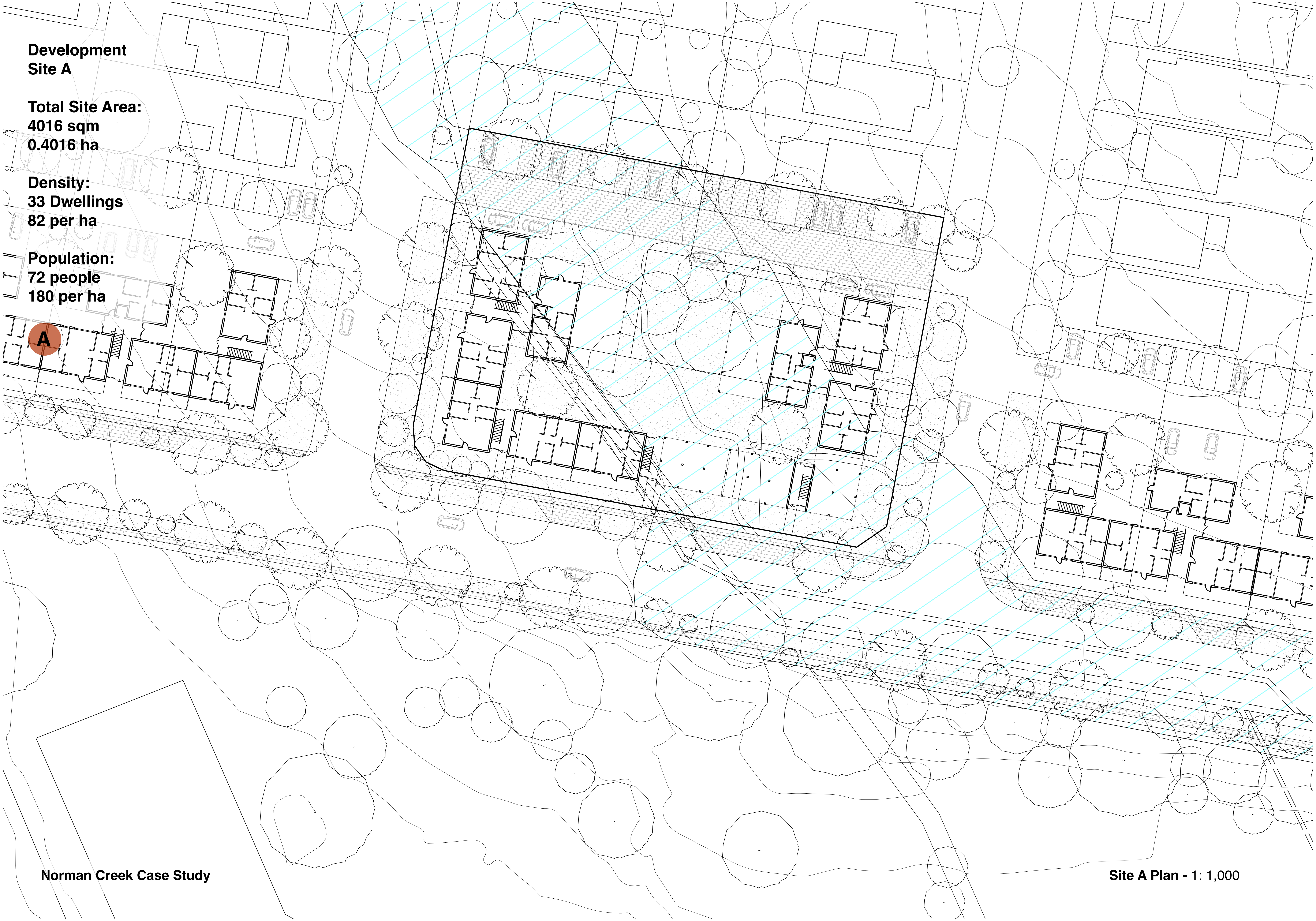
Site A Plan - 1: 1,000

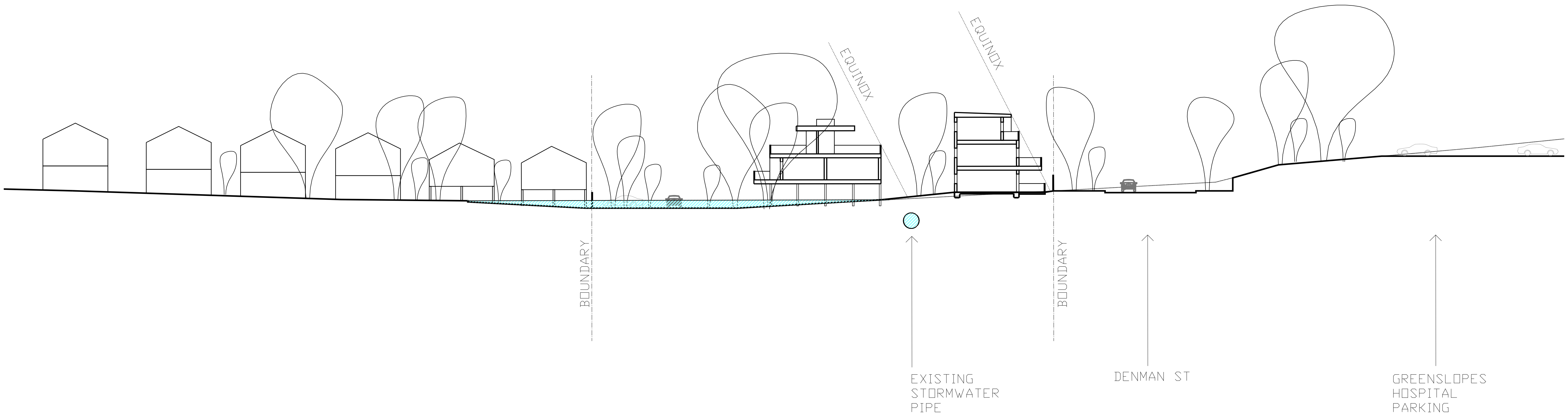
Development Site A

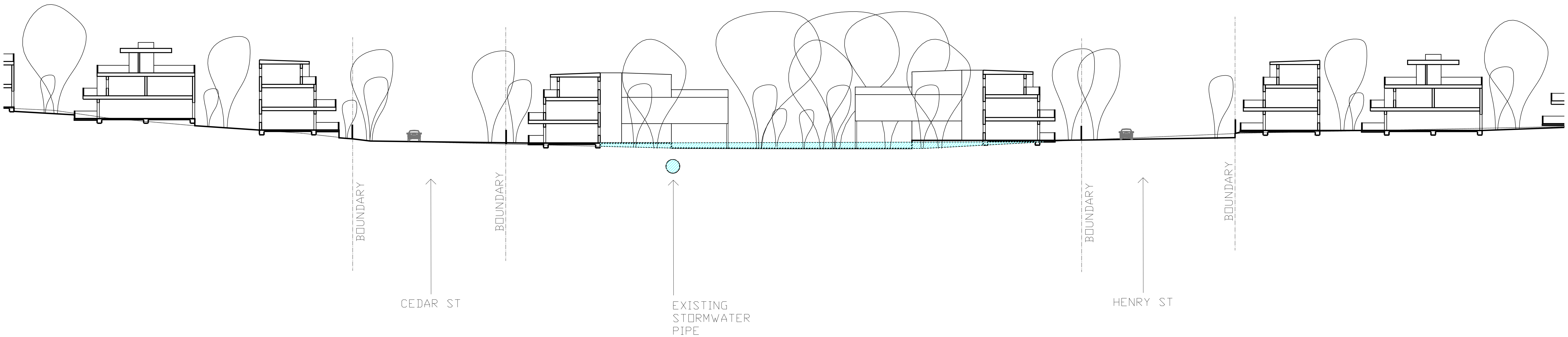
Total Site Area:
4016 sqm
0.4016 ha

Density:
33 Dwellings
82 per ha

Population:
72 people
180 per ha




EQUINOX
EQUINOX
BOUNDARY
BOUNDARY
EXISTING
STORMWATER
PIPE
DENMAN ST
GREENSLOPES
HOSPITAL
PARKING



Norman Creek Case Study

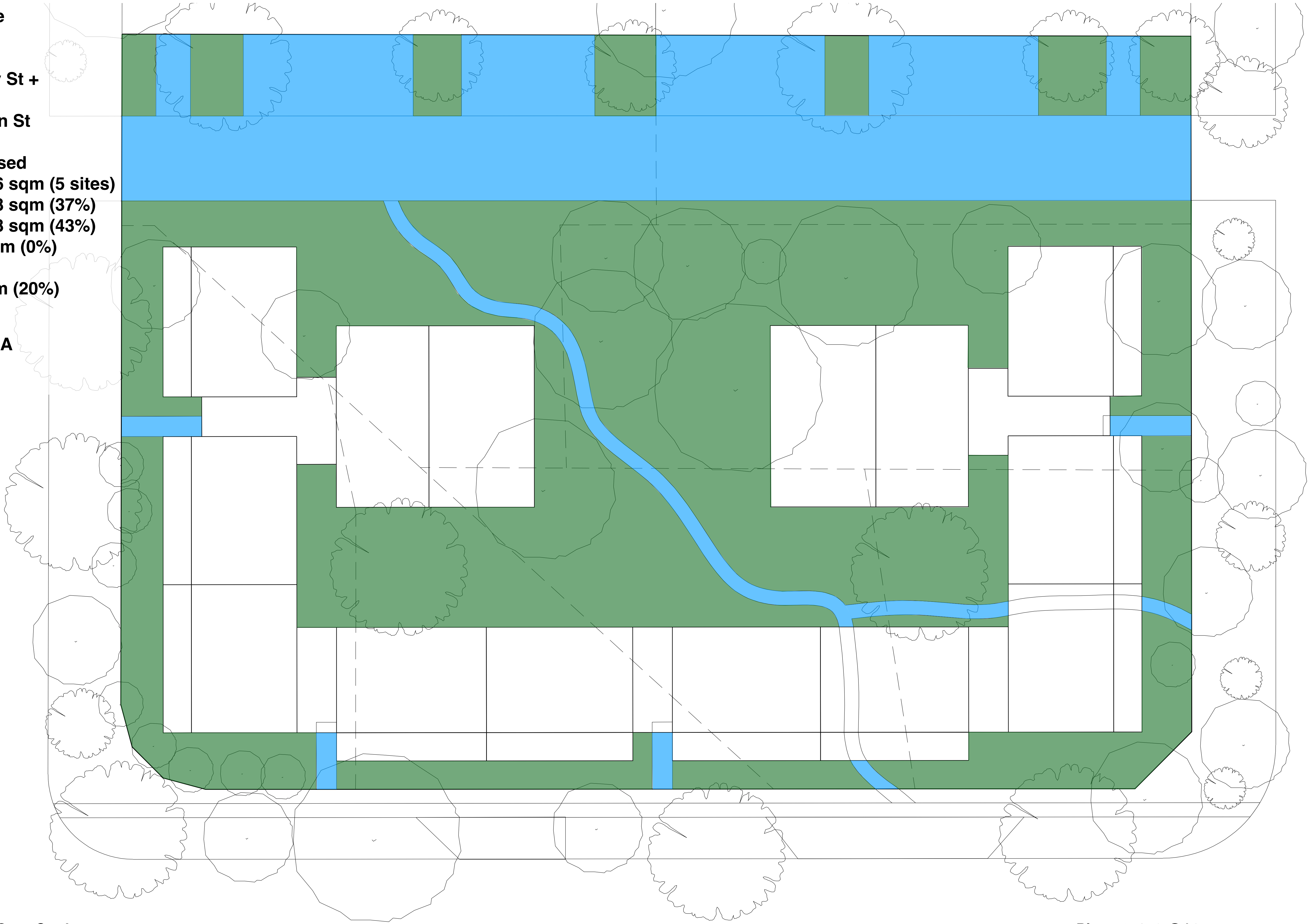
Site A Section EW - 1: 500

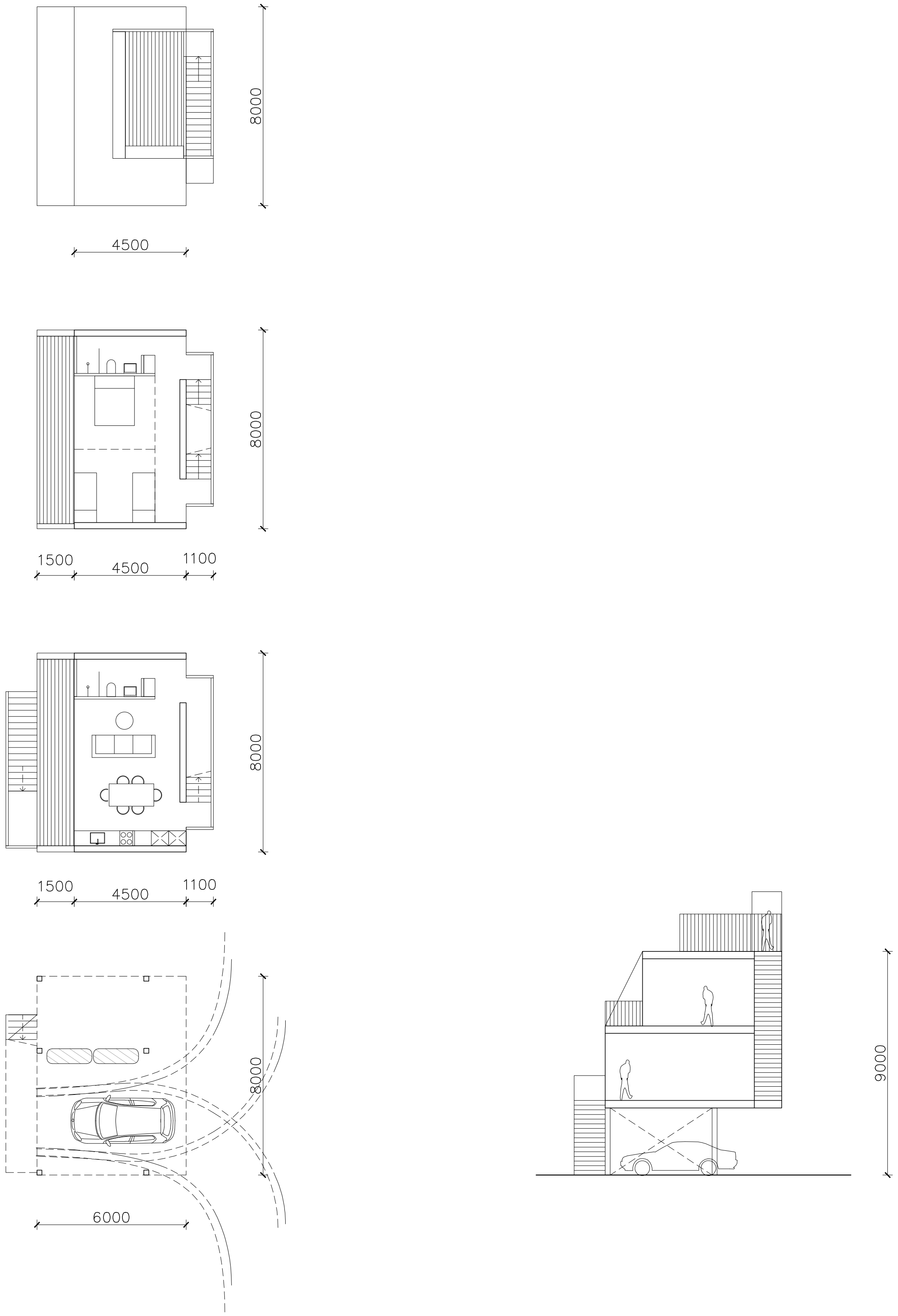
Water Sensitive Design (WS)

109 - 111 Henry St +
98 Cedar St +
97 -105 Denman St

Type A - Proposed
Site Area: 4016 sqm (5 sites)
Roof: 1488 sqm (37%)
Garden: 1708 sqm (43%)
Concrete: 0 sqm (0%)
Permeable Paving: 820sqm (20%)

A **WS Type A**



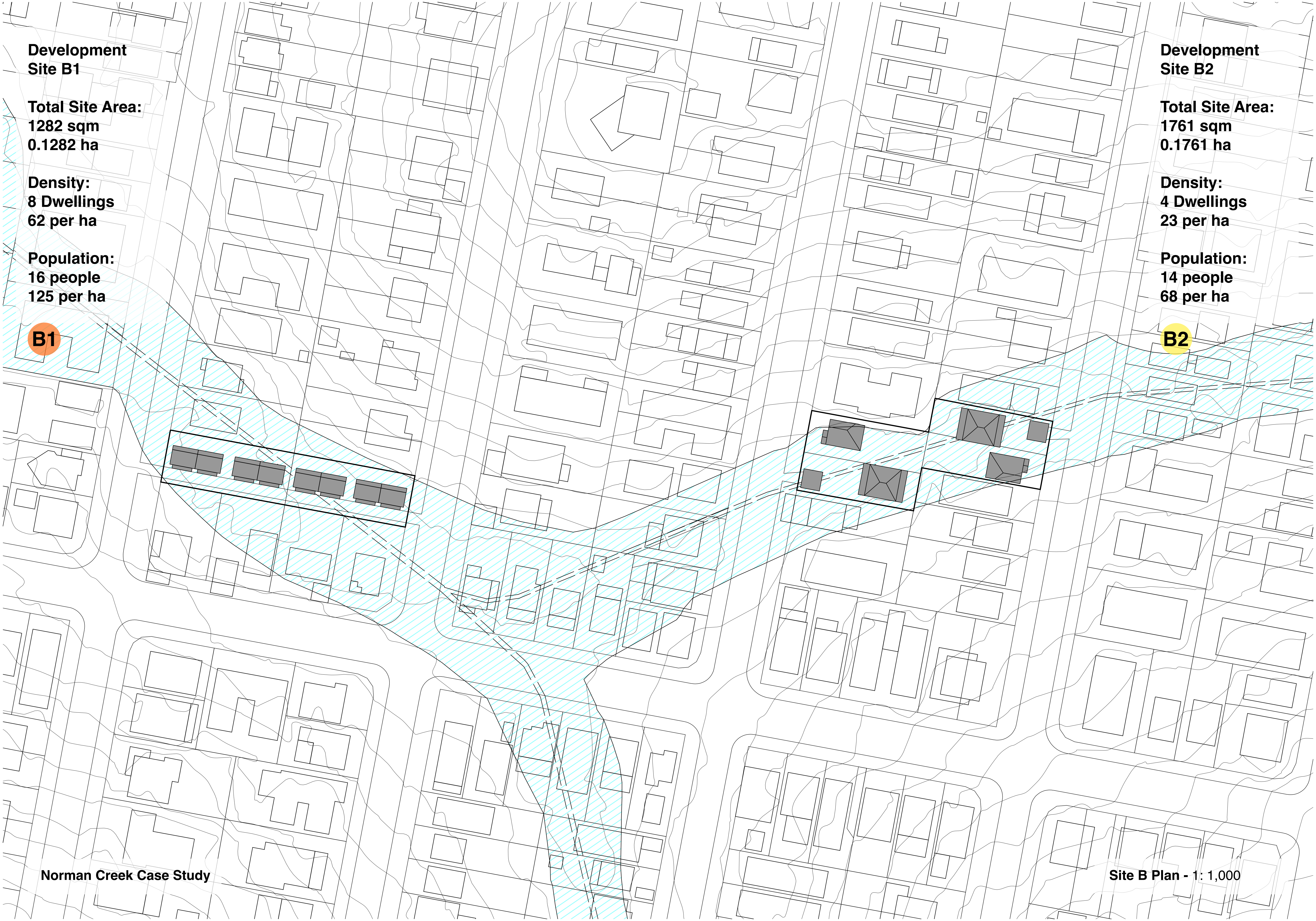


Hover Typology

Norman Creek Case Study

1: 250


Norman Creek Case Study
Site B Plan - 1: 1,000



Development Site B1

Total Site Area:
1282 sqm
0.1282 ha

Density:
8 Dwellings
62 per ha

Population:
16 people
125 per ha

Development Site B2

Total Site Area:
1761 sqm
0.1761 ha

Density:
4 Dwellings
23 per ha

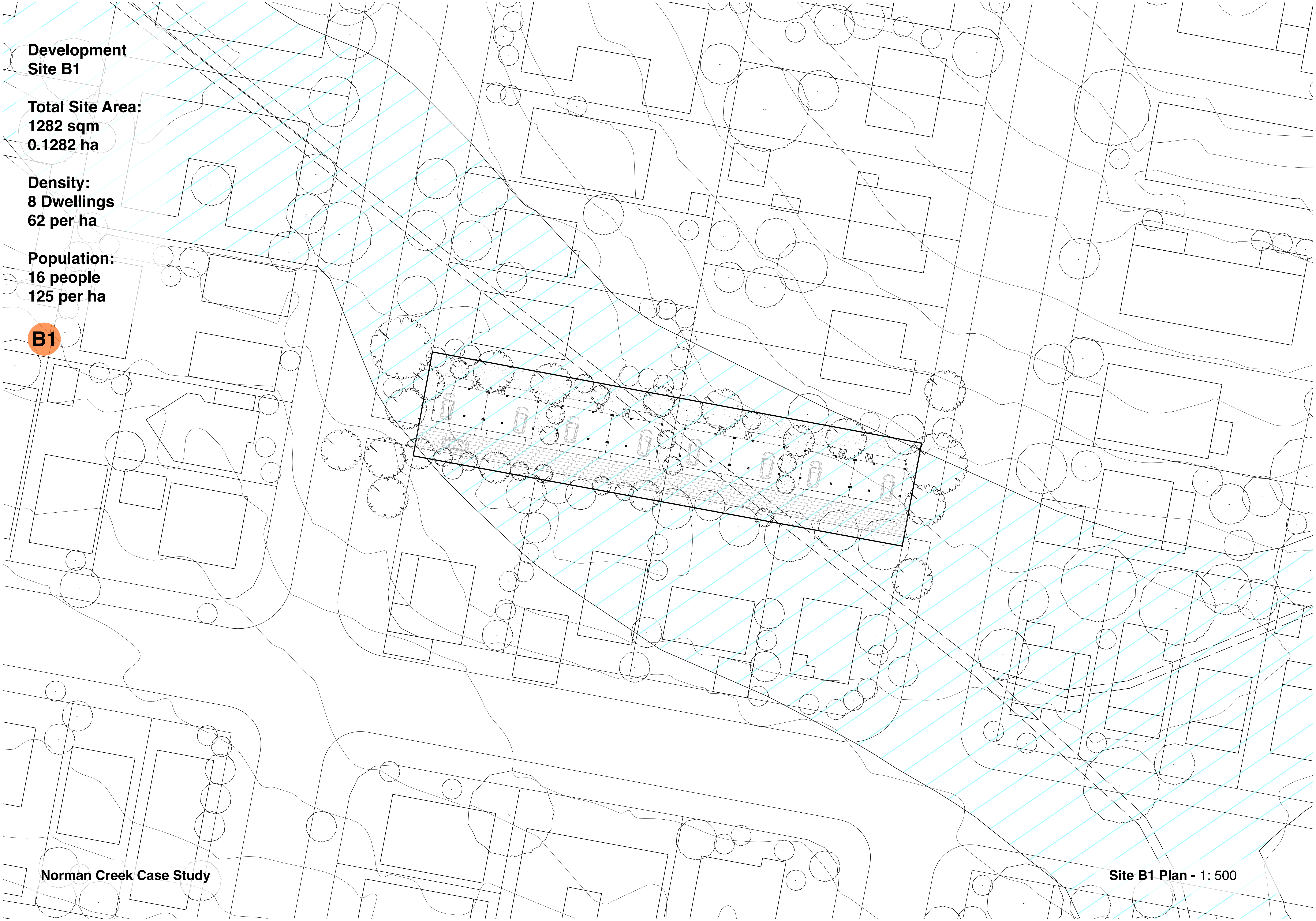
Population:
14 people
68 per ha

Development
Site B1

Total Site Area:
1282 sqm
0.1282 ha

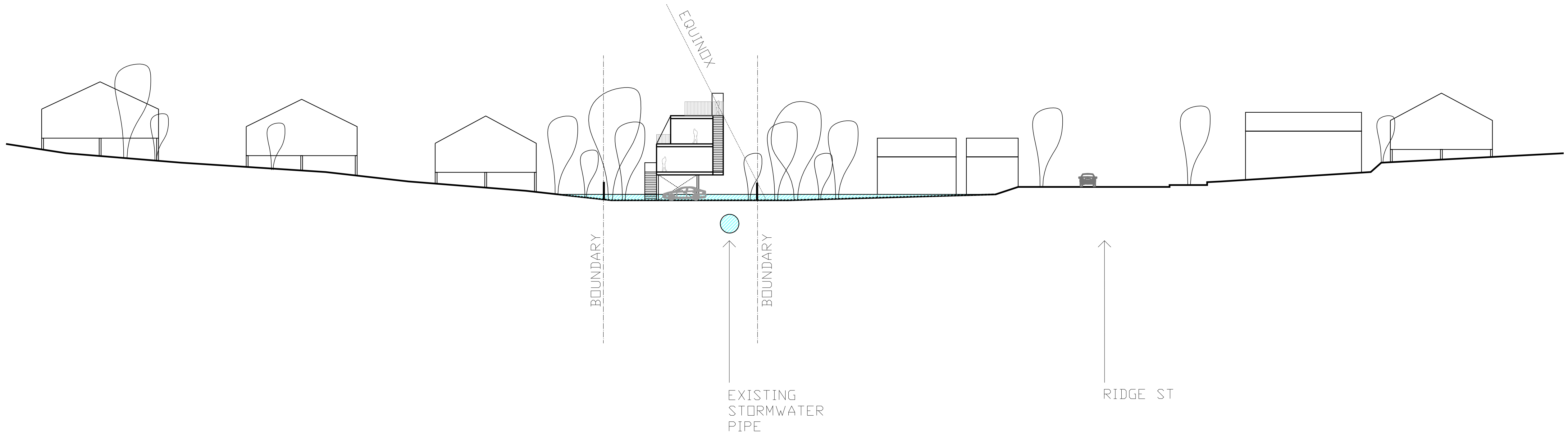
Density:
8 Dwellings
62 per ha

Population:
16 people
125 per ha



Norman Creek Case Study

Site B1 Plan - 1: 500



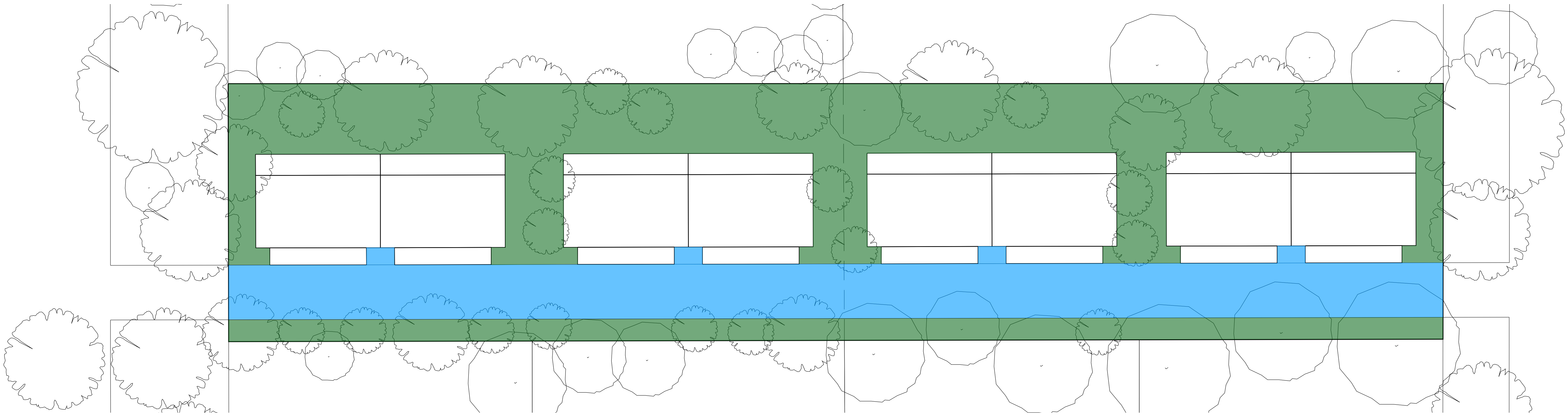
Site B1 Section - 1: 500

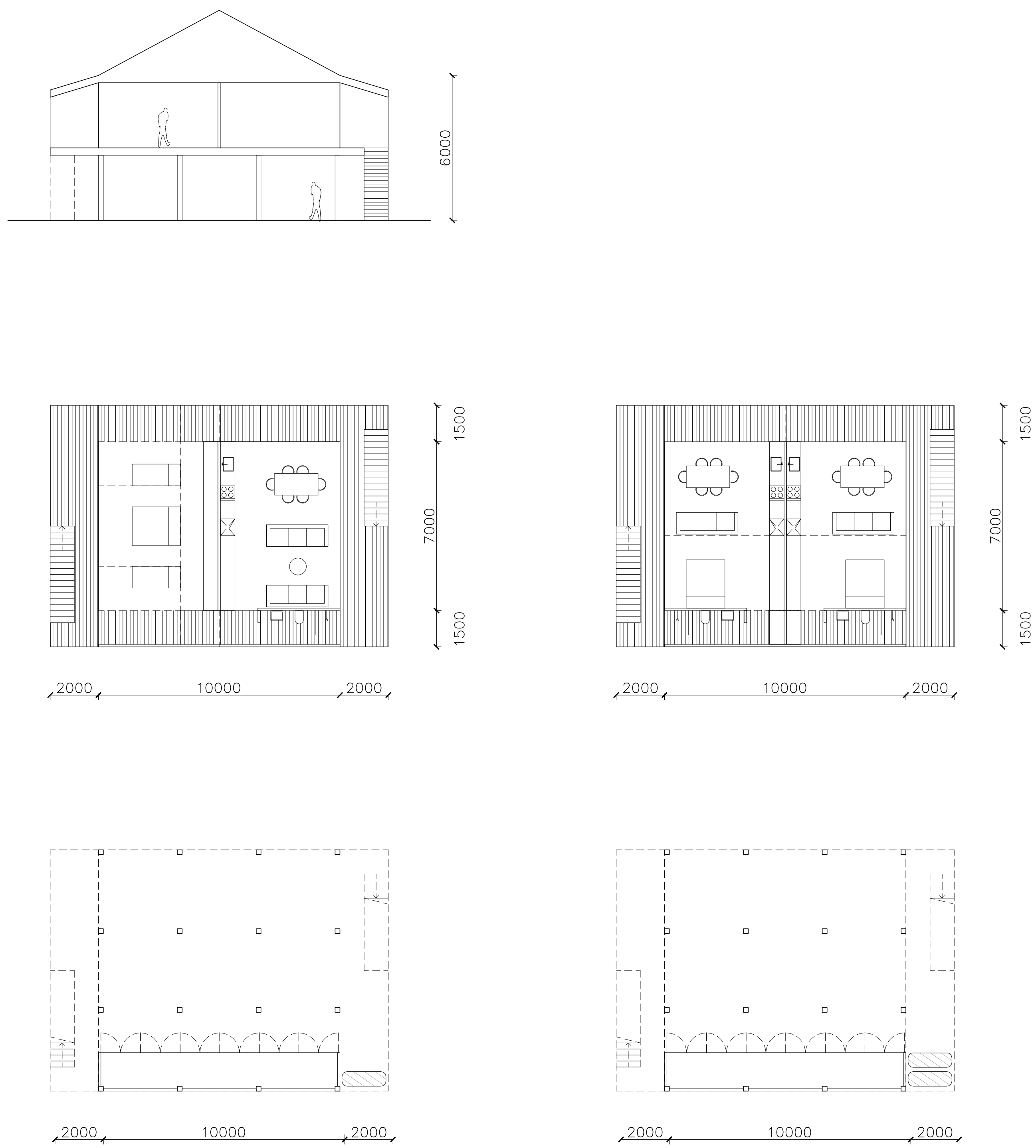
Water Sensitive Design (WS)

70 Peach St + 65 Bunya St

Type B1 - Proposed
Site Area: 1282 sqm (2 sites)
Roof: 438 sqm (34%)
Garden: 564 sqm (44%)
Concrete: 0 sqm (0%)
Permeable Paving: 280sqm (22%)

B1 WS Type B1





Queenslander Typology

Norman Creek Case Study

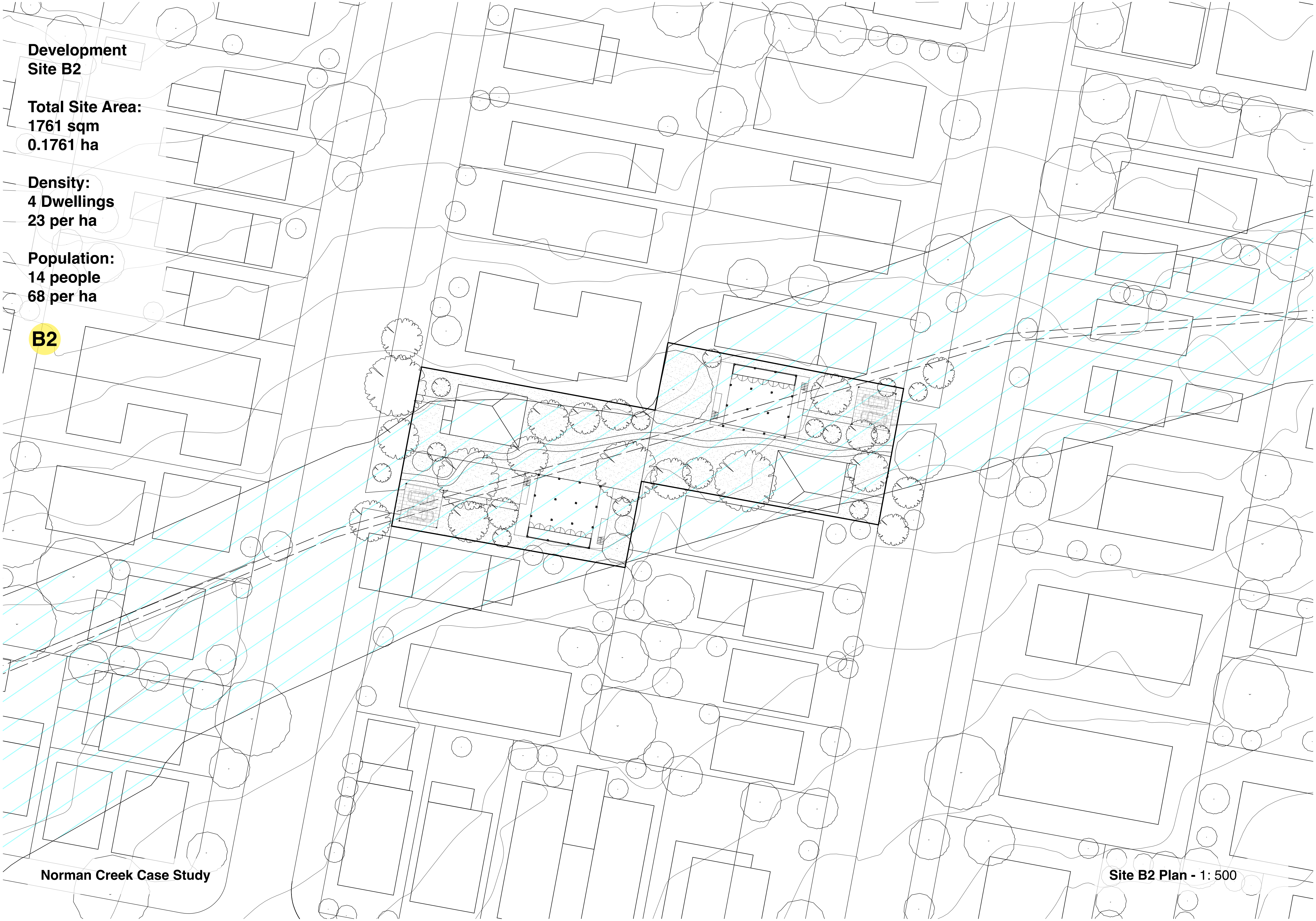
1: 250

Development Site B2

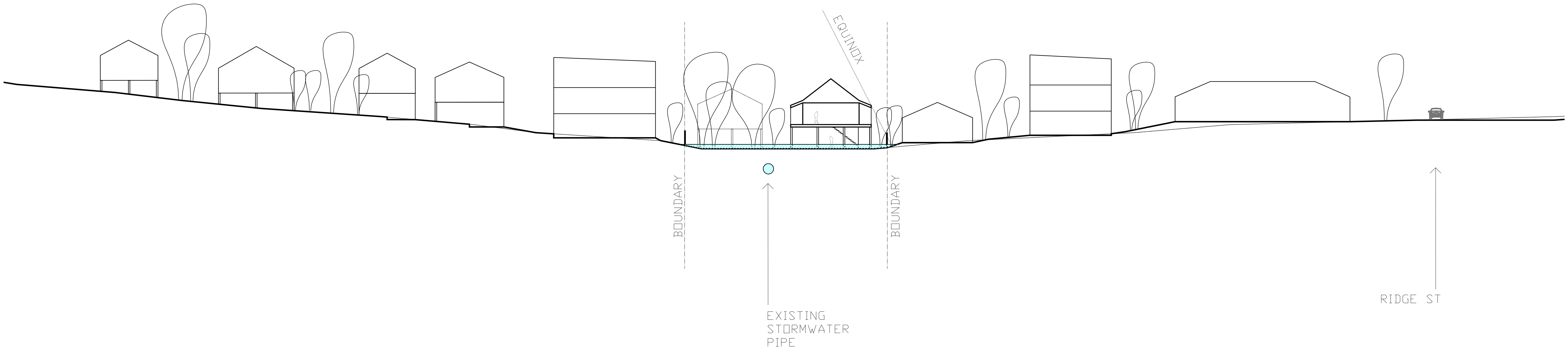
Total Site Area:
1761 sqm
0.1761 ha

Density:
4 Dwellings
23 per ha

Population:
14 people
68 per ha



Site B2 Plan - 1: 500

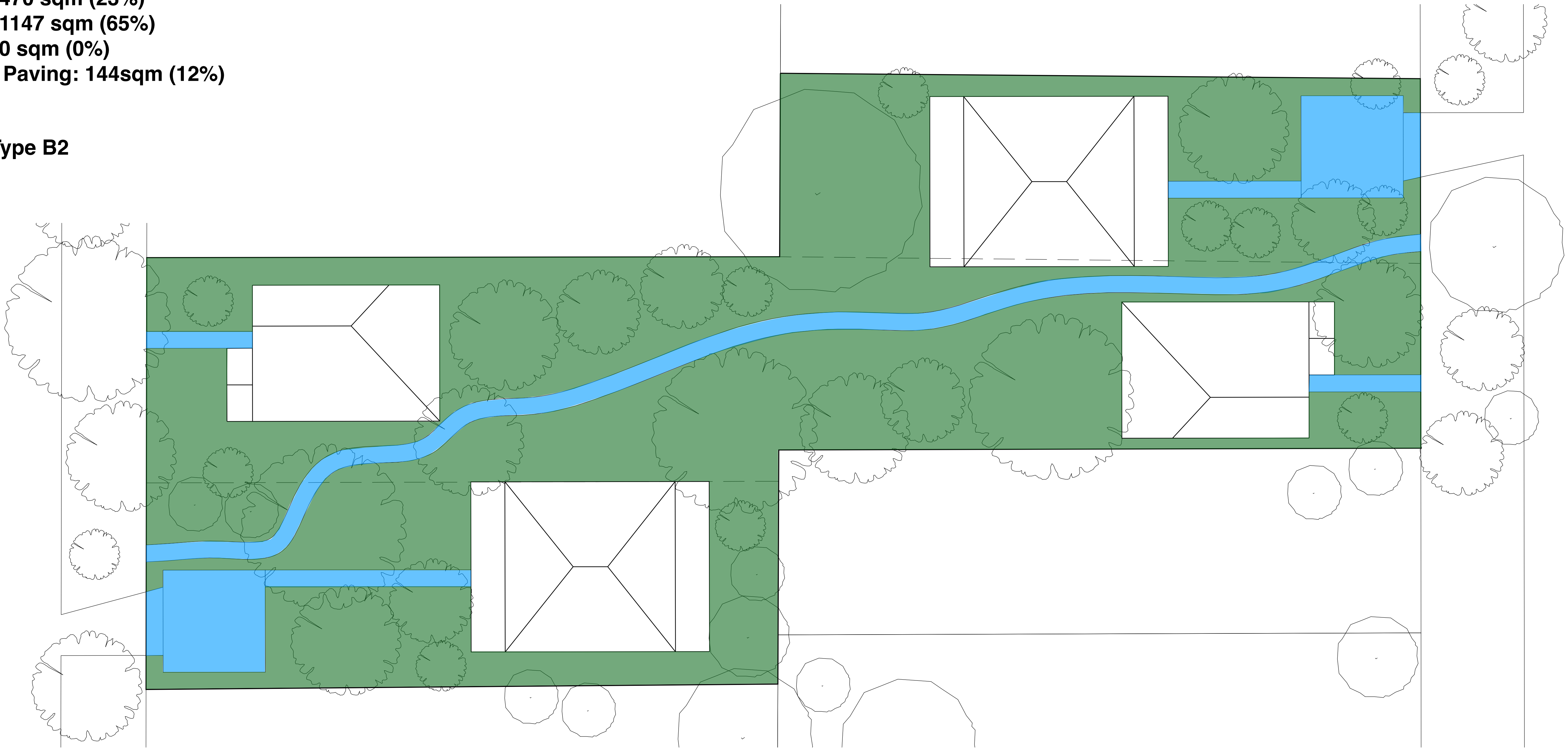

EQUINOX
BOUNDARY
BOUNDARY
EXISTING
STORMWATER
PIPE
RIDGE ST

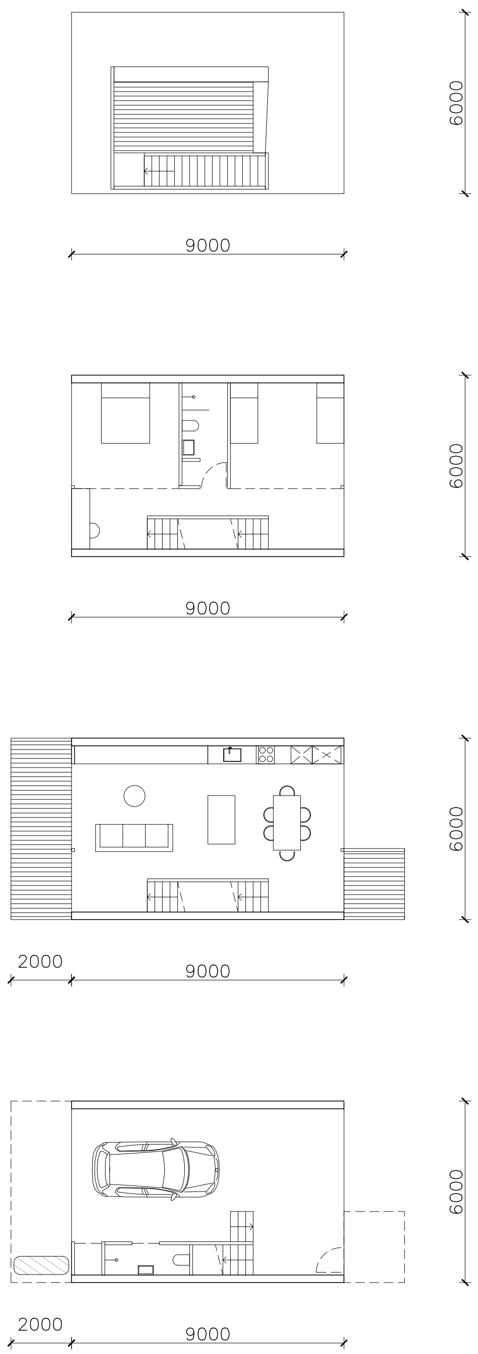
Water Sensitive Design (WS)

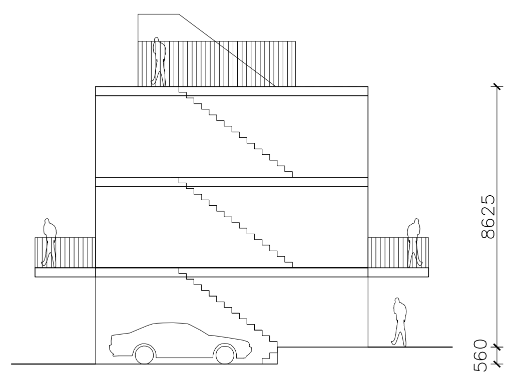
60 - 62 Cedar St + 63 - 65 Henry St

Type B2 - Proposed
Site Area: 1761 sqm (4 sites)
Roof: 470 sqm (23%)
Garden: 1147 sqm (65%)
Concrete: 0 sqm (0%)
Permeable Paving: 144sqm (12%)

B2 **WS Type B2**







Townhouse Typology

1: 250

Norman Creek Case Study

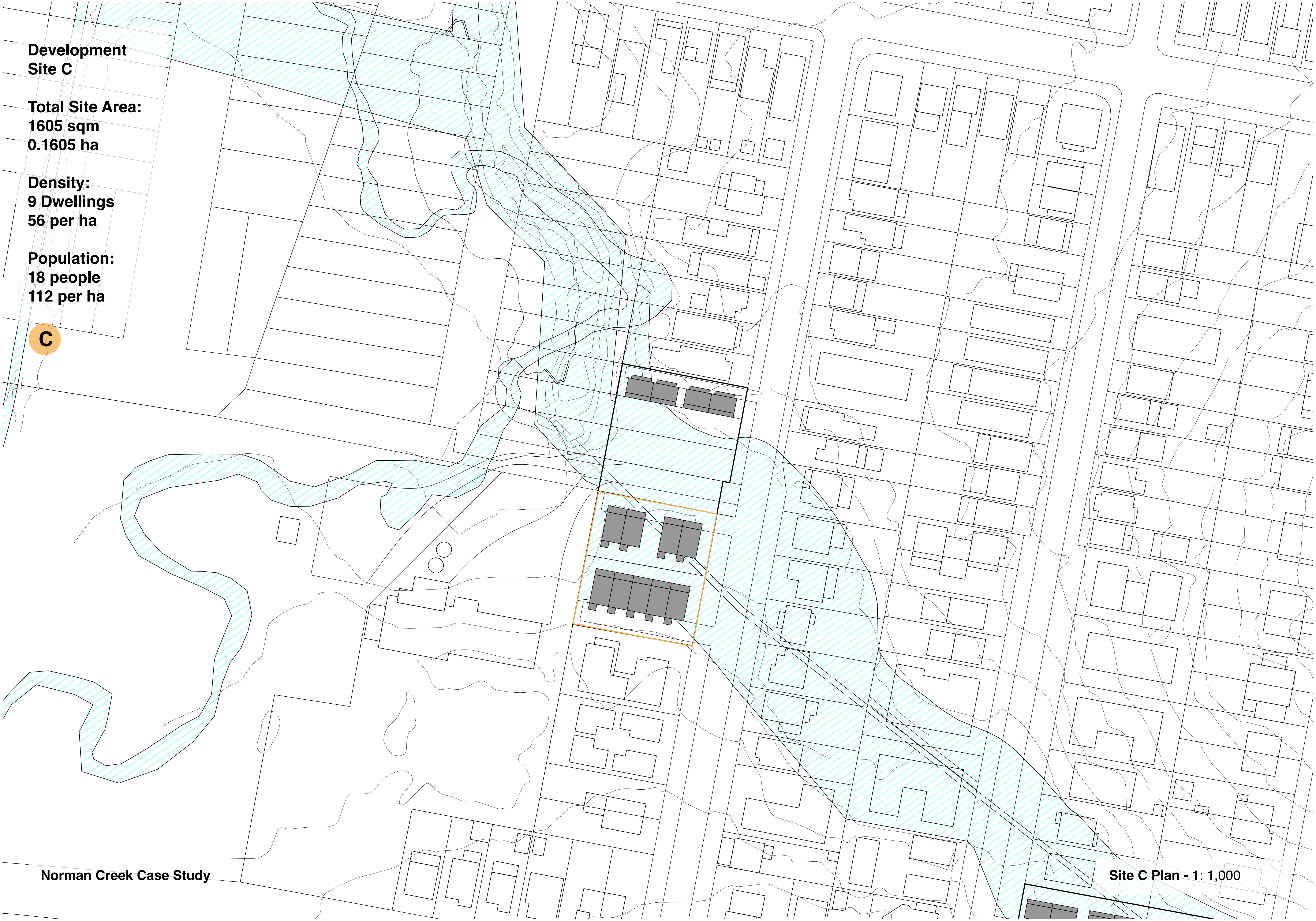

Norman Creek Case Study
Site C Plan - 1: 1,000

Development Site C

Total Site Area:
1605 sqm
0.1605 ha

Density:
9 Dwellings
56 per ha

Population:
18 people
112 per ha



Site C Plan - 1: 1,000

Development
Site C

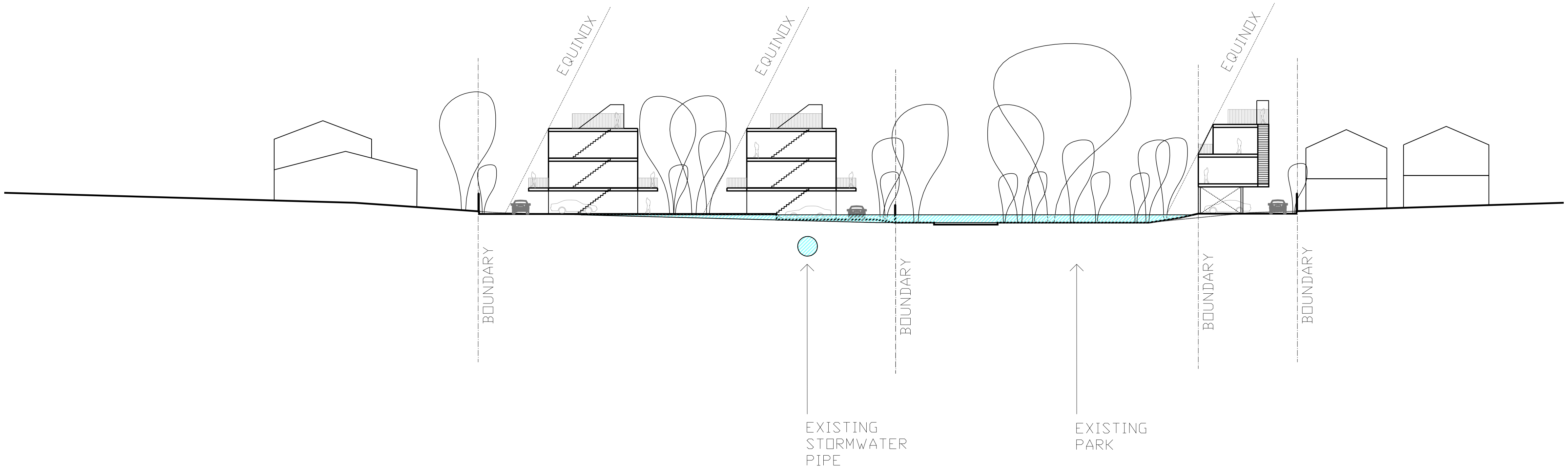
Total Site Area:
1605 sqm
0.1605 ha

Density:
9 Dwellings
56 per ha

Population:
18 people
112 per ha

C

Site C Plan - 1: 500

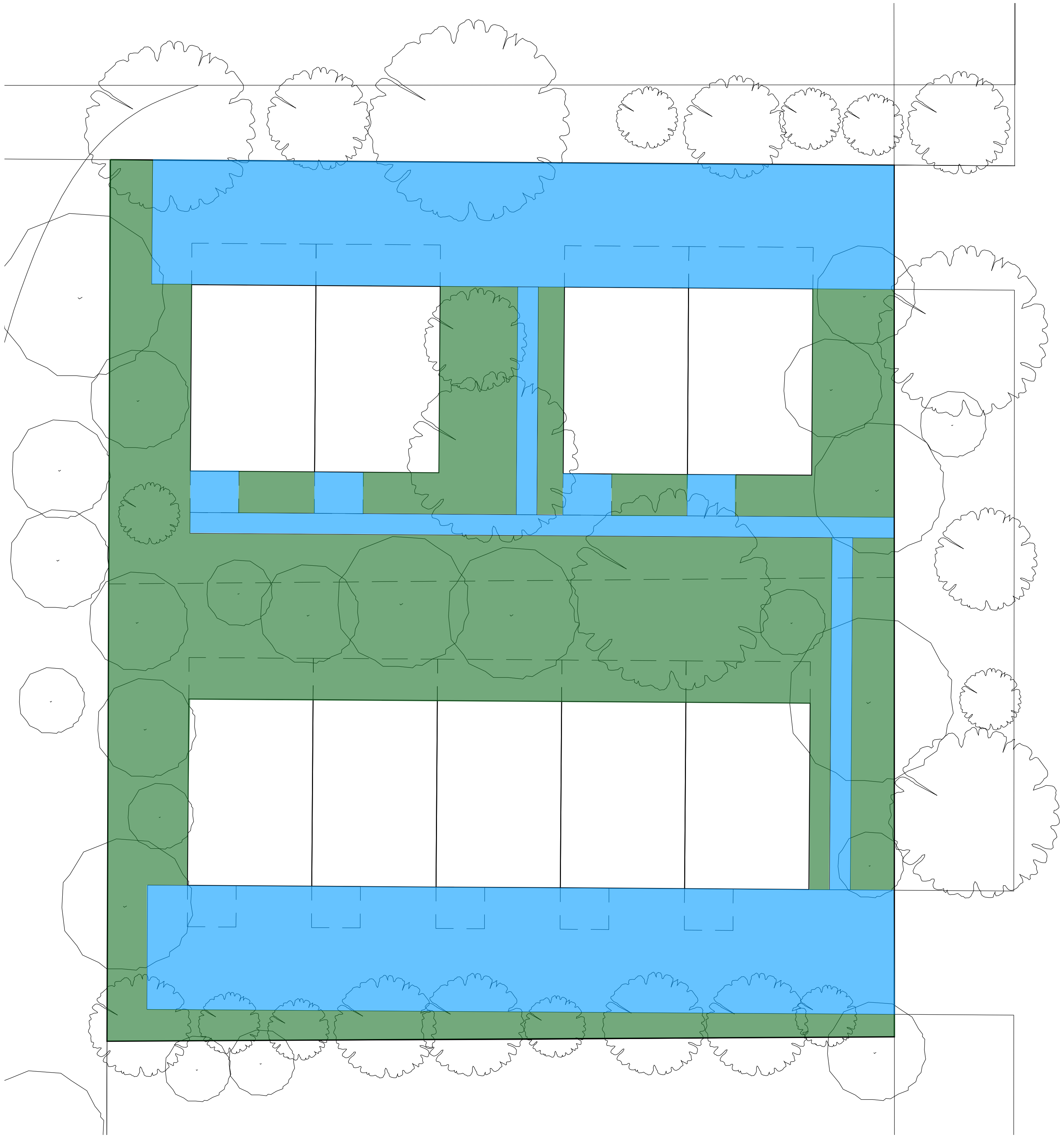

EQUINOX
EQUINOX
EQUINOX
BOUNDARY
BOUNDARY
BOUNDARY
BOUNDARY
EXISTING
STORMWATER
PIPE
EXISTING
PARK

Water Sensitive Design (WS)

55 - 59 Pear St

Type C - Proposed
Site Area: 1605 sqm (2 sites)
Roof: 486 sqm (30%)
Garden: 608 sqm (38%)
Concrete: 0 sqm (0%)
Permeable Paving: 511sqm (32%)

C WS Type C



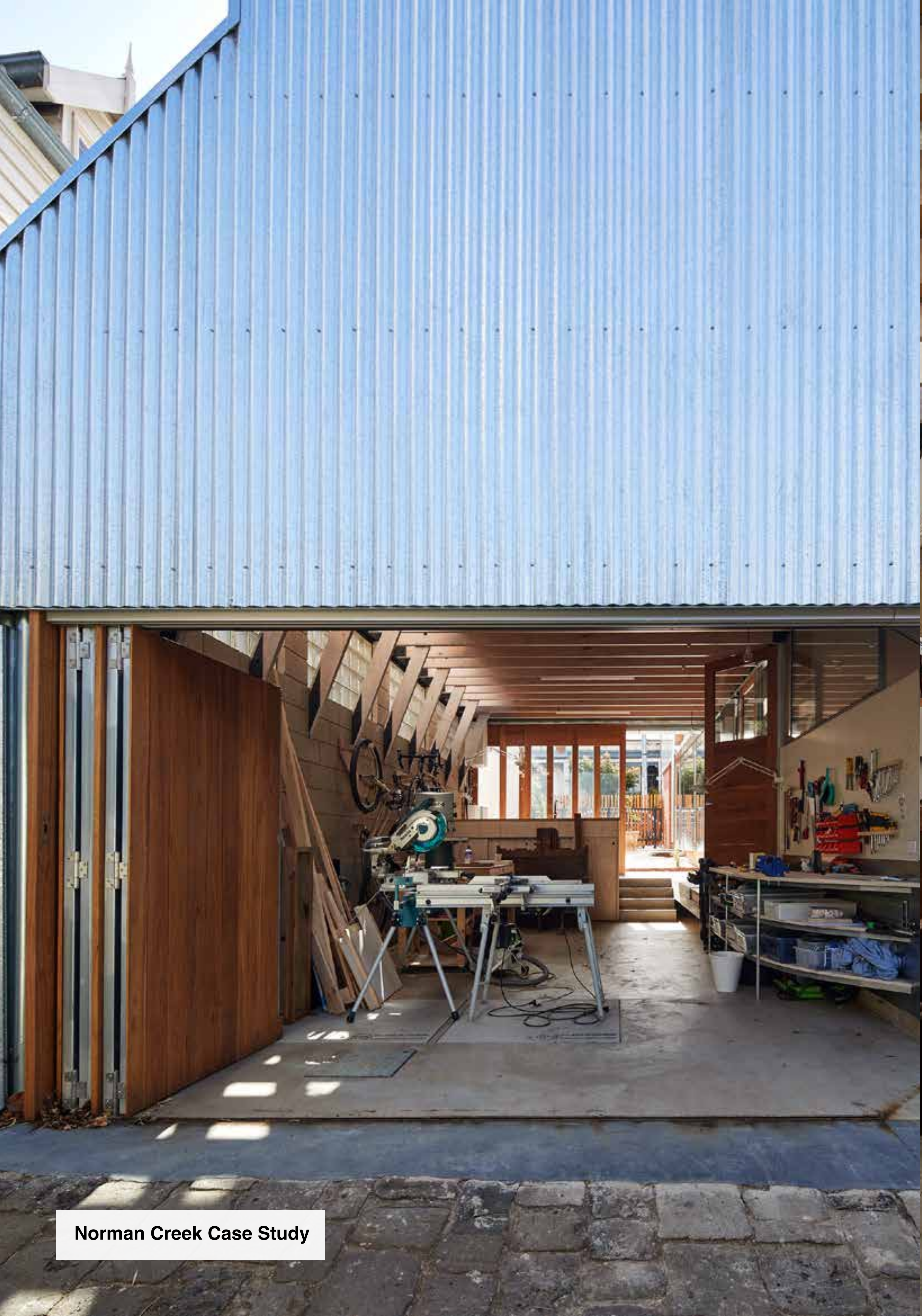
Precedent Images

Orientate to parks

Norman Creek Case Study

Precedent Images

Street spaces



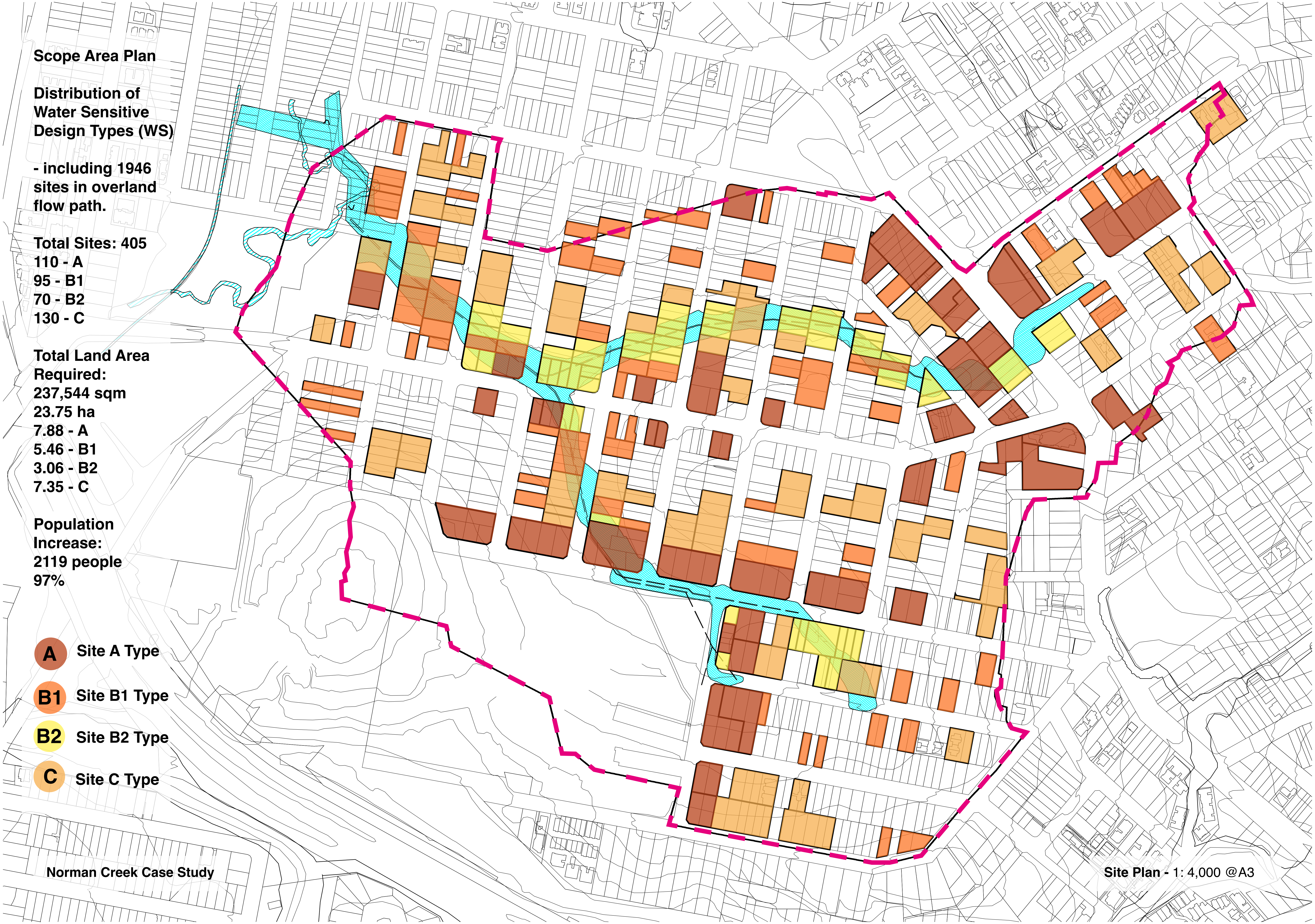
Norman Creek Case Study

Precedent Images

Dual use garages

Precedent Images

Undercroft spaces


Scope Area Plan
Distribution of Water Sensitive Design Types (WS)
- including 1946 sites in overland flow path.
Total Sites: 405
110 - A
95 - B1
70 - B2
130 - C
Total Land Area Required:
237,544 sqm
23.75 ha
7.88 - A
5.46 - B1
3.06 - B2
7.35 - C
Population Increase:
2119 people
97%
A Site A Type
B1 Site B1 Type
B2 Site B2 Type
C Site C Type
Norman Creek Case Study
Site Plan - 1: 4,000 @A3

Attachment B – Technical report on Scenario Tool analysis: urban heat and water balance

c i t y   p r o j e c t s   o f f i c e

Greenslopes Catchment Urban Flows and Urban Heat

Water Sensitive Typology Assessment

April 2021

Prepared by City Projects Office,

Brisbane Infrastructure,
Brisbane City Council

Dedicated to a better Brisbane

Brisbane City Council

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Document Control:

Issue No.	**Date of Issue**	**Amdt**	**Prepared By (Author/s)**		**Edited and Proofread By**		**Reviewed By**		**Approved for Issue (Project Director)**	
			Name	**Initials**	**Name**	**Initials**	**Name**	**Initials**	**Name**	**Initials**
1	13/05/2020	1	Niloo Tara	NT	C.Thrupp	CT	C. Thrupp	CT	C.Thrupp	CT
1.1	23/06/2020	1	Niloo Tara Chris Vos	NT CV			C. Thrupp	CT	C.Thrupp	CT
1.2	16/04/2021	1	Chris Vos NilooTara	NT CV						

Executive Summary

This report describes the application of the Infill Performance Evaluation Framework (Renouf *et al.,* 2020) to an urban precinct in the Brisbane suburb of Greenslopes located within the Norman Cree Catchment. This report aimed to quantify and mitigate the adverse effects of infill development. This study was conducted as a collaboration between Brisbane City Council and the Cooperative Research Centre for Water Sensitive Cities IRP4 project - *Water Sensitive Outcomes for Infill Development*. The key objective of IRP4 was to develop a performance evaluation framework to understand and quantify the impacts of residential densification (infill) on water and urban heat. Further, the project aimed to develop water sensitive urban designs that could potentially mitigate any negative impacts of infill development.

This case study applied the Evaluation Framework (Renouf *et al.*, 2020) to understand the context-specific water-related and urban heat impacts. It also looked at how water sensitive design typologies and water servicing variables can improve the performance of the urban precinct. The project sought to improve water management and other factors within a pilot study precinct and; hence, contribute to livability, water security and resilience for that area.

The project team collaborated closely with architects, urban planners and water practitioners in the case-study area, to better understand the local context, needs and aspirations for the study area. This informed development of the proposed design. The process of applying the Evaluation Framework can be primarily broken down into the following steps:

- Scenarios were developed representing the existing/base-case situation (NOW), Future without intervention (NEW) and Future with water-sensitive interventions (NEXT).
- Site-plans were created for dwelling typologies for each of the scenarios. Site-specific parameters related to architectural design and water are defined.
- Typologies created were expanded to the full 9.6ha precinct to represent the three scenarios and produce the precinct plan.
- The subsequent precinct plans were evaluated against several performance principles, in terms of urban water flows and urban heat, using the Evaluation Framework.
- Finally, performance indicators were generated from the Evaluation Framework to understand overall performance of the water-sensitive design scenarios against others. Indicators are also compared with the context-specific targets where available.
- Water performance was assessed at a precinct-scale, using daily water balance with “Aquacycle”. Urban heat was evaluated using CRC WSC Scenario Tool platform.

Study Objectives

The study was delivered in two stages with the second aimed at improving on works undertaken in the first stage. Considerable changes between the two stages were the naming convention adopted for scenarios and the defined study area. The objectives of each of these studies were:

- **Stage 1**
    - o To assess the future development (land-use intensification) as per current City Plan (BCC, 2014) guidelines, on urban water flows and urban heat within the Greenslopes catchment, and,

- To assess the impact of developed 'Water Sensitive' typologies on urban water flows and urban heat within the Greenslopes catchment.

- **Stage 2**
  - To assess the future development (land-use intensification) as per current City Plan (BCC, 2014) guidelines, on urban water flows and urban heat within the Greenslopes catchment
  - To assess the impact of developed 'Water Sensitive' typologies on urban water flows and urban heat within the Greenslopes catchment;
  - To assess the impact of storage tanks for Water Sensitive typologies on urban water flows; and,
  - To assess the impacts of streetscape interventions on urban heat.

Note: The methodology and results for stage 2 of the modelling is presented the addendum report in Appendix C.

Model Development

Stage 1

Modelling Urban Water Flows

Urban water flows were estimated for each development scenario using the Aquacycle model (Mitchell *et al*., 2001) and compiled into urban water mass balances, based on the approach described in the Infill Performance Evaluation Framework (Renouf *et al.*, 2020).

- **NOW Scenario:** Existing catchment conditions: Represents the current state of development in the study area as it was in 2019-20 and is used as the reference case;
- **NEW Scenario:** Fully developed catchment conditions under current Brisbane City Council (BCC) City Plan guidelines (land use only): NEW scenario represents extent of infill development likely to occur over a mid-term horizon (10 years). The basis of this scenario is developed based on reviewing examples of development in the catchment. Refer to Appendix A for further details;
- **NEXT Scenario:** is characterized by the type of development envisaged in the urban design scenarios developed for this project and is the development that would satisfy the vision for a Water Sensitive City. The NEXT infill development scenarios represent an alternative path for achieving the same population increase as NEW, with construction of an additional 50 units. Four types of NEXT typologies have been designed by Monash University. For further details about typologies, refer to Appendix B.

Modelling Urban Heat

Urban heat of the case study area under each development scenario was modelled using the Scenario Platform developed by Tool and Products (TAP), (CRCWSC 2020). The scenarios used for modelling urban heat are the same as those described above for modelling urban flows.

Stage 2

Modelling Urban Water Flows

Urban water flows were estimated for each development scenario using the Scenario Platform developed by Tool and Products (TAP), (CRCWSC 2020).

- **EXG Scenario:** Existing catchment conditions: Represents the current state of development in the study area as it was in 2019-20 and is used as the reference case;
- **BAU Scenario:** Fully developed catchment conditions under current Brisbane City Council (BCC) City Plan guidelines (land use only): BAU scenario represents extent of infill development likely to occur over a mid-term horizon (10 years). The basis of this scenario is developed based on reviewing examples of development in the catchment. Refer to Appendix A for further details;
- **WSC Scenario:** Characterized by the type of development envisaged in the urban design scenarios developed for this project and is the development that would satisfy the vision for a Water Sensitive City. The WSC infill development scenarios represent an alternative path for achieving the same population increase as WSC, with construction of an additional 50 units. Four types of WSC typologies have been designed by Monash University. For further details about typologies, refer to Appendix B.
- **WSC Storage Scenario: C**haracterized by the type of developed envisaged in the urban design scenario developed for this project along with 10 kL storage tank for collecting rainwater for each dwelling.

Modelling Urban Heat

Urban heat of the case study area under each development scenario was again modelled using the Scenario Platform developed by Tool and Products (TAP), (CRCWSC 2020). The scenarios used for modelling urban heat are the same as those described above for modelling urban flows with the exception of the storage scenario. Instead a green streets scenario was simulated.

- **WSC Green Streets Scenario:** is characterized by a reduction in road cover and concrete fractions within the road corridors and an increase in tree and permeable surfaces.

Model Results

Stage 1

Modelling Urban Water Flows

An overview of performance for each of the scenarios within the study area is shown in **Error! Reference source not found.**. "Good" performance or "target performance" comprises the outer circle or 100% score.

The Evaluation Framework compares existing and future scenarios with "pre-developed" conditions. This helps compare the hydrology prior to introduction of urban surfaces. A key indicator of water performance is the "Precipitation fraction not converted to run-off". In the PRE-developed case, 13% of rainfall would runoff. In contrast, in the NOW case, 42% of rainfall is converted to runoff (i.e. 320% of the pre-developed volumes). NEW case development levels would increase this to 50% rainfall conversion to runoff. In contrast, NEXT would only have 31-39% of rainfall converted to runoff, depending on the extent of stormwater and rainwater harvesting.

As indicators, water supply and self-sufficiency are based on how reliant the precinct is on "imported water" (mains water supply) versus local sourced (supplementary water) supplies to meet demand. In the NOW and NEW cases, there is no harvesting of rainfall, so consequently the self-sufficiency is 0. In the NEXT scenario, 'people supplied per Kl imported water' is reduced due to use of water efficient fixtures.

Modelling Urban Heat

The Scenario Tool developed by the CRC for Water Sensitive Cities was utilised to simulate urban heat for all scenarios. Both Land Surface Temperature (LST) and Air Temperature were simulated and evaluated. Under the NEW scenario, land surface temperatures increased by 2.4°C, compared to the NOW scenario. Under the NEXT scenario conditions, the LST reduced by 0.9°C, when compared to NOW. Similar trends were seen when evaluating changes in air temperature for each scenario. When assessing the Universal Thermal Comfort Index (UTCI), 61% of the study area resulted in temperatures above 42°C under the NOW scenario, increasing to 69% for NEW and decreasing to 57% for NEXT.

Stage 2

Modelling Urban Water Flows

The different modelling approach adopted for stage 2 meant it was not possible to directly translate results for use in the performance criteria assessment. However, using the same “Precipitation fraction not converted to run-off” the fraction for the existing conditions was 63% which increased to 66% under BAU conditions, decreased to 61% under WSC and for the storage scenario reduced further to 45%.

Modelling Urban Heat

Under the BAU scenario, land surface temperatures increased by 1.1°C, compared to the EXG scenario. Under the WSC scenario conditions, the LST reduced by 0.3°C, when compared to NOW. Similar trends were seen when evaluating changes in air temperature for each scenario. When assessing the Universal Thermal Comfort Index (UTCI),60% of the study area resulted in temperatures above 42°C under the BAU scenario, increasing to 75% for NEW and decreasing to 52% for WSC.

Conclusions

Based on this analysis in Norman Creek, the water-related impacts of infill development are significant. Alternative and water sensitive designs can lead to considerable influence on runoff, infiltration, evapotranspiration, urban heat and other beneficial changes. This case study demonstrated that it is possible to provide housing for additional (beyond target) population growth and simultaneously mitigate existing previous negative consequences of relatively unplanned (hydrologically) development.

Work undertaken during this project provides a foundation around which future performance objectives and targets (e.g. for hydrological performance or infill self-sufficiency of supply) could be considered for this development area. It is noted that performance can be strongly influenced by annual shifts in rainfall, as well as local conditions, such as soil types and consistencies.

The work also provides a significant foundation from which a more quantified business case for water sensitive outcomes can be achieved from new development designs and typologies. As an example, the impact on water supply, wastewater flow, flooding, building costs and air conditioning could be quantified from the designs presented in this report.

Contents

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1.0 Introduction

It is predicted that most Australian cities and towns will experience rapid growth over the coming decades. The responses toward population growth in cities have historically been divided into two main pathways.

- greenfield development—the release of undeveloped land located on the periphery of cities for the delivery of low-density housing; and

- brownfield or greyfield development—redevelopment in established areas, delivering medium-density to high-density residential development in existing urban areas.

As the number of available greenfield sites reduces, many local government areas are focusing on infill development. Infill development involves developing vacant or underutilised parcels of land within existing urban areas.

This project has been undertaken in partnership with the Corporative Research Centre for Water Sensitive Cities (CRC WSC) Integrated Research Program (IRP) 4 - Water Sensitive Outcomes for Infill Development. The main objective of the CRC IRP4 research project is to explore urban infill development typologies that can achieve water sensitive outcomes, by evaluating the 'water sensitive' performance of different infill design typologies at actual case study sites. To achieve this, IRP4 has developed a performance evaluation framework to understand the impacts of infill development and compare design options to mitigate impacts and improve outcomes.

Norman Creek Regional infill case study has focused on investigating different development methods, in order to minimise impact of infill development on the environment within a pilot study area. The project demonstrates how a water mass balance analysis can be undertaken to understand the impact of infill development.

As part of the project, an existing *Infill Performance Evaluation Framework* (Renouf *et al*., 2020) was developed and applied to a selection of case studies, in order to answer the following research questions:

- What are the water-related impacts of infill development and how do they vary in different Australian contexts?

- What are the urban heat impacts of infill and what role can water play in heat mitigation?

- How do water demand alternatives influence performance in different contexts?

- Which design and water use variables should guide design solutions?

- What performance objectives or targets might be appropriate for infill development?

- What design typologies give good performance in Brisbane context?

In this work, the Evaluation Framework was applied to an urban precinct in the Norman Creek Catchment, in the south of Brisbane, Queensland (QLD). This area is predominantly comprised of urban residential areas and is uniquely placed to influence the character of urban growth in one of the fastest growing regions in metropolitan Brisbane. This case study area was selected, in consultation with the CRCWSC team, who are global research leaders in Water Sensitive city design. The study aimed to answer the above questions, in the context of Norman Creek and to investigate the potential for translating findings into responses to infill challenges across Brisbane city more generally.

1.1 Case study area

At the time of this study (2019-20), 99% of the study area was residential, with a few vacant lots (Figure 1).The study area is bounded at the west by Norman Creek, which provides some green space with sport fields and small pocket parks. However, there is poor connectivity between these green open spaces and residential areas. Existing housing stock is predominantly modest homes on average blocks, in streets with generous verge widths and established native trees. The average number of people per dwelling in the Norman Creek Region is 2.2, which is lower than the Australian average of 2.6 (ABS, 2016).

The median household income in the Norman Creek Region is $1,671. It is ranked in the 'category 3 and 4 most advantage' (on a scale of 1-5), in the 2016 *Index of Relative Socio-economic Advantage and Disadvantage* (IRSAD) (ABS, 2018) (Figure 1). It is representative of a high socio-economic residential context.

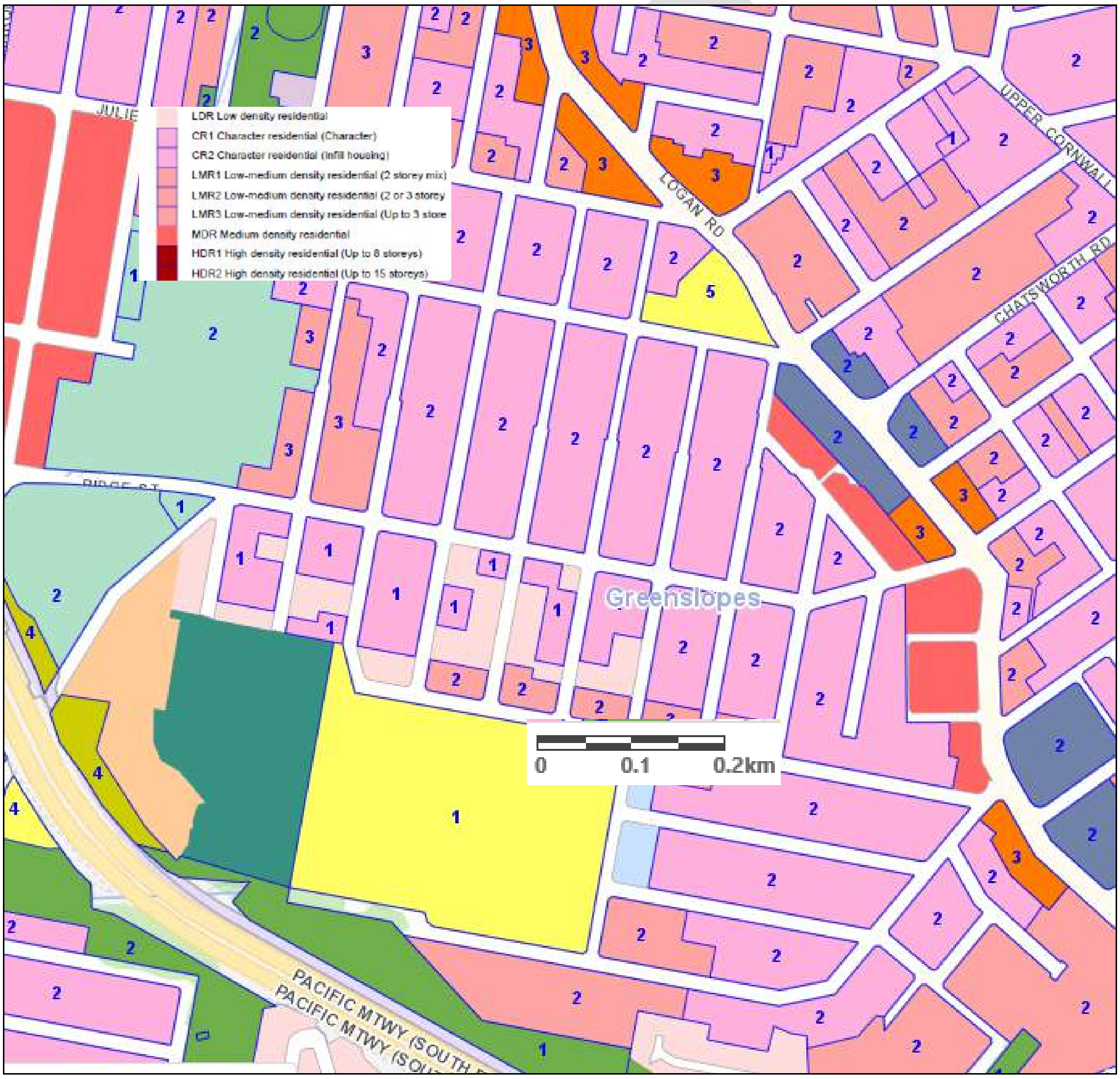


Figure 1: ***City Plan 2014*** **- Land use for Norman Creek Regional Study**

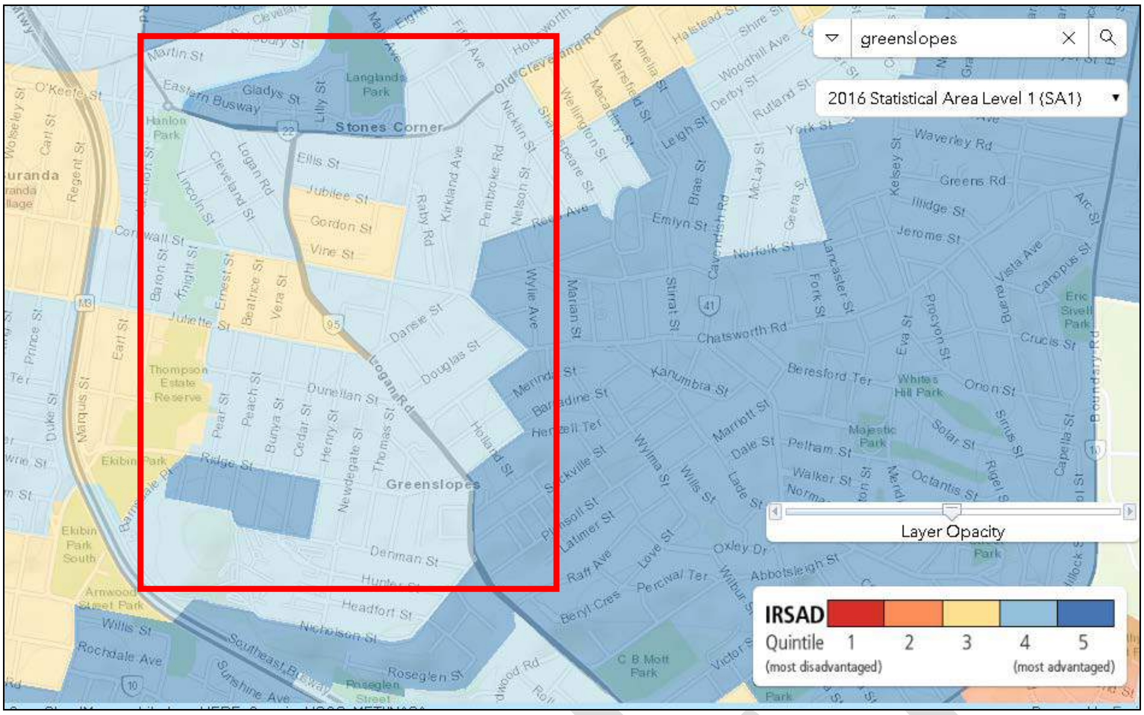


Figure 2: ***Index of Relative Socio-economic Advantage and Disadvantage*** **(IRSAD) Map – Norman Creek Regional study**

The study area is located in sub-tropical climatic conditions, with mild and dry winters, and hot and wet summers, when most of the yearly rainfall occurs. Refer to Figure 3 for the annual rainfall and potential evapotranspiration of the area, based on gauge number 402014, located in Brisbane City.

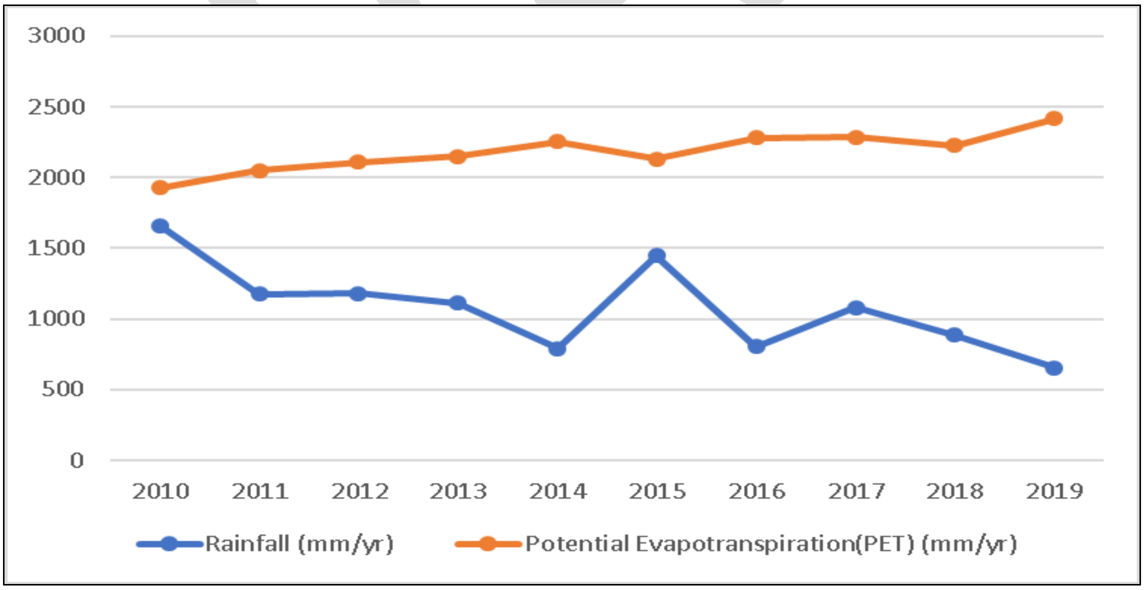


Figure 3: Rainfall and potential evapotranspiration for study area, derived from SILO(2020)

1.2 Future development projections

Under the current Brisbane *City Plan 2014*, a number of lots are highlighted for future intensification (Figure 1). Also, in the current *City Plan 2014*, small lot development of 300 m^2 and smaller is allowed in the case study area.

There is currently a mismatch between existing housing stock and household demographics. An overwhelming majority of existing houses are 3 and 4-bedroom detached houses, with a significant proportion of single and two-person households. This trend is expected to continue. Many residential owners are at retirement age, signalling a generational change of ownership that may trigger demographic changes. With demographic changes, there may be an increased demand for a wider variety of housing forms, including smaller houses and/or fewer bedroom houses in the future. Trends towards smaller allotments, driven by affordability, are also observed. For example, delivery of 2 and 3-bedroom houses on allotments of less than 150 square metres may be required.

The current population for the 9.6 ha area selected for this case study [Note: ideal numbers for typology testing are approximately 1,200 people, so the selected case study area has approximately this population]. The proposed population increase in the case study area is to around 1,900 people. For the proposed evaluation framework analysis, these numbers have been used.

1.3 Opportunities and aspirations

Consultation with the case study partners (Brisbane City Council, CRCWSC) identified the following aspirations for urban renewal in the study area:

- Amenity / liveability / health benefits that could be derived from -
  - I. better dwelling design, in terms of access, orientation, interface with the landscape, affordability and meeting the needs of changing demographics in future populations. Identification of priority areas for infill could feed into strategic land acquisitions for strategic renewal.
  - II. water sensitive urban design in the public realm, specifically better connectivity for walkability, improved access to open spaces and new parks and linkages. These recommendations for street upgrades can inform future budget bids and infrastructure renewal.
  - III. urban heat mitigation through increasing street tree canopies, retention of old trees and more grassed areas.
- Improved water security and productivity from water through -
  - I. enhanced infiltration of rainwater into soils to further support urban greening.
  - II. reduced demand for potable water through the end-use water efficiencies from higher densities.
  - III. Reduced demand for potable water through utilising rainwater tanks for irrigation purposes.

2.0 Method

2.1 Method overview

The performance of alternative infill scenarios for the study area were evaluated using the approach described in the Infill Performance Evaluation Framework (Renouf *et al.*, 2020). Performance was evaluated at the precinct scale, to represent the performance of the study area before and after infill development, and to compare the performance of alternative infill scenarios relative to the existing state.

Steps followed were:

1. Creation of site-plans for dwelling typologies that represent the existing (NOW) case, the business-as-usual (NEW) infill case and alternative water sensitive (NEXT) infill cases. Design parameters are defined for each (surface characteristics and areas, imperviousness, vegetation, and irrigation assumptions).

2. Creation of precinct-plans for various development scenarios in the study area, including the existing (NOW) development case (as at 2019), expected infill development under business-as-usual (NEW) conditions, and alternative infill development scenarios based on water sensitive (NEXT) city principles. Land uses within the study area under each development scenario were categorised into land use clusters (residential, vacant land, streets, etc.).

3. Definition of water servicing assumptions for each development scenario.

4. Evaluation of the following aspects for each of the development scenarios described below

- Urban water flows were estimated for each development scenario using the Aquacycle model (Mitchell *et al.*, 2001) and compiled into urban water mass balances, based on the approach described in the Infill Performance Evaluation Framework (Renouf *et al.*, 2020).

- Urban heat of the case study area under each development scenario was modelled using the Scenario Platform developed by Tool And Products (TAP), (CRCWSC 2020).

- Architectural and urban space qualities of each development scenario were developed by Monash University Architecture.

5. Generation of multiple performance indicators to rate and compare the performance of the NEW and NEXT infill scenarios against the NOW case.

2.2 Precinct-Scale infill scenarios

In this work, three scenarios were defined. Existing (NOW), Business-as-usual (NEW) and Water sensitive (NEXT). The NOW development case represents the current state of development in the study area, as at 2019-20. It is the reference case against which the impact of infill development scenarios was compared. Land use within the study area was categorised into the following –

residential, vacant land and street. The residential cluster was further sub-categorised into Residential Low (REL) and Residential Medium density (REM) typologies. Average number of dwelling densities per ha is 15 units.

The NEW scenario represents extent of infill development likely to occur over a mid-term horizon (10 years). The basis of this scenario is developed based on reviewing examples of development in the catchment. Refer to Appendix A for further details.

The NEXT infill development scenarios represent an alternative path for achieving the same population increase as NEW, with construction of an additional 50 units. Four types of NEXT typologies have been designed by Monash University. For further details about typologies, refer to Appendix B.

Figures 5 to 8 show the land use (overall and detailed), population changes and changes in the surface impervious area in all scenarios.

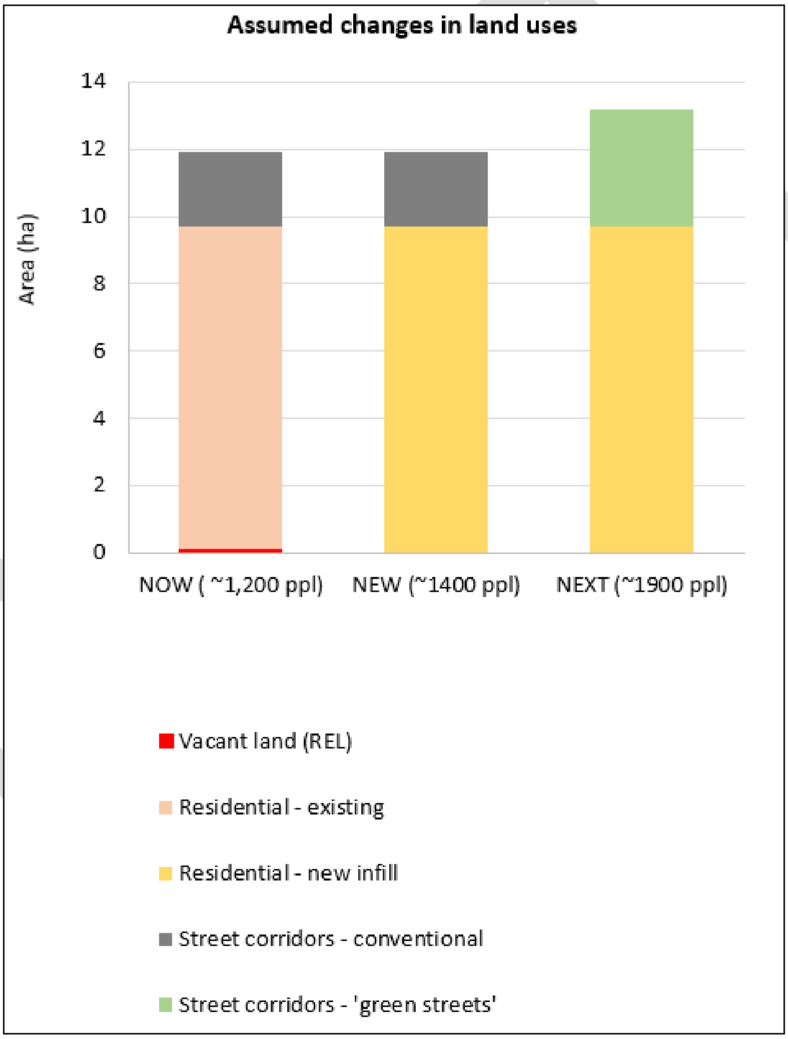


Figure 4: Assumed overall land use changes

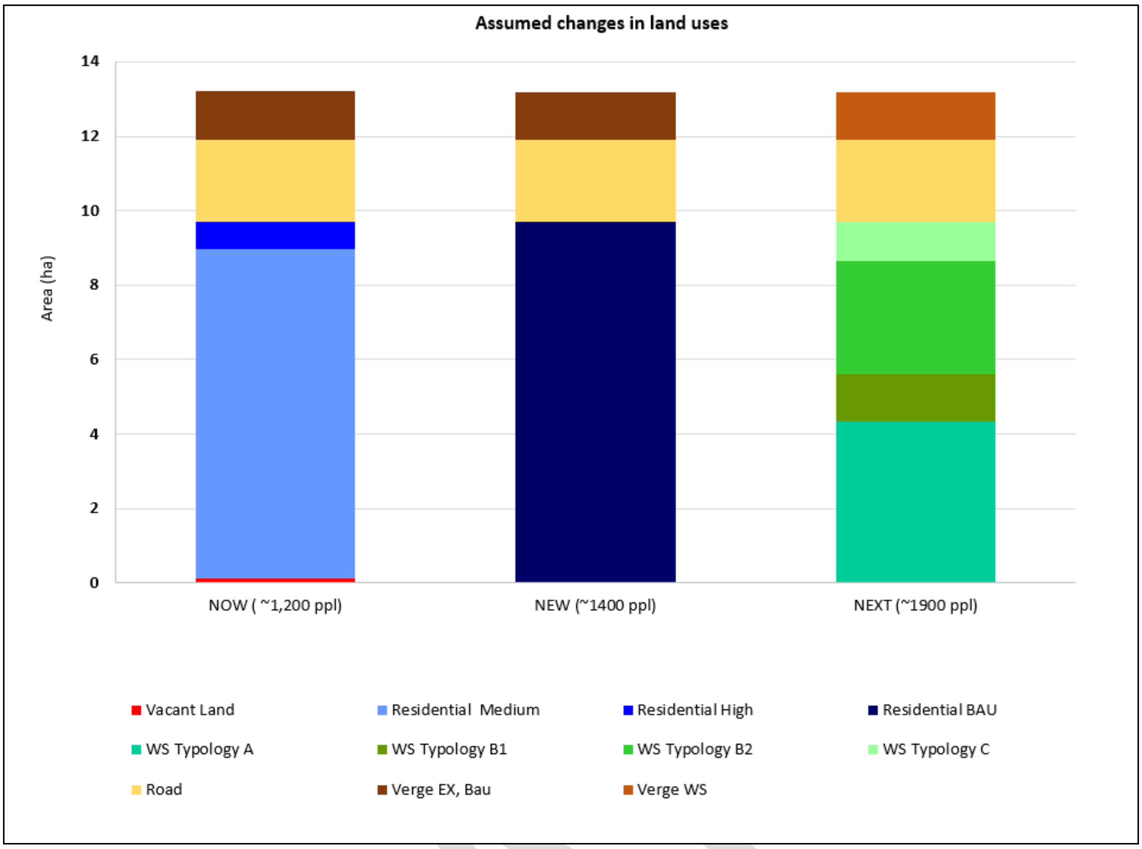


Figure 5: Assumed detailed land use changes

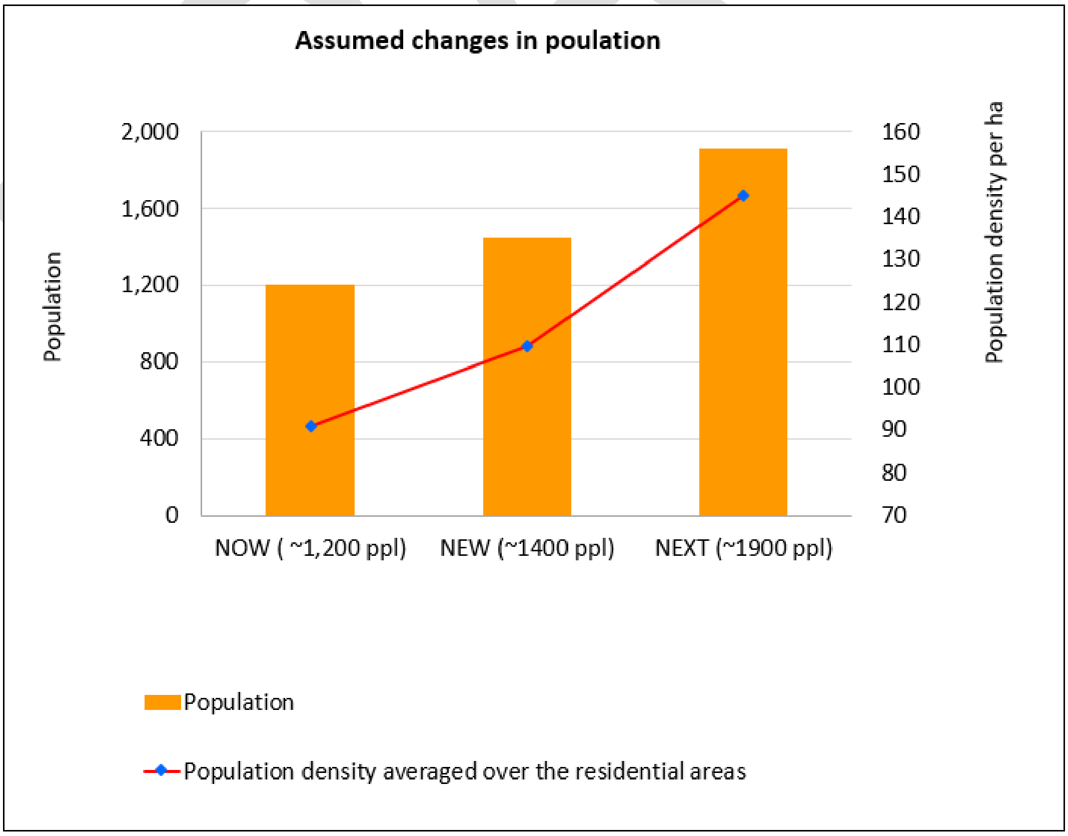


Figure 6: Assumed population increase

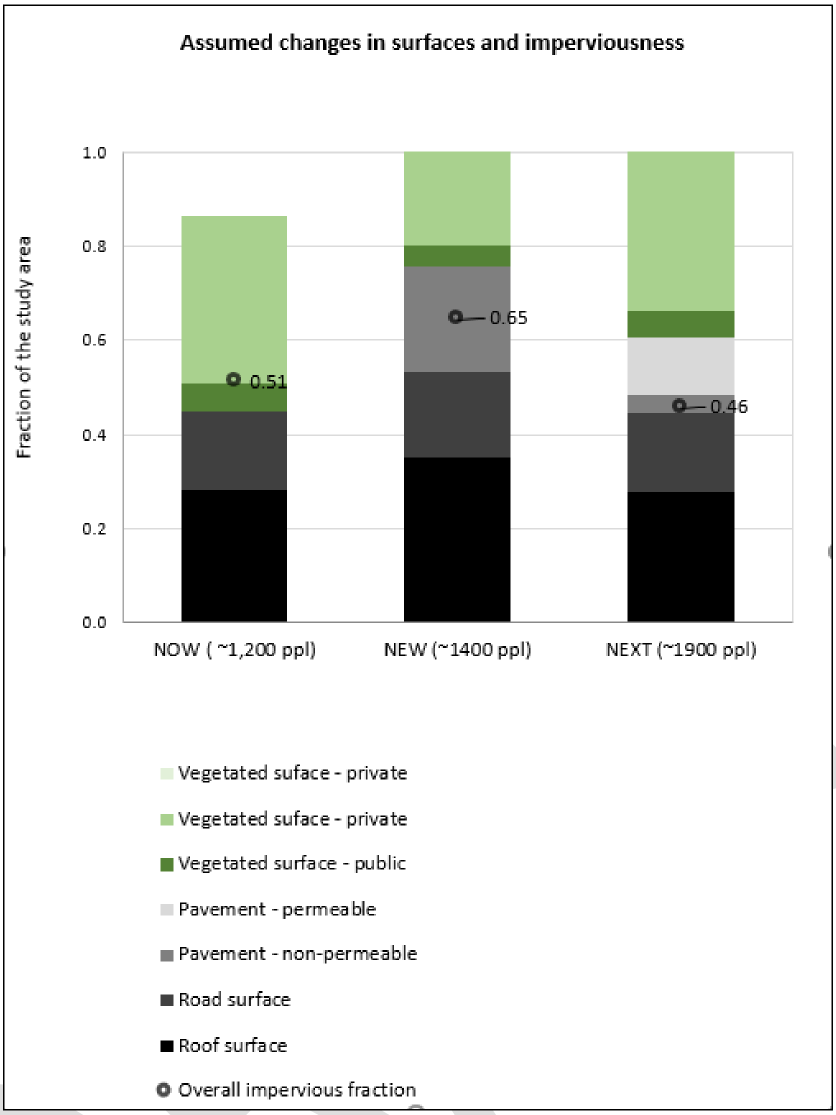


Figure 7: Assumed changes in surface and imperviousness

2.3 Modelling urban water flows with Aquacycle

The Aquacycle model (Mitchell *et al*., 2001) was used to estimate annual urban water flows for the study area. Aquacycle was selected because it is more suited than other models to analysis at the precinct-scale and for investigating the use of locally generated stormwater and wastewater as supplementary water supplies. Flows of interest are precipitation, evapotranspiration, infiltration, stormwater discharge, supply of mains water (imported water), supplies of supplementary water (harvested rainwater or stormwater).

These flows were estimated with Aquacycle for each of the development scenarios (NOW, NEW and NEXT), and for the pre-urbanised state (PRE), which is a point of reference for the hydrology indicators. Water flow data were compiled into water mass balances, as per the *Infill Performance Evaluation Framework* (Renouf *et al.*, 2020) from which the water performance indicators were generated.

Calibration parameters used in the hydrological model within Aquacycle were based derived from parameters used in MUSIC modelling and recommended by Myers *et al.* (2015, p.79).

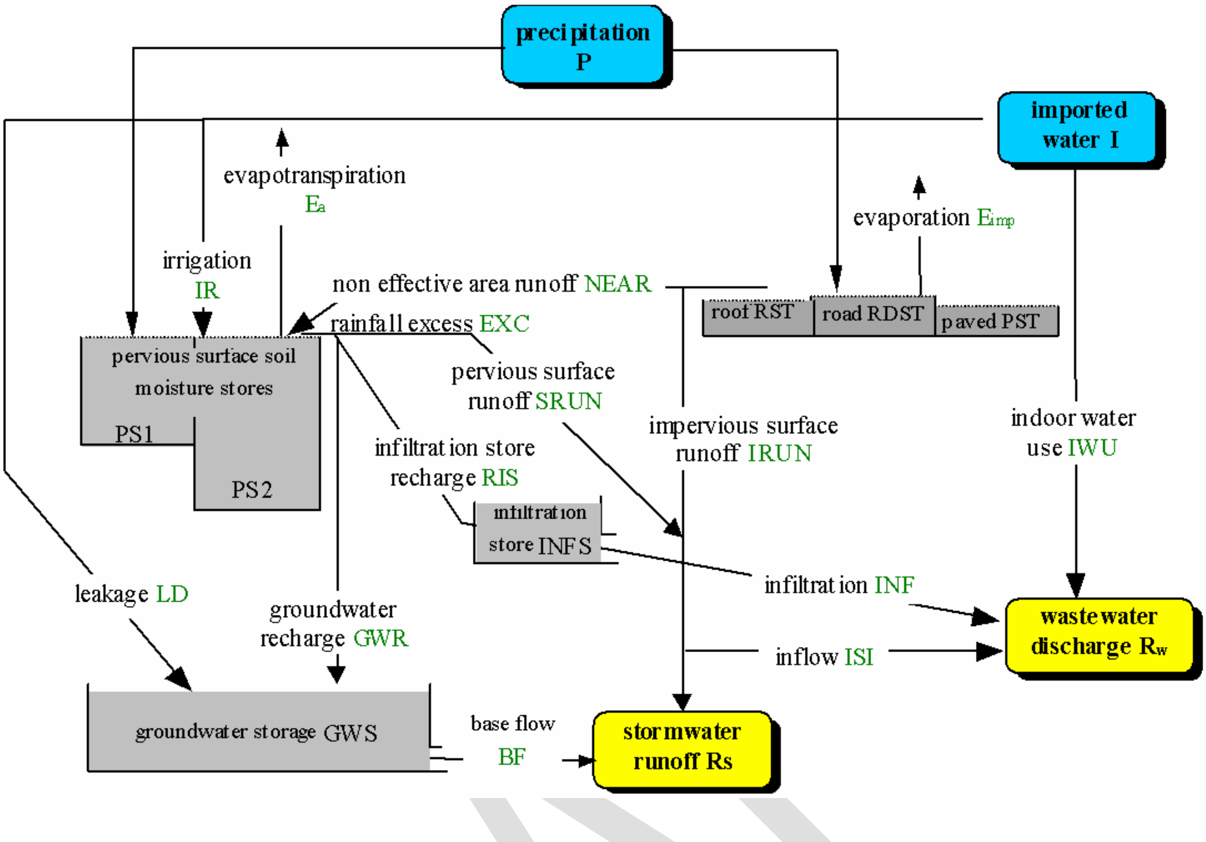
Aquacycle also requires a ‘per person indoor water use for various household sizes’ to be specified. These were derived from a regression algorithm developed by Makki *et al.* (2015), which was based on the key determinants of household demographics, appliance efficiencies and use habits. Figures were calibrated against a survey of household water use in Brisbane. Refer to Figure 8 for the conceptual representation of Aquacycle model.

Table 1: Parameters used in Aquacycle for the Brisbane context

Stormwater	**Range**	**1**	**2**	**3**	**4**	**5**
		REL	**REM**	**REH**	**Roads**	**Verge**
% area of pervious store 1 [1]	0 to 100	50	50	50	50	50
Capacity of pervious store 1 (mm)	>=0	40	40	40	40	40
Capacity of pervious store 2 (mm)	>=0	40	40	40	40	40
Roof area maximum initial loss (mm)	>=0	1	1	1	1	1
Effective roof area (%)	0 to 100	90	90	90	90	90
Paved area maximum initial loss (mm)	>=0	1	1	1	1	1
Effective paved area (%)	0 to 100	80	80	80	80	80
Road area maximum initial loss (mm)	>=0	1	1	1	1	1
Effective road area (%)	0 to 100	90	90	90	90	90
Base flow index (ratio)	0 to 1	0.25	0.25	0.25	0.25	0.25
Base flow recession constant (ratio)	0 to 1	0	0	0	0	0
Wastewater						
Infiltration index (ratio)	0 to 1	0	0	0	0	0
Infiltration store recession constant (ratio)	0 to 1	0	0	0	0	0
% of surface runoff as inflow (%)	0 to 100	0	0	0	0	0
Water use						
Garden trigger-to-irrigate	0 to 1	0.4	0.4	0.4	0.4	0.4

Aquacycle provides yearly analysis on yearly basis. The analysis provided in the figures is based on 2010. Analysis for other years is also available.

[1] Refer to Figure 9



STORAGE LEVELS

RST = roof surface storage level
PST = paved surface storage level
RDST = road surface storage level
GWS = groundwater storage level
INFS = infiltration storage level
PS1 = pervious store 1 level
PS2 = pervious store 2 level

Note:
GREEN capitals indicate processes that are represented by algorithms
RED capitals indicate a measured Parameter
BLUE Capitals represent a calibrated Parameter

Epc = 7mm

MAIN MODEL ALGORITHMS

$BF = BRC.GWS$

$E_a = A1.\min\{(PS1/PS1_C).E_{pc}, E_P\} + (100-A1).\min\{(PS2/PS2_C).E_{pc}, E_p\}$

$E_{imp} = \max(E_P, RST).(roof_{area}/cluster_{area}) + \max(E_P, PST).(paved_{area}/cluster_{area}) + \max(E_P, RDST).(road_{area}/cluster_{area})$

$EXC = \{\max(PS1-PS1_C, 0)\}.A1 + \{\max(PS2-PS2_C, 0)\}.(100-A1)$

$INF = IRC.\sqrt{INFS}$

$IR = \max(TG.PS1_c - PS1, 0).A1.\%GI + \max(TG.PS2_c - PS2, 0).(100-A1).\%GI$

$IRUN = ERA.(P-(RIL+RST)).(roof_{area}/cluster_{area}) + EPA.(P-(PIL+PST)).(paved_{area}/cluster_{area}) + ERDA.(P-(RDIL+RDST)).(road_{area}/cluster_{area})$

$ISI = \%I.(SRUN+IRUN)$

$IWU = I - IR - LD$

$LD = \%L.(IR+IWU)/(100-\%L)$

$NEAR = (100-ERA).(P-(RIL+RST)).(roof_{area}/cluster_{area}) + (100-EPA).(P-(PIL+PST)).(paved_{area}/cluster_{area}) + (100-ERDA).(P-(RDIL+RDST)).(road_{area}/cluster_{area})$

$GWR = BI.EXC$

$RIS = II.EXC$

$Rs = IRUN + SRUN - ISI + BF$

$Rw = IWU + INF + ISI$

$SRUN = EXC - RIS - GWR$

Figure 8: The conceptual representation of urban water cycle

2.4 Modelling Urban Heat

The Cooperative Research Centre (CRC) for Water Sensitive Cities (WSC) has been developing a planning-support tool enabling users to simulate urban development and performance outcomes of water management interventions (CRCWSC, 2019). Within this ‘Scenario Tool’ there are a number of performance assessment models, two of which were deployed in this study for modelling urban heat:

- Land Surface Temperature;
- TARGET (The Air-temperature Response to Green/blue infrastructure Evaluation Tool; and
- Universal Thermal Climate Index (UCTI).

These modules perform evaluations based on a range of underlying datasets. The Scenario Tool used Geoscape digital datasets as a default providing information on buildings, surface cover and tree cover. Trees. This scenario includes a number of workflow nodes, which enable the user to make changes to the urban form of a given area or include green infrastructure. Scenarios can then be simulated and used to assess changes against a baseline.

2.4.1 Land Surface Temperature

The Land Surface Temperature (LST) module enables quantification of the spatial variation of LST for an assigned case study area (in this instance Greenslopes). The model uses a ‘microclimate grid’ for a specified area, summarising the land cover data within each grid cell and grants a mean temperature for the cell area. Simulations are run based on assigned inputs over the three hottest days for the appropriate temperature station and averaged out to provide a static output.

2.4.2 TARGET

The TARGET module is used to simulate the Urban Heat Island (UHI) effect within the scenario tool. This UHI effect is a result of higher temperatures in urban areas caused by a reduction in natural, vegetated landscapes and the increased heat storage capacity of dark paved surfaces. TARGET can be used to assess both temporal and spatial variance of air temperature (and surface temperature) over a three-day period. The model again utilises the input data, as well as relevant meteorological data at half-hourly timesteps to provide a timeseries output.

2.4.3 Universal Thermal Climate Index

The Universal Thermal Climate Index (UTCI) assesses the thermo-physiological effects of the atmospheric environment on the human biometeorology (UTCI, 2020). It considers dry temperature, relative humidity, solar radiation and wind speed to determine the reference temperature causing human discomfort (Baaghideh *et al*., 2016). UTCI specifies a number of heat stress categories ranging from extreme heat stress to extreme cold stress (Figure 9). The performance indicator for Urban Heat is the fraction of outdoor areas that are above 42°C.

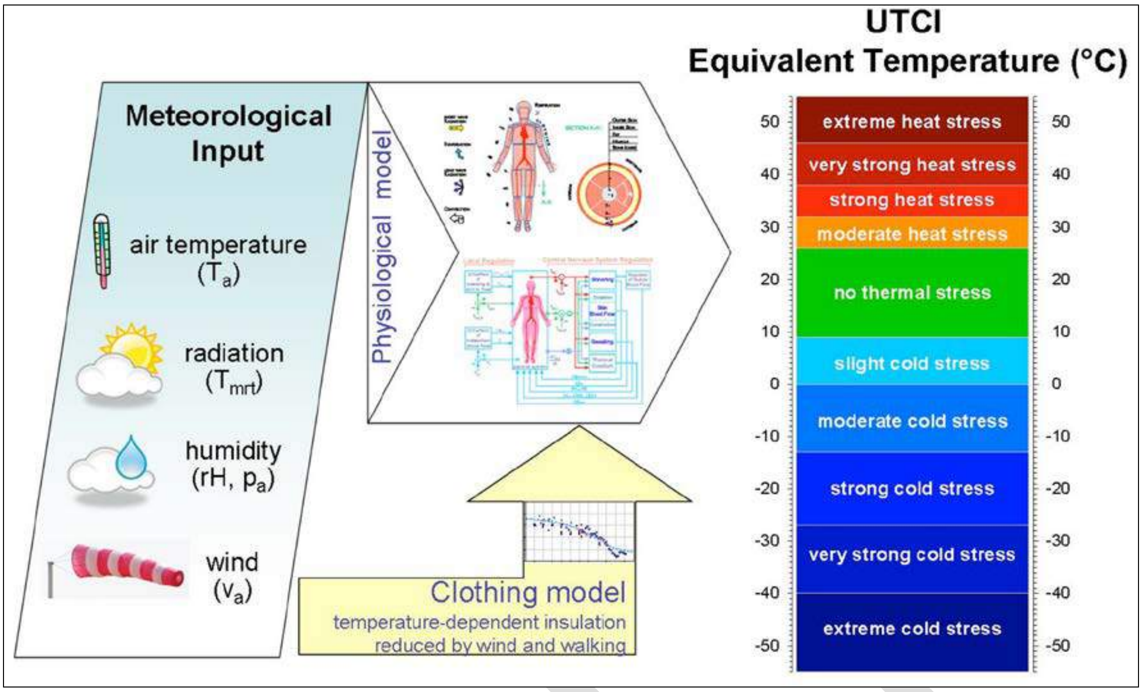


Figure 9: Universal Thermal Climate Index (UTCI) from Brode et al. (2011)

2.4.4 Norman Creek Study

The scenario tool was used to set-up a range of scenarios for the Norman Creek case study. These scenarios were used to simulate and assess changes in LST, Air Temperature and UHI. The defined case study area is presented below in Figure 10. It is worth noting that this differs from the assessment area used to extract and present results, as discussed in Section 3.3

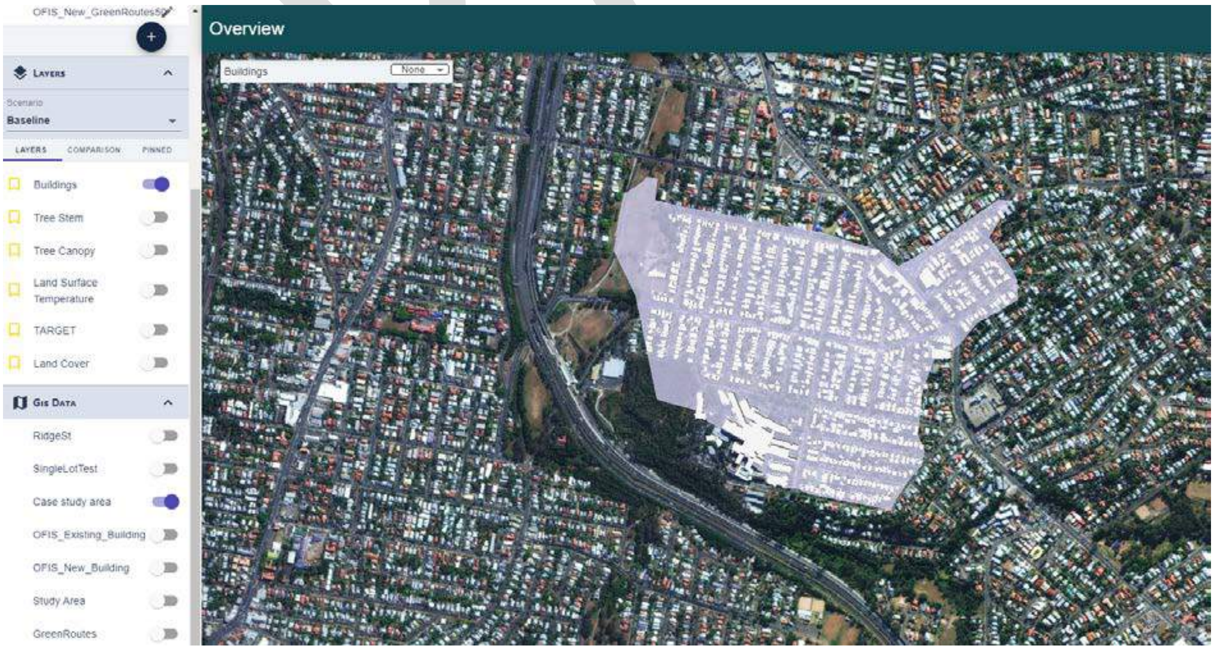


Figure 10: Scenario Tool Case Study Area

Model set-up largely used the default Geoscape datasets; however, a more recent building footprint dataset was incorporated for assessment. This Council dataset was not vastly different to that presented by Geoscape; however, more closely reflected recent development in the area.

Default imperviousness assigned by the Scenario Tool for the study area was notably larger than that previously presented for modelling urban flows. The change in imperviousness for the urban heat scenarios was proportionately weighted based on this disparity.

2.4.5 Scenarios

As with other performance evaluations, three scenarios were established, simulated and assessed (NOW, NEW and NEXT). The way in which these were established is presented in Table 2.

Table 2: Urban Heat Scenarios

Model Input	Now	New	Next
Building Footprint	BCC Dataset	BCC Dataset	New Design Typologies
Land Cover	Geoscape	Increase Imperviousness (26%)	Geoscape

2.5 Generation of performance indicators

Performance indicators aim to represent how each of the infill scenarios performs relative to the existing reference case. Performance criteria relate to hydrology, water demand and supply, greening, urban heat, architectural and urban space qualities.

Figure 11 summarizes the cause and effect relationships between urban design parameters (on the left of the diagram) and performance criteria (on the right). It also shows the indicators that can be used to quantify performance, either at the end-point (actual performance) or at a mid-point (key determinants of performance) in the cause-effect chain. The performance indicators reported for Norman Creek case studies are those highlighted in red in Figure 11.

Refer to the Infill Performance Evaluation Framework (Renouf *et al.*, 2020) for an explanation and justification of these indicators.

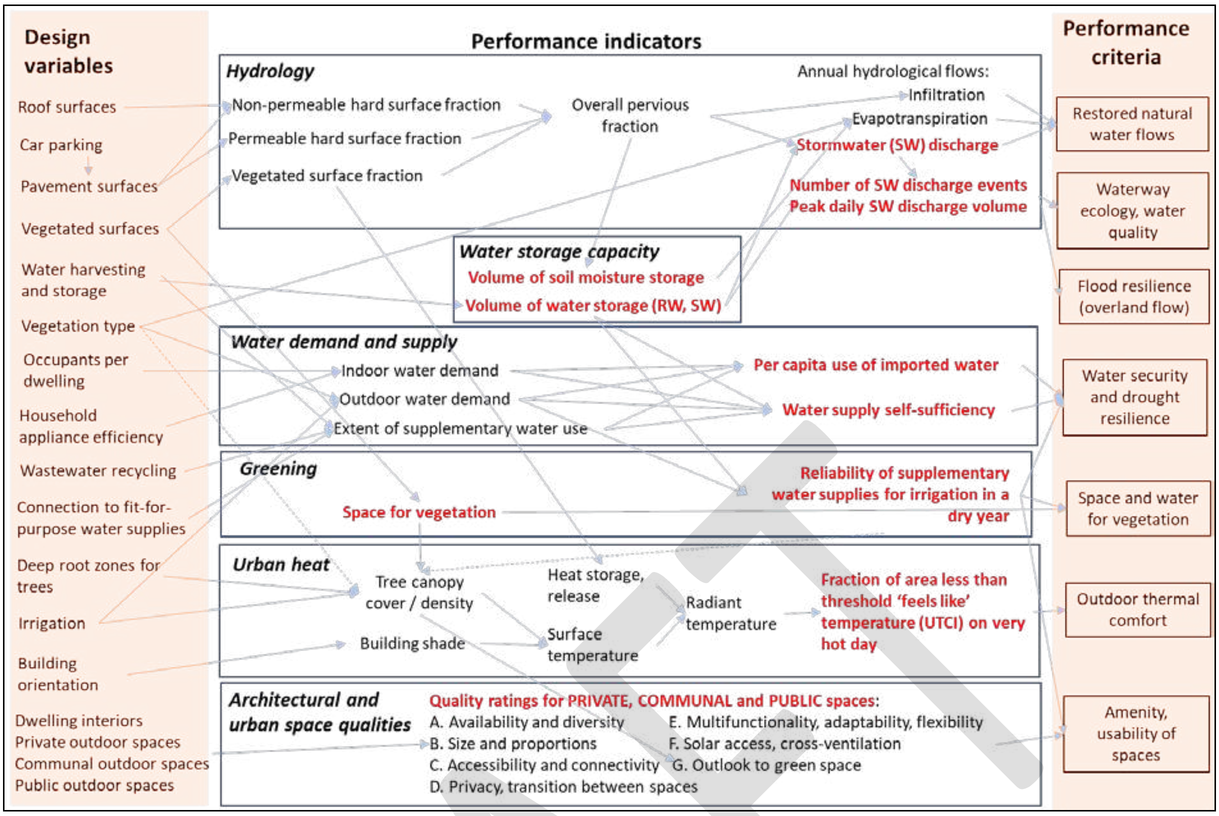


Figure 11 : Cause and effect relationship between design parameters and performance criteria

3.0 Performance Evaluation

3.1 Hydrology

The performance principle for hydrology is that “infill design does not further adversely alter the natural hydrology (infiltration, evapotranspiration and stormwater discharge) of the development area, and ideally aims to mimic the pre-urbanised hydrological water balance” (Renouf *et al.*, 2020).

Changes to hydrological flows - infiltration (I), evapotranspiration (ET) and stormwater discharge (SW) due to infill can be observed from the annual volumes for the development cases (NEW, NEXT). These have been compared to the existing (NOW) cases and to the pre-urbanised (PRE) case Figure 12. Changes in storage are also included, which show some accumulation of water in the system (in rain and stormwater storages and in the soil) between the start and the end of the reported year (Jan to Dec 2010).

The naturally impervious clay soils in the study area mean that infiltration (I) of rainfall into soils is naturally very low, so changes to “I” volumes from changes in imperviousness are only slight (Clark et al., 2015). Changes in hydrology are instead driven by reduced ET due to less vegetation and pervious surfaces in the developed cases. The consequence of reduced ET and reduced “I” is increased SW. Rainfall that does not evaporate, transpire through vegetation, or soak into the ground must go somewhere, so it drains away as runoff. Hence, the annual volume of SW discharge is a useful indicator of hydrological performance, with the performance criteria being the maintenance or restoration of SW towards the more natural state (PRE).

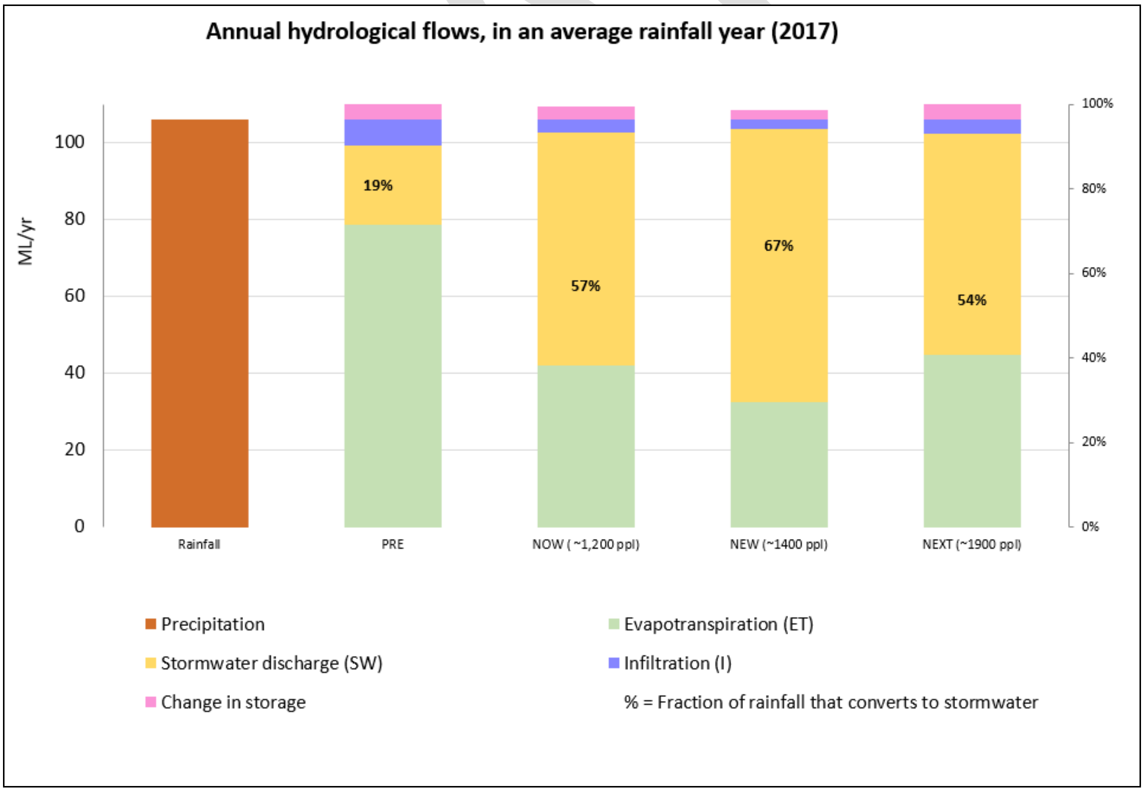


Figure 12: Hydrological flows in an average rainfall year (2017 with rainfall of 1079mm)

Table 3: Indicators of hydrological performance

	Rainfall	PRE	NOW	NEW	NEXT
% = Fraction of rainfall that converts to stormwater		19%	57%	67%	54%
Stormwater naturalness			2.9	3.4	2.8

Indicators for representing SW in Table 3 are the fraction of annual rainfall that converts to SW (%) and stormwater 'naturalness' (ratio of post- to pre-urbanised SW).

For the PRE-reference state, the annual volume of WS discharge was estimated to be around 19% of rainfall in an average rainfall year. The NOW case has increased SW discharge to 57% of rainfall, which is a 2.9 times PRE, and NEW infill development is expected to further increase SW discharge to around 67% of rainfall, to be 3.4 times than PRE. The increases are predominately due to a reduction in pervious surfaces in the study area.

The NEXT infill scenario is expected to produce volumes of SW discharge that are less than the NEW scenario, and less than the NOW case – around 54% of rainfall. The NEXT infill scenario enables an increase in population of the study area to 1,900 whilst maintaining annual volumes of SW discharge at the same or less than the NOW state (2.8 times PRE). In comparison, NEW infill will further increase SW discharge to 3.4 times PRE to achieve the same population increase.

The favourable performance of NEXT infill over NEW infill is due to two factors. The first is the purposeful design of the built form to include as much permeable and vegetated surfaces as possible to promote evapotranspiration and some infiltration.

One of the scenarios that is tested for NEXT infill scenario was the effect of rainwater tanks and changes in the hydrology. The following assumptions were made when determining volume to be incorporated into the NEXT Scenario model:

- Only new and reconfigured buildings within the floodplain were considered for rainwater tank inclusion.
- -Rainwater tank storage was calculated for each building based on building type. Adopted tank volumes were as follows:
    - Unit - 2000L
    - Townhouse – 3000L
    - House – 5000L
- Assume a 90% efficiency of collection of rainwater from the roof into the tank.
- Tank assumed to be empty prior to event, in order to simulate a 'best case' storage scenario.

For each of the scenarios [NOW – NEW – NEXT], it is assumed that 50% of garden areas will be irrigated by mains water in NOW and NEW scenario and with rainwater tanks in the NEXT scenario. Figure 13 present the findings from this model run.

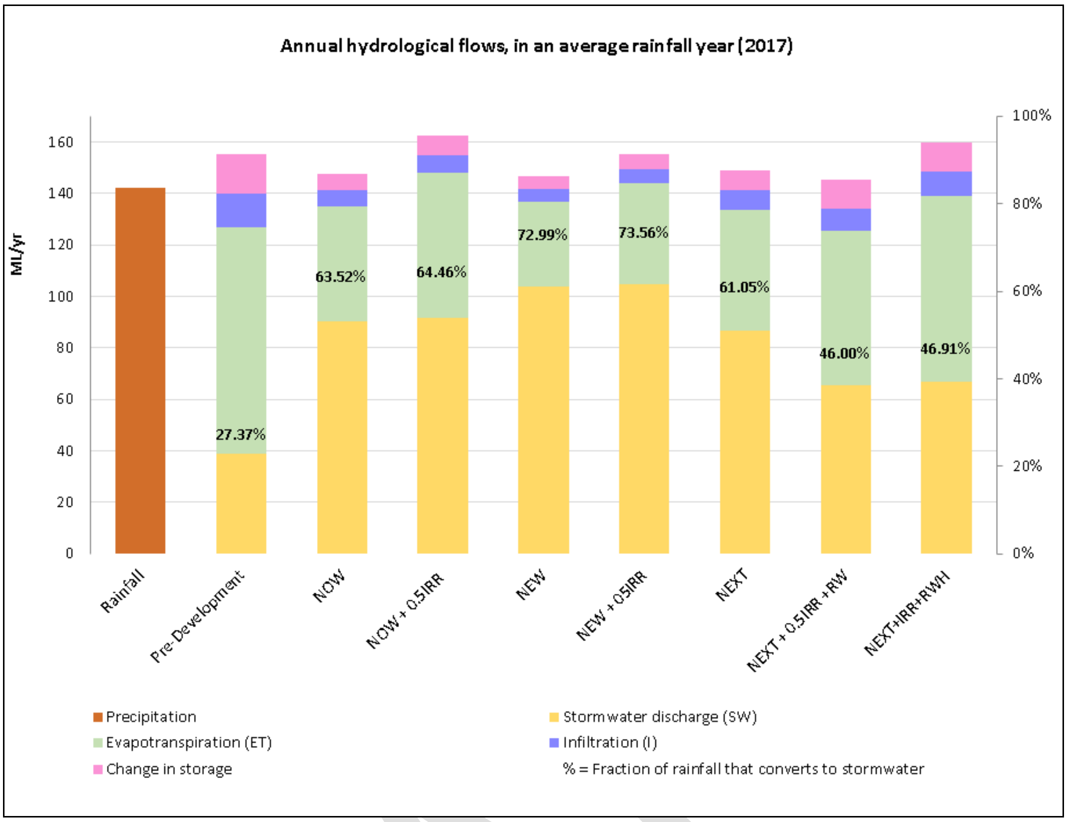


Figure 13: Annual hydrological flows in 2017

3.2 Water demand and supply

In relation to water supply, the Evaluation Framework makes a distinction between water sourced from within the urban system (in this case harvested rainwater and stormwater), and water imported from outside the urban system [in this case mains water supplied by Urban Utilities (UU)]. The performance principle for this aspect is that "infill designs enable reduced reliance on imported water through use of supplementary water supplies" (Renouf *et al.*, 2020). The degree of water self-sufficiency is the indicator for this, which represents the percentage of water demand that is met by water sourced from within the urban system. Impacts of the infill scenarios (NEW and NEXT) on water demand, , supply and , self-sufficiency in an average rainfall year, compared to the NOW state, are shown in Figure 14.

Water servicing options for the development scenarios is only mains water. There are no other servicing options for the now case.

For the existing (NOW) case and the business as usual (NEW) infill case, it was assumed that:

- gardens of residential dwellings are partially irrigated (50% of garden area), using imported (mains) water;
- road verges are not irrigated;
- all indoor and outdoor water demand is met by imported (mains) water; and
- there is no significant rainwater harvesting at residential dwellings.

For the water sensitive infill scenario (NEXT), it was assumed that:

- new infill dwellings have rainwater tanks;
- Rainwater harvested and used by each dwelling, for garden irrigation and non-potable indoor uses (toilets and clothes washers);
- road verges are not irrigated; and
- all indoor water demand is met by imported (mains) water.

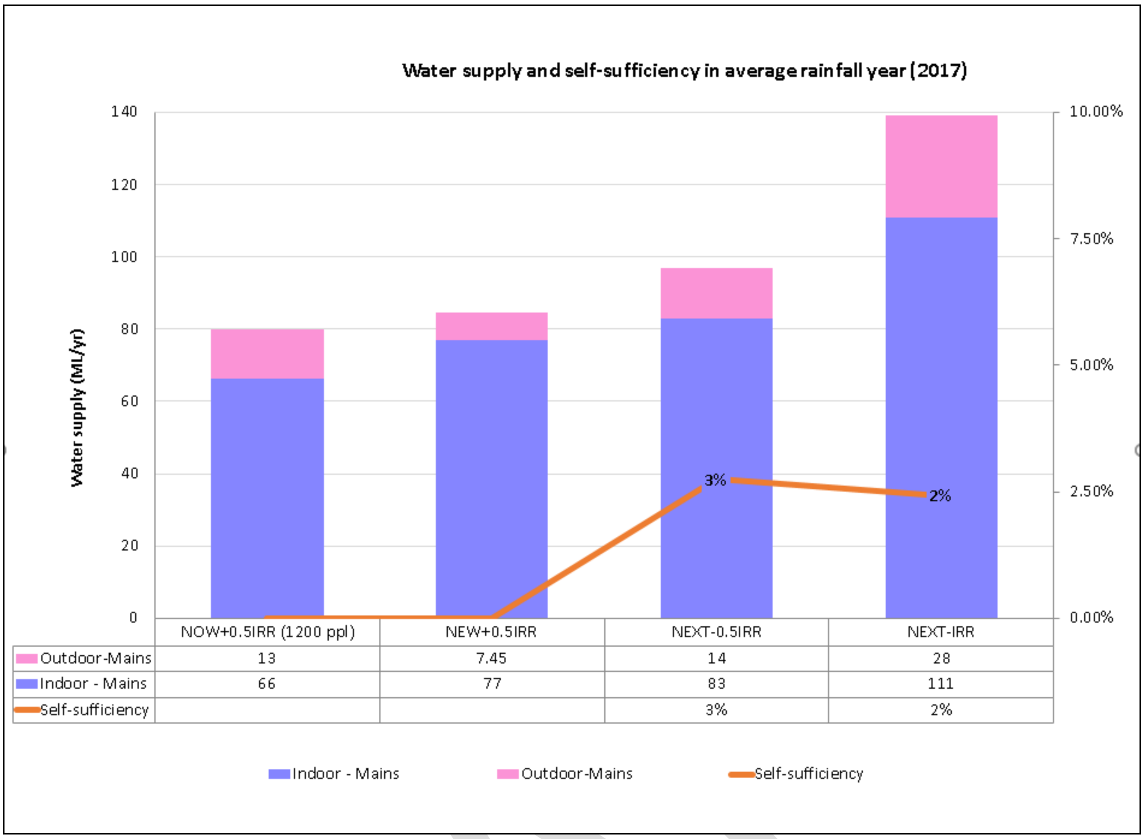


Figure 14: Water Supply and self-sufficiency in average rainfall year

3.3 Urban Heat

Similarly, to previous performance evaluations, three scenarios were simulated to represent the changes in urban heat. The differences between these scenarios was a change in the building footprint but also a change in the total imperviousness. Results presented in this section are a reflection of changes within the study boundary and not the suburb boundary. The study boundary is indicated by the orange polygon in Figure 15.

Figure 15: Scenario Tool Study Boundary

3.3.1 Changes in Land Cover

To incorporate changes in imperviousness, the land cover was altered within the scenario tool. A workflow node was created for this project, which enabled land cover fractions to be shifted between land uses. The land covers adopted for urban heat scenarios and resultant imperviousness are presented in Figure 16 and Figure 17 respectively.

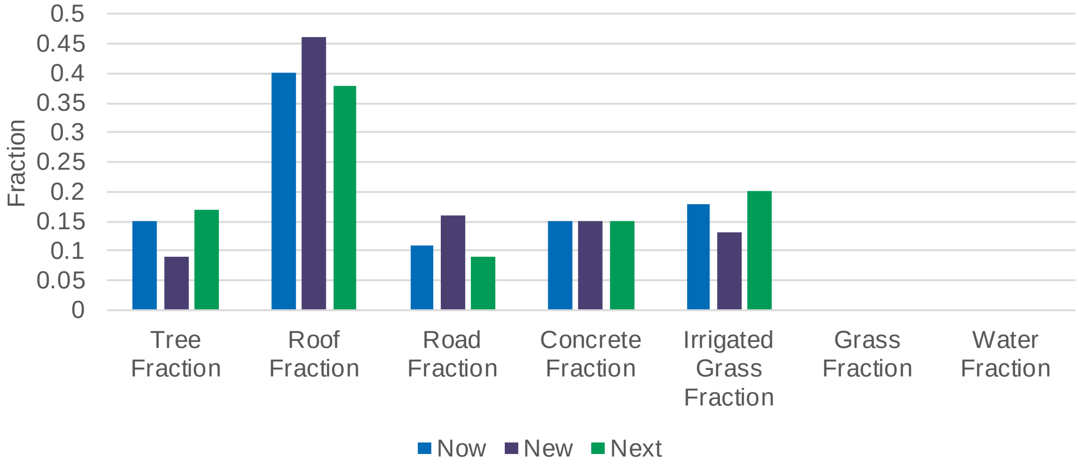


Figure 16: Land Cover Fractions

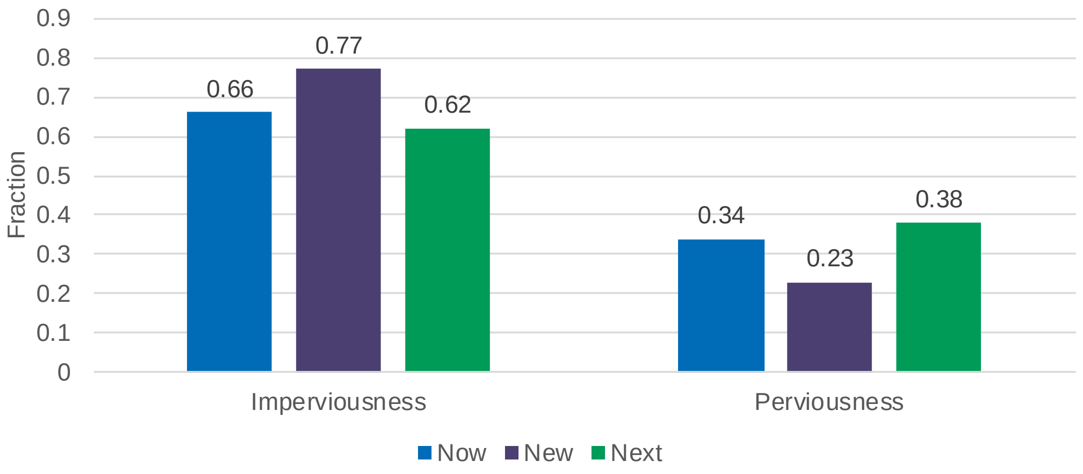


Figure 17: Imperviousness Fractions

3.3.2 Temperature

The scenario tool is capable of simulating both LST and Air Temperature. Outputs for LST from the scenario tool are presented in Figure 18. As expected, the changes in LST were commensurate with the changes in imperviousness. There is an increase of 2.4°C from NOW to NEW and a decrease of 3.3°C from NEW to NEXT.

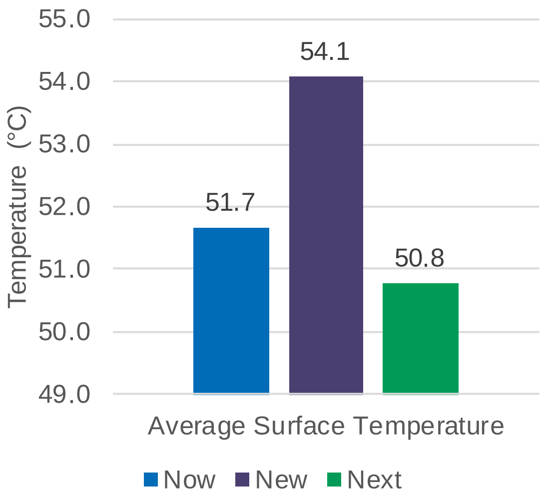


Figure 18: Temperature Results

Air Temperature was extracted as a timeseries and has been presented as a box and whiskers plot in Figure 19. The upper and lower limits represent the 25th and 75th percentiles of the data, with the line through the box indicating the 50th percentile (or median). The x indicates the mean, whilst the extended lines (whiskers) indicate the minimum and maximum values. Dots above the maximum indicate outliers and, for this reason, the maximum was not directly extracted as a scenario tool model output.

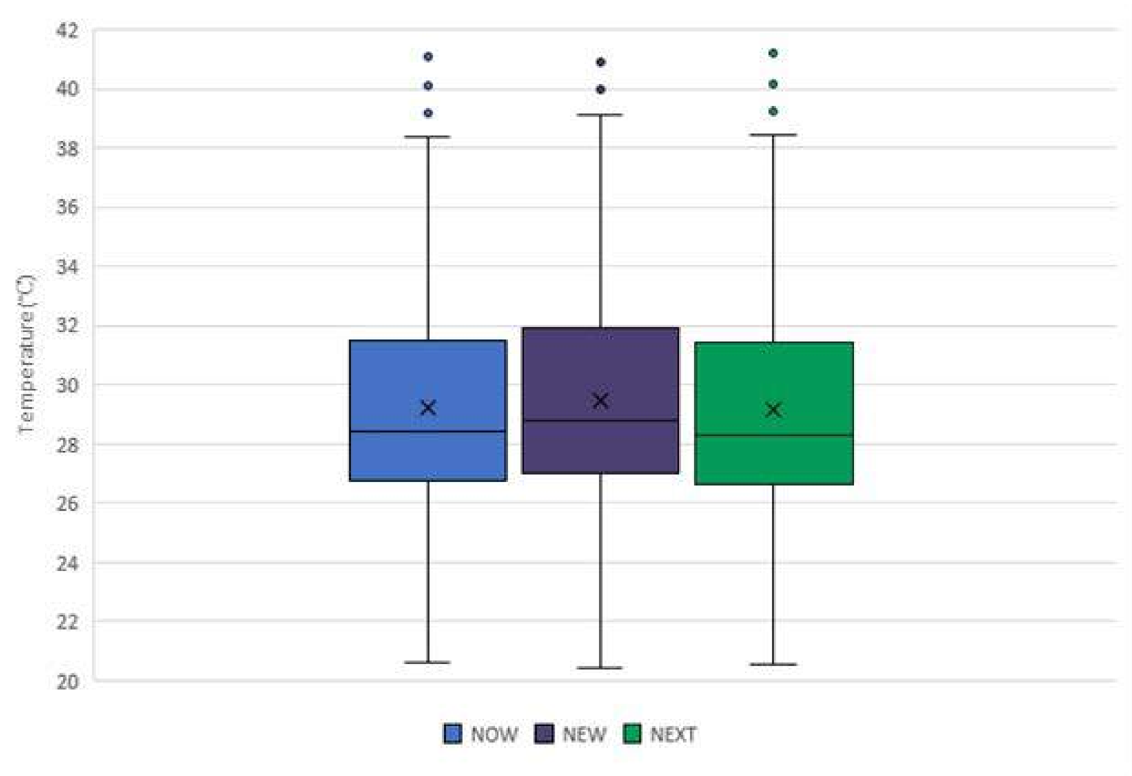


Figure 19: Air Temperature

The associated data from this plot is presented in Table 4. For all distributions, there is an increase in air temperature from NOW to NEW. The NEXT scenario results in the lowest air temperature of all three scenarios across all distributions (except for the maximum). There is a 0.8°C increase from NOW to NEW (when looking at the maximum), which then decreases by 0.7°C for the NEW Scenario.

Table 4: Air Temperature Data

	NOW (°C)	NEW (°C)	NEXT (°C)
Maximum	38.35	39.12	38.42
75th percentile	31.47	31.78	31.26
Mean	29.01	29.34	28.92
Median	28.41	28.81	28.27
25th percentile	26.69	26.98	26.62
Minimum	20.59	20.41	20.58

3.3.3 Universal Thermal Climate Index

The performance indicator for Urban Heat is the fraction of outdoor areas that are above 42°C Universal Thermal Climate Index (UTCI). The UTCI assesses the thermo-physiological effects of the atmospheric environment on the human biometeorology (UTCI, 2020). It considers dry temperature, relative humidity, solar radiation and wind speed to determine the reference temperature causing human discomfort (Baaghideh *et al.*, 2016). UTCI specifies a number of heat stress categories, ranging from extreme heat stress to extreme cold stress.

To generate the UTCI outputs, the scenarios were run again using the CRC Scenario tool over a three day period in February 2017. This period was selected, as it closely reflected the highest monthly mean temperature over summer in Brisbane (32.5°C). Distribution of these Heat stress categories for the three scenarios is presented in Figure 20.

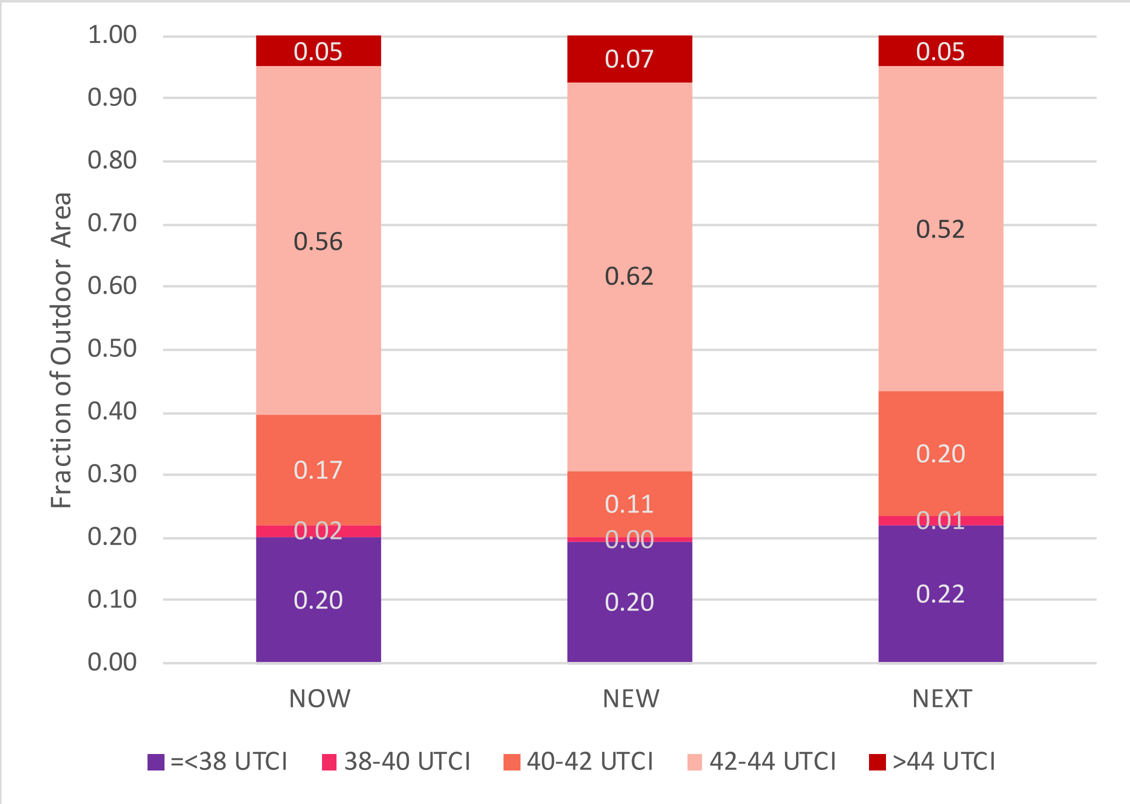


Figure 20: UTCI Distribution

In the NOW scenario, 61% of the study area indicates temperatures are exceeding 42°C. This value increases to 69% under the NEW and returns to 57% under the NEXT scenario. Distribution over the precinct area has been presented as a temperature distribution in Figure 21.

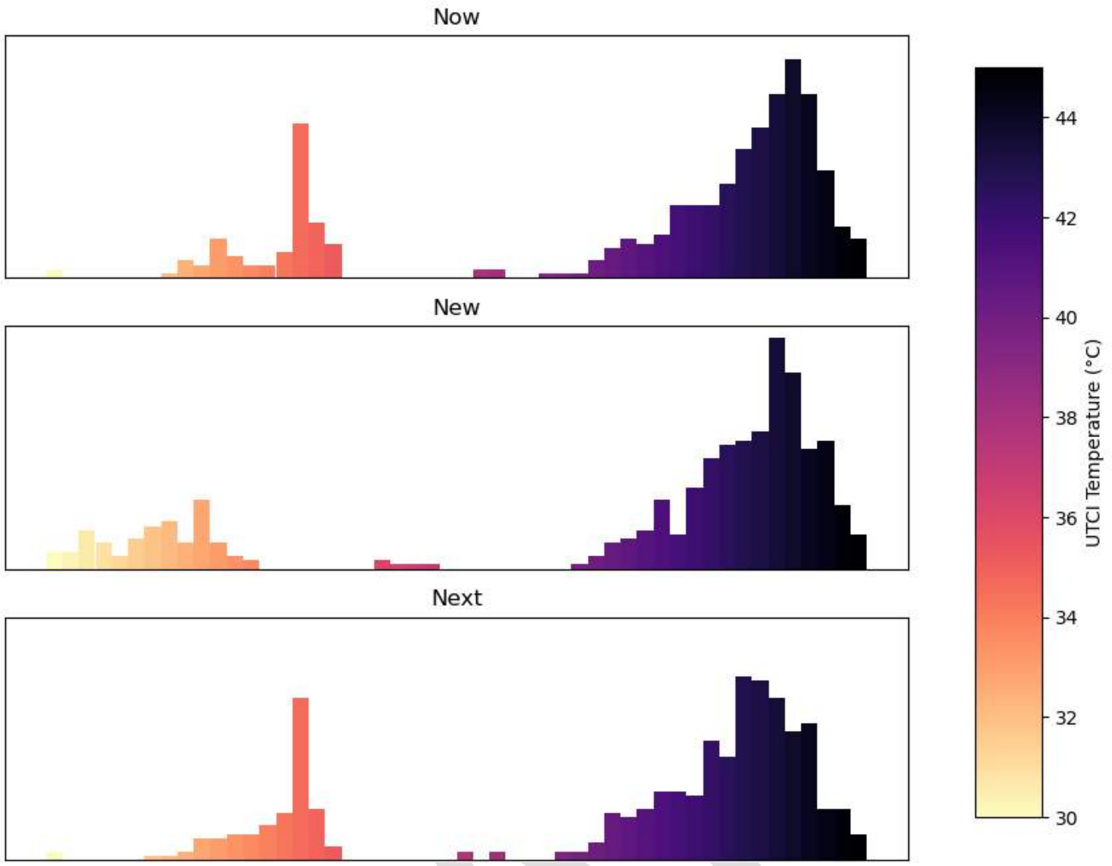


Figure 21: Scenario Temperature Distribution

3.4 Multi-criteria performance assessment

An overall comparison of performance across all the scenarios is shown in Figure 22, with the associated performance ranges and ratings summarised in Table 5: Performance ranges and ratings. Essentially, the larger the envelope the better the performance. This figure shows that the NEXT scenario, with rainwater harvesting and reduction in impervious fraction, can deliver higher dwelling yields, whilst also providing cooler temperatures.

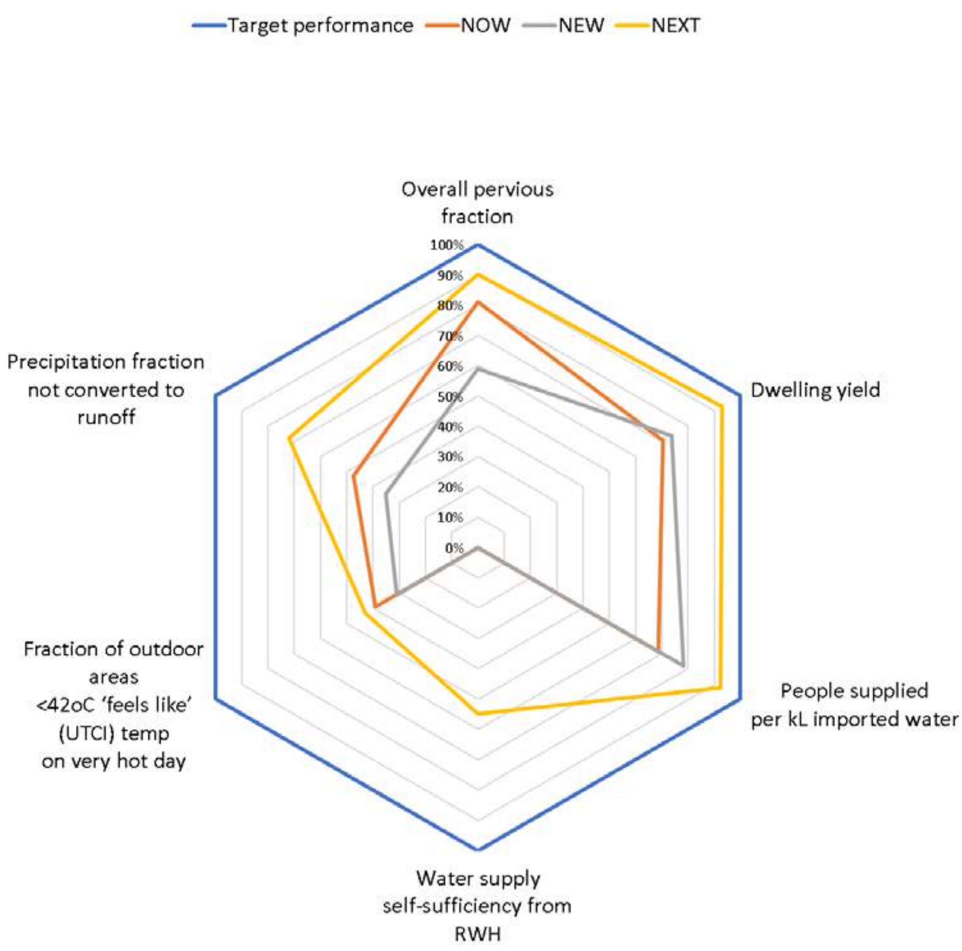


Figure 22: Overall Performance comparison across multiple performance criteria

Table 5: Performance ranges and ratings

	Performance range		Performance rating		
	Bad	Good	Now	NEW	NEXT
Precipitation fraction not converted to runoff	0.0	0.75	0.36	0.26	0.54
People supplied per kL imported water	0.0	8.0	5.5	6.3	7.4
Water supply self-sufficiency from RWH	0	0.1	0	0	0.03
Dwelling yield	0	0.00	564	591	744
Overall pervious fraction	0.00	0.60	0.49	0.35	0.54
Fraction of outdoor areas <42o^{C} 'feels like' (UTCI) temp on very hot day	0	100	39	31	43

4.0 Discussion

Based on this analysis in Norman Creek, it is evident that the water-related impacts of infill development are significant. Alternative and water sensitive designs can lead to considerable influence on runoff, infiltration, evapotranspiration, urban heat and other beneficial changes. This case study demonstrated that it is possible to provide housing for additional (beyond target) population growth, while simultaneously mitigating existing previous negative consequences of relatively unplanned (hydrologically) development. Specifically, it showed that, if implemented to their full extent in the NEXT scenario, the water sensitive design principles could significantly increase the population to around 1,900 of the 9.6ha precinct, whilst also restoring the annual volumes of WS discharge to only twenty percent higher than the pre-developed state.

With the combined use of rainwater and mains water in NEXT scenario, it could provide irrigation-supported with rainwater tanks in the study area and improve on imported water use efficiency to 135L/person/day.

In the existing case, 61% of the study area exhibits temperatures above 42ºC (Universal Thermal Comfort Index) on a high stress heat day. With the NEW scenario, this would increase to 69%, whereas the new typologies in the NEXT scenario could reduce this to 57%.

This work provides a foundation around which future performance objectives and targets (e.g. for hydrological performance or infill self-sufficiency of supply) could be considered for the Greenslopes development area. It must be noted that performance can be strongly influenced by annual shifts in rainfall, as well as local conditions, such as soil types and consistencies.

The work also provides a significant foundation from which a more quantified business case for water sensitive outcomes can be achieved from new development designs and typologies. As an example, the impact on water supply, wastewater flow, flooding, building costs and air conditioning could be quantified from the designs presented in this report.

5.0 References

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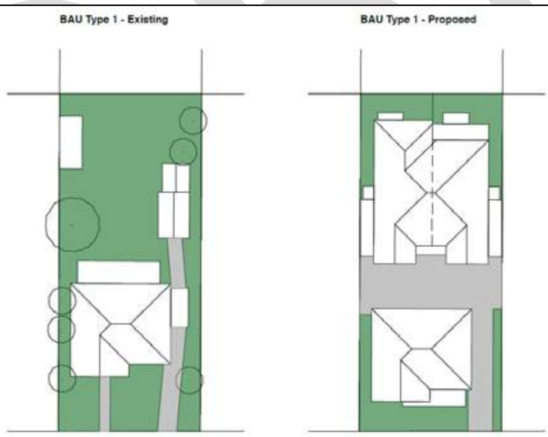
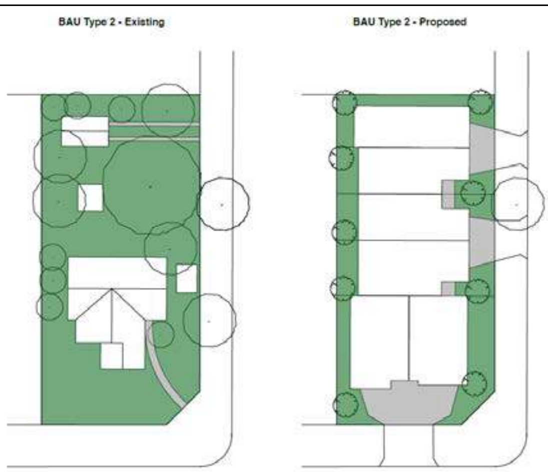
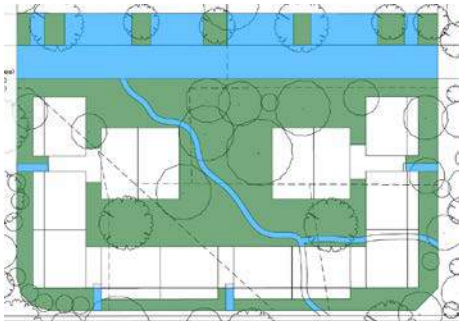
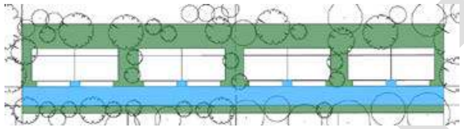
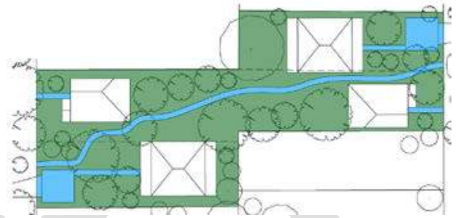
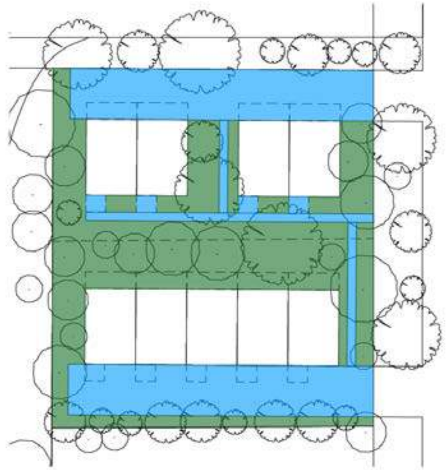
Appendix A: New/ BAU Scenario

	BAU1		BAU2	
				
	Existing	**Proposed**	**Existing**	**Proposed**
Roof	31	58	25	66
Garden	62	22	72	21
Concrete	7	20	3	13

Appendix B: WSC Scenario Typologies

	WS-A	WS-B1	WS-B2	WS-C
				
Roof	37	34	23	30
Garden	43	44	65	38
Permeable Paving	20	22	12	32

Appendix C: Stage 2

Background

In June 2020 a study was presented that assessed water sensitive outcomes for infill development (BCC,2020). This study was conducted as a collaboration between Brisbane City Council and the Cooperative Research Centre for Water Sensitive Cities IRP4 project - *Water Sensitive Outcomes for Infill Development*. The key objective of IRP4 was to develop a performance evaluation framework to understand and quantify the impacts of residential densification (infill) on water and urban heat.

This work used the Norman Creek catchment as a pilot study area and investigated different development methods, in order to minimise impact of infill development on the environment. As part of the project, an existing *Infill Performance Evaluation Framework* (Renouf *et al*., 2020) was developed and applied to a selection of case studies.

The work showed that alternative and water sensitive designs can lead to considerable influence on runoff, infiltration, evapotranspiration, urban heat and other beneficial changes. This case study demonstrated that it is possible to provide housing for additional (beyond target) population growth, while simultaneously mitigating existing previous negative consequences of relatively unplanned (hydrologically) development.

Following the initial iteration of this work a number of modifications and improvements were made to the underlying assumptions and datasets and a new package of work was undertaken to incorporate these changes. This report is an addendum to the previous study and outlines the changes from the original work and presents the final results based on the latest iteration.

Method overview

Again, the performance of alternative infill scenarios for the study area were evaluated using the approach described in the Infill Performance Evaluation Framework (Renouf et al., 2020).

Steps followed were:

1. Creation of site-plans for dwelling typologies that represent the existing (EXG) case, the business-as-usual (BAU) infill case and alternative water sensitive (WS) infill cases. Design parameters are defined for each. It is worth noting that these scenarios were previously documented as NOW, NEW and NEXT.

2. Creation of precinct-plans for various development scenarios in the study area, including the existing (EXG) development case (as at 2019), expected infill development under business-as-usual (BAU) conditions, and alternative infill development scenarios based on water sensitive (WS) city principles. Land uses within the study area under each development scenario were categorised into land use clusters (residential, vacant land, streets, etc.).

3. Definition of water servicing assumptions for each development scenario.

4. Evaluation of the following aspects for each of the development scenarios described below

- o Urban water flows were estimated for each development scenario using the Scenario Platform developed by Tool And Products (TAP), (CRCWSC 2020). Previous iterations of the water cycle modelling were undertaken using Aquacycle model (Mitchell *et al*., 2001)

- o Urban heat of the case study area under each development scenario was modelled using the Scenario Platform developed by Tool And Products (TAP), (CRCWSC 2020).

- o Architectural and urban space qualities of each development scenario were developed by Monash University Architecture.

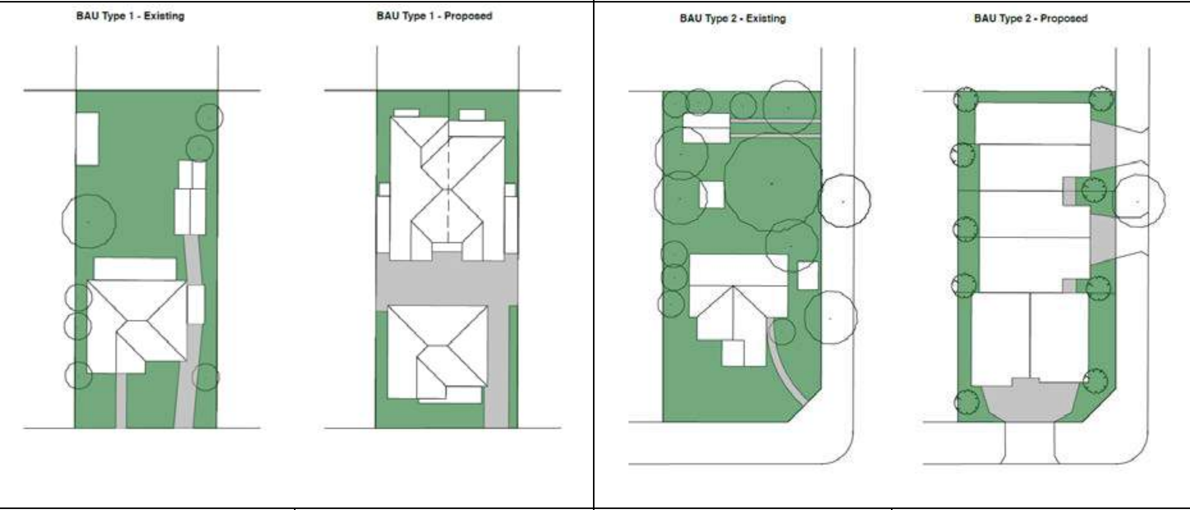
5. Generation of multiple performance indicators to rate and compare the performance of the BAU and WS infill scenarios against the EXG case.

Precinct-Scale infill scenarios

Business as Usual

Land use allocations provided by Monash for the business as usual (BAU) typologies are presented below in Table 6 along with the land use allocation distributions for each typology. Two typologies were developed based on two typical examples of how infill development is currently occurring within the Norman Creek catchment.

Table 6: Monash Percentage Allocations (BAU)

	BAU1		BAU2	
				
	Existing	**Proposed**	**Existing**	**Proposed**
Roof	31	58	25	66
Garden	62	22	72	21
Concrete	7	20	3	13

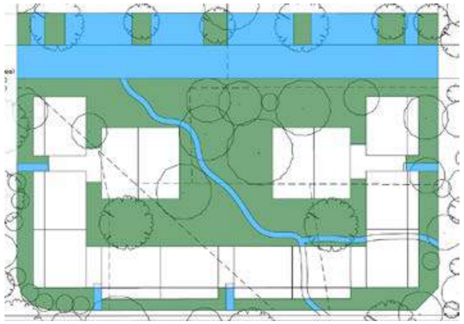
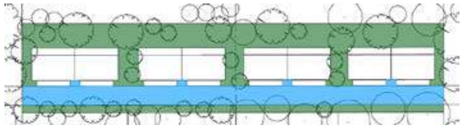
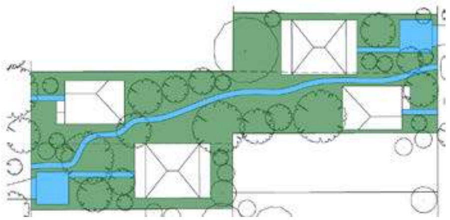
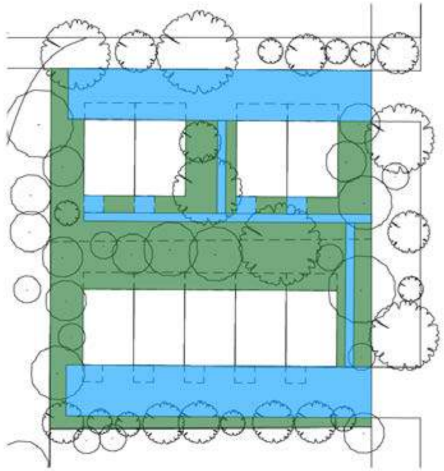
These two example typologies were spatially assigned across the entire Norman Creek catchment based on the existing lot size. This distribution is presented in Figure 23.

Figure 23: BAU Design Typology Distributions

Water Sensitive

Land use allocations provided by Monash for four water sensitive (WS) typologies are presented below in Table 7 along with the land use allocation distributions for each typology.

Table 7: Monash Percentage Allocations (WS)

	WS-A	WS-B1	WS-B2	WS-C
				
Roof	37	34	23	30
Garden	43	44	65	38
Permeable Paving	20	22	12	32

These four typologies were spatially assigned across the entire Norman Creek catchment based on the existing lot size. This distribution is presented in Figure 24.

Figure 24: WS Design Typology Distribution

Catchment Scale Land Use Change

The catchment wide land use changes are presented below in Figure 25. These naming conventions vary slightly from those provided by Monash as the CRC scenario tool uses a different classification system. The assumptions around translating one to the other is detailed further in Section 0. The change in population across scenarios is presented in Figure 26.

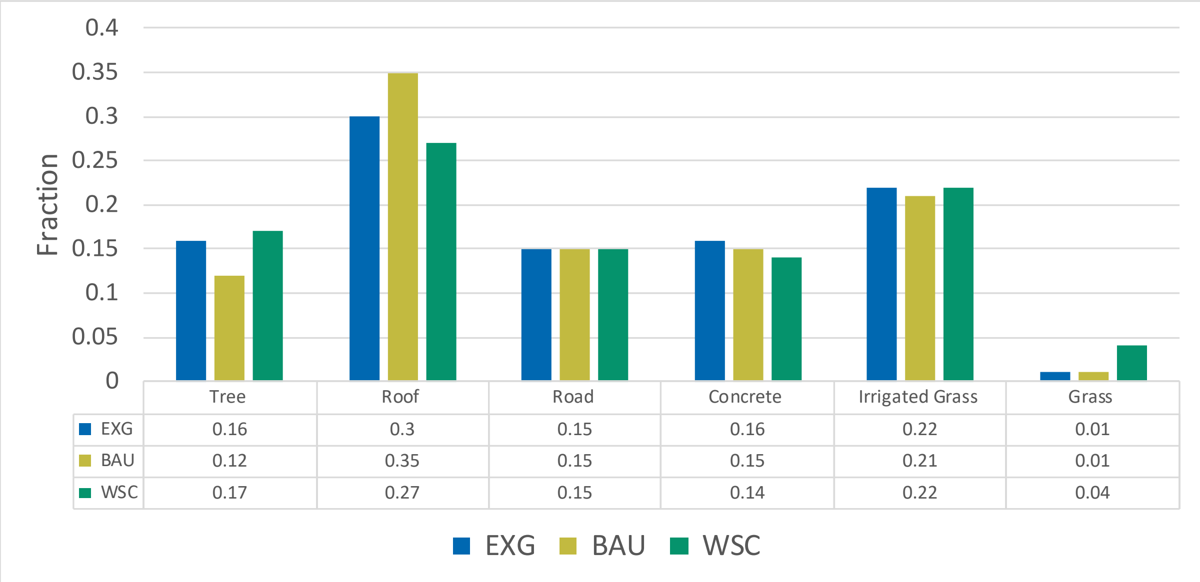


Figure 25: Catchment Scale Land Use Change

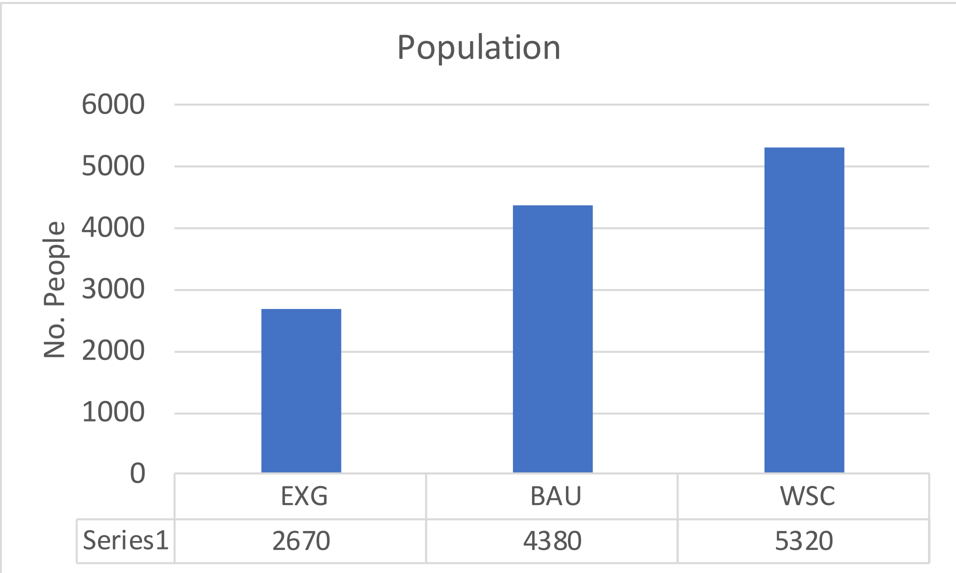


Figure 26: Change in Population

Modelling Approach

CRC Scenario Tool

For both the urban heat and water cycle components the CRC Scenario Tool was utilised. Currently the Scenario Tool is capable of simulating:

- Land Surface Temperature;
- TARGET (The Air-temperature Response to Green/blue infrastructure Evaluation Tool;
- Universal Thermal Climate Index (UCTI), and;
- Urban Water Cycle.

These modules perform evaluations based on a range of underlying datasets. The Scenario Tool uses Geoscape digital datasets as a default providing information on buildings, surface cover and tree cover. The Scenario Tool also includes a number of workflow nodes, which enable the user to make changes to the urban form of a given area or include green infrastructure. Scenarios can then be simulated and used to assess changes against a baseline.

Scenarios

For both urban heat and water cycle a total of four scenarios were simulated. Both modules included an existing, business as usual and water sensitive scenario. An additional scenario was simulated using the urban heat module that looked at the impacts of green streets and an additional water cycle scenario was investigated looking at the creation of additional storages. Both these additional scenarios for the water cycle and urban heat components are described further in Section 0 and 0 respectively.

Land Use Allocations

Land uses within the scenario tool are differentiated slightly differently to the land uses provided by Monash. The scenario tool uses tree, roof, road, concrete, irrigated grass, grass and water fractions. The tool also uses a 20m x 20m grid resolution which leads to some of the finer grain detail being lost when spatial data is imported into the tool. Previous iterations of this modelling had resulted in some anomalies in results due to this loss of detail causing inconsistencies between scenarios. For example, an assessment of the lots within the scenario tool indicates that there is a fraction of road included in the land parcels that is not represented in the land use fractions provided by Monash.

To best mitigate the impacts of these inconsistencies the parcels for both BAU and WS were imported into the scenario tool and an assessment of the existing land use as defined by the scenario tool was extracted for comparison against what Monash had determined to be the existing land use. It is worth noting that Monash used a set of examples lots whilst the scenario tool would extract data for all lots across the catchment. Once the existing land use were extracted from the scenario tool the proposed BAU and WS land use fractions were adjusted to ensure consistency. The outcomes and assumptions for each future scenario are included in the following sections.

Business as Usual

These are presented below in Table 8 along with the adjusted expectant land fractions. The adjustments from those distributions presented above are to preserve fraction of land use not represented by the Monash typologies. This largely relates to the fraction of roads which is captured by the scenario tool platform within the parcels. The following assumptions are made translating Monash percentages for use in the scenario tool:

- The road fraction remains constant between existing and BAU. This will illuminate the issues caused by roads when outputting the UTCI values seen in previous modelling.
- Roof and concrete fractions are allocated based on an adjusted percentage which is lost to roads. For example, 9% of proposed BAU 1 is roads, so the roof fraction in Monash’s values is 91% of the value previously presented.
- Tree fraction is assigned as a percentage of the available garden fraction based on what is presented in the drawings provided.
- The remaining garden fraction available is distributed between Irrigated Grass and Grass based on the existing distribution.

Table 8: Scenario Tool Percentage Allocations (Business as Usual)

	Tree	Roof	Road	Concrete	Irrigated Grass	Grass
BAU 1	18	42	9	15	15	1

BAU 1 Proposed	0	52.78	9	18.2	18.77	1.25
BAU 2	12	46	10	18	11	3
BAU 2 Proposed	4.2	59.4	10	11.7	11.55	3.15

Water Sensitive

Similarly, to BAU, the WS typologies were representative of a single lot that was then adopted across the catchment. The proposed lots were again ported into the scenario tool to extract the representative existing case for these lots so that the WS scenarios could be accurately represented. For the proposed scenario the following assumptions are made:

- The road fraction remains constant between existing and BAU. This will illuminate the issues caused by roads when outputting the UTCI values seen in previous modelling.

- Roof fractions are allocated based on an adjusted percentage which is lost to roads. For example, 8% of proposed WS-A is roads, so the roof fraction assigned in the scenario tool is 92% of the value provided by Monash.

- The garden fraction provided by Monash is split evenly between irrigated grass and trees. This seems fitting with what is presented in the drawings.

- The permeable paving fraction provide my Monash is split evenly between concrete and grass fractions.

Table 9: Scenario Tool Percentage Allocations (Water Sensitive)

	Tree	Roof	Road	Concrete	Irrigated Grass	Grass
WS A Existing	12	47	8	17	13	3
WS A Proposed	19.78	34.04	8	9.2	19.78	9.2
WS B1 Existing	15	42	12	18	13	0
WS B1 Proposed	19.36	29.92	12	9.68	19.36	9.68
WS B2 Existing	14	39	13	17	16	1
WS B2 Proposed	28.28	20.01	13	5.22	28.28	5.22
WS C Existing	17	46	9	14	13	1

Modelling Urban Water Cycle

The urban water flows were simulated using the water cycle model made available in the CRC scenario tool. The water cycle model serves to detail the flow of water in and out of a specified system ,in the case the Norman Creek catchment. The model accounts for all inputs, outputs and what is retained in the system through the principle of mass conservation. The model adopts a conceptual modelling framework similar to that used by MUSIC (eWater, 2012) and Aquacycle (which was used for previous iterations of this modelling).

The model functions at both a lot and sub-catchment scale and routes lot scale to sub-catchment scale on a daily timestep, using 24-hour data inputs (rainfall and evapotranspiration). The model allows for a specified timeframe to be adopted and as such a period representative of annual average rainfall was adopted (calendar year 1989 ~1070mm). The lot scale schematic is presented in Figure

27 with further detail documented on the scenario tool web page (CRC, 2020). The sub-catchment scale simply combines streams of several lots to a catchment.

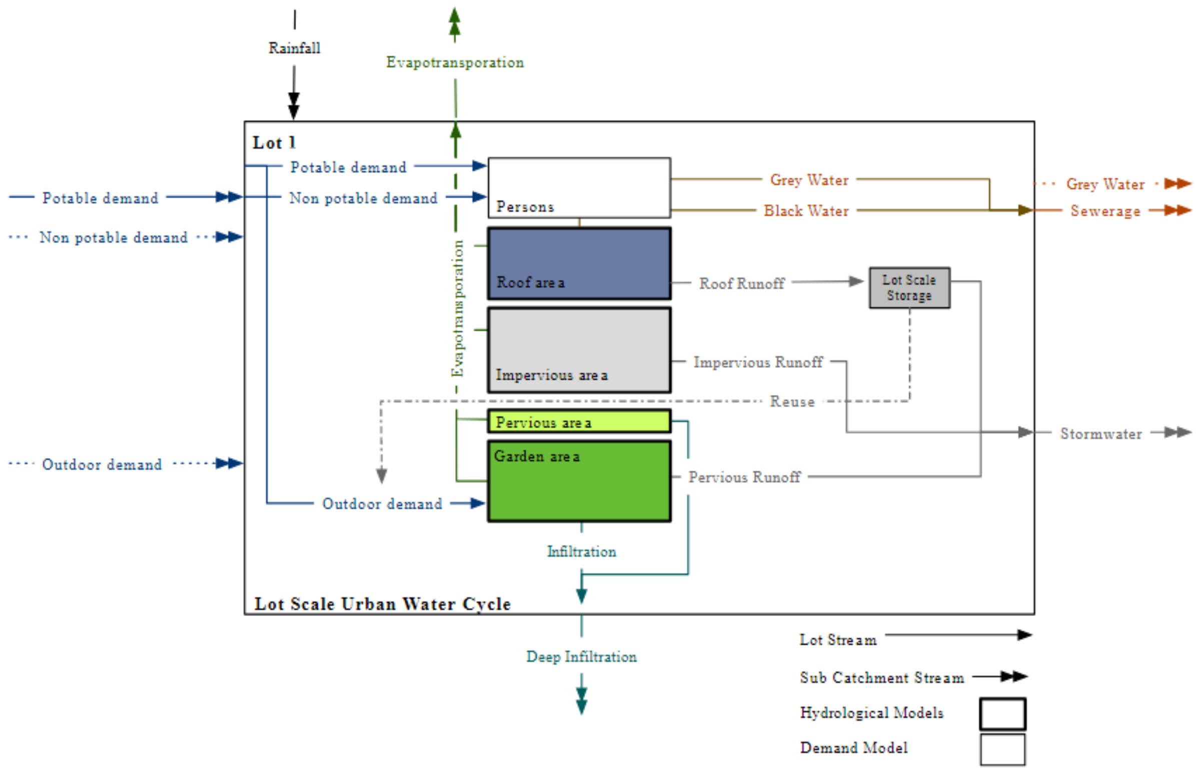


Figure 27: Lot Scale Urban Water Cycle Schematic

Scenarios

Similarly, to urban heat, the EXG, BAU and WS scenarios were simulated that represented the land use changes and the changes in population. The green streets scenario was also simulated as well as a scenario that look at storages for each new dwelling. The assumption made was that each new dwelling would include an additional 10kL of storage.

Modelling Urban Heat

Scenarios

For simulating urban heat, a total of four scenarios were simulated. The EXG, BAU and WS scenarios were simulated using the change in land use fractions as previously described. An additional scenario was simulated looking at introducing a number of green streets. The green streets created are presented below in Figure 28: Green Streets Scenario

. The landcover fractions were adjusted for this yellow parcel based on similar works undertaken in Salisbury. The fraction of road was reduced by 50% that was allocated to tree cover, similarly the fraction of concrete was reduced by 40% and allocated to irrigated grass.

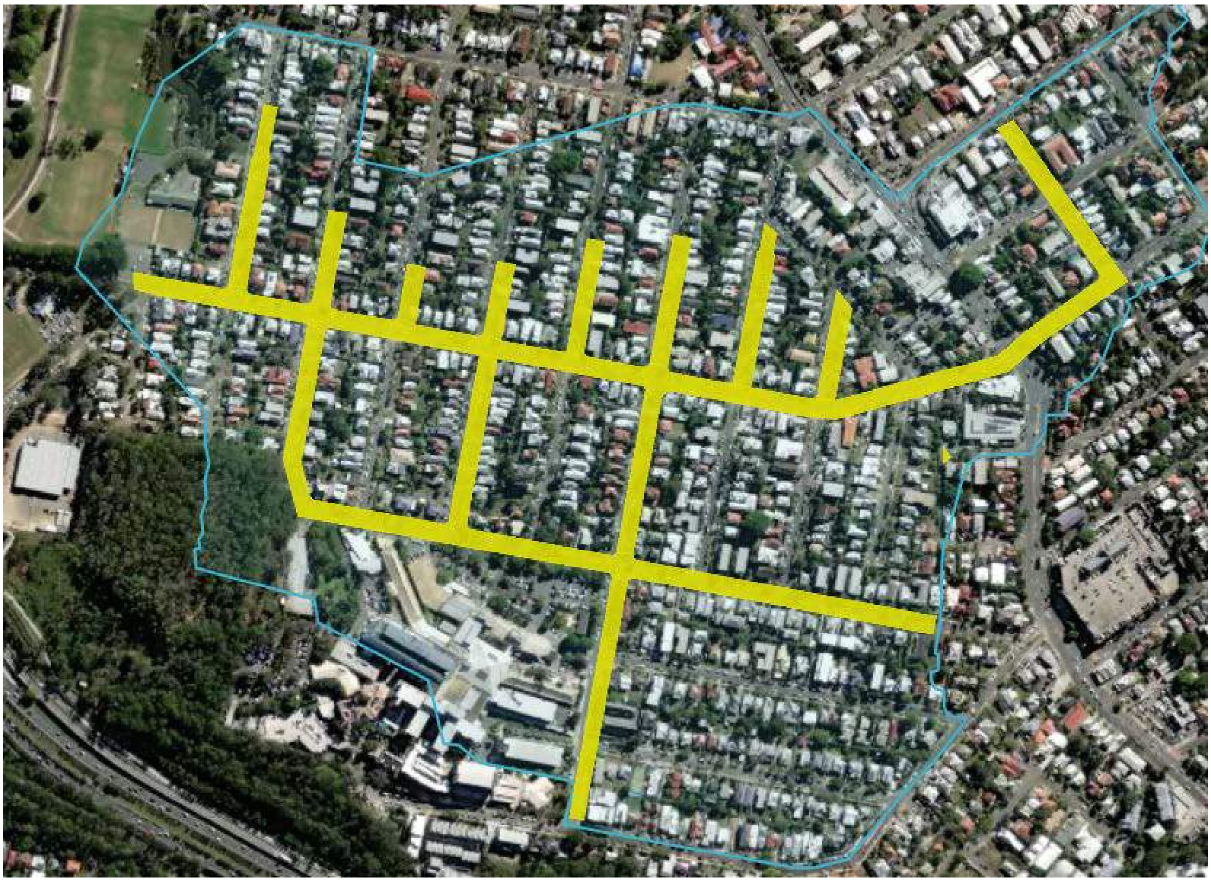


Figure 28: Green Streets Scenario

Whole of Catchment (Scenario Tool)

For comparison, the whole of catchment impervious fractions were extracted from the scenario tool. These are presented in Table 10.

Table 10: Whole of Catchment Land Use Values

Category	Tree	Roof	Road	Concrete	Irrigated Grass	Grass
EXG	0.16	0.3	0.15	0.16	0.22	0.01
BAU	0.12	0.35	0.15	0.15	0.21	0.01
WSC	0.17	0.27	0.15	0.14	0.22	0.04
WSC-Green Streets	0.2	0.27	0.12	0.12	0.24	0.04

Performance Evaluation

Urban Heat

The results for both ambient and land surface temperature are presented below in Table 11.

Table 11: Ambient and LST

Scenario	Ambient Temperature	LST
EXG	39.15	50.3
BAU	39.37	51.4

WSC	39.11	50
WSC-Green Streets	38.99	49.2

UTCI

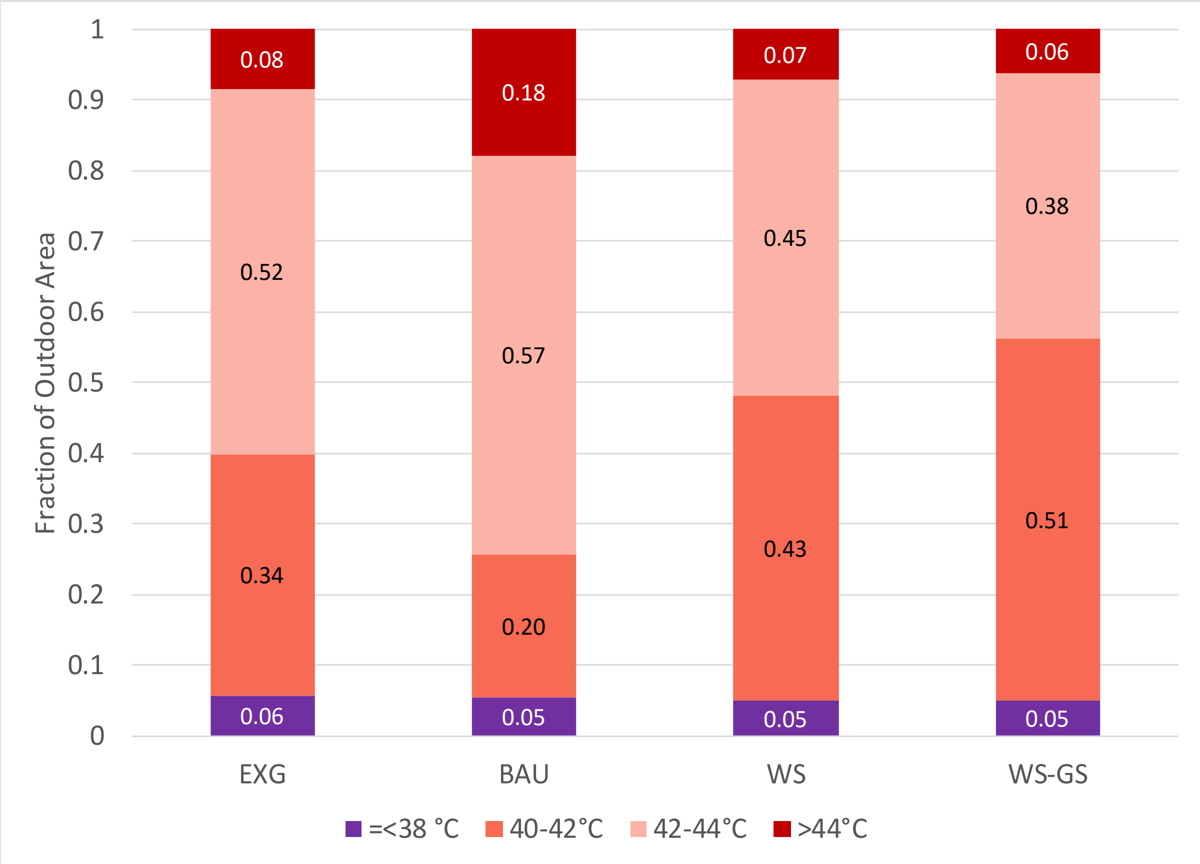


Figure 29: UTCI

Water Cycle

To ensure there were no vast disparities in results between the scenario tool and those previously presented using Aquacycle a scenario was established within the scenario tool for comparison. This scenario adopted a similar 13ha area to that used in the previous iteration of the study. The results from this comparison are presented in Figure 30. It is worth noting that the Aquacycle model had used a 51% imperviousness whilst the assigned value in the scenario tool was 52.5%. The results compare quite favourably with the only notable difference being in the infiltration values. Regardless for the purposes of this relative assessment it is not of concern.

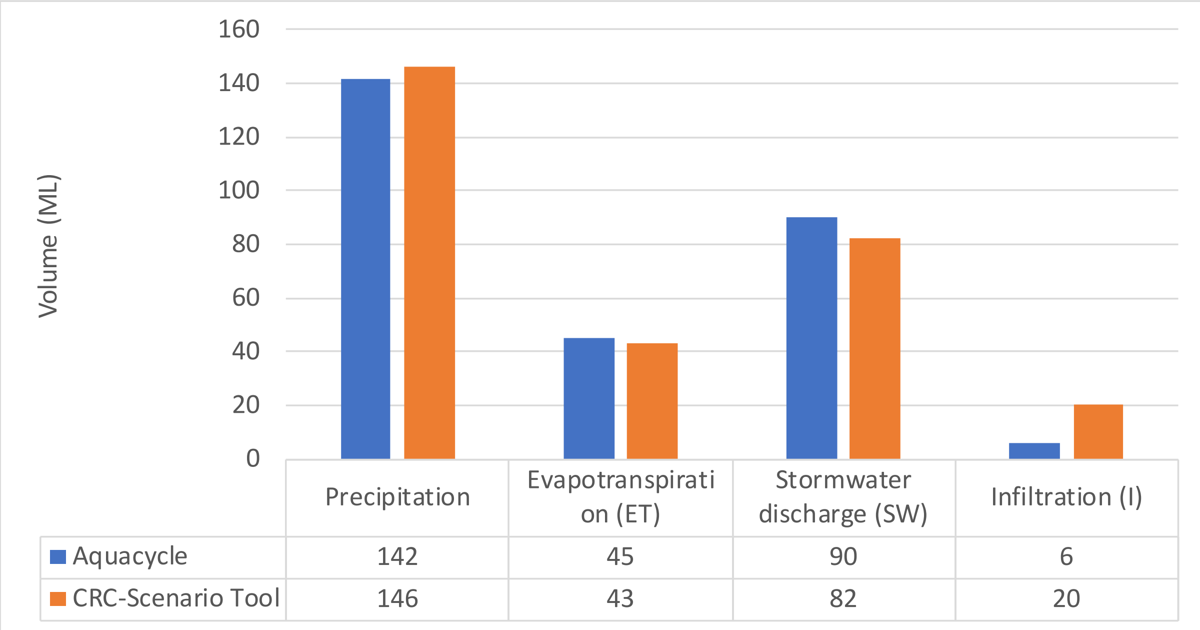


Figure 30: Aquacycle and CRC-Scenario Tool Comparison

Table 12: Water Cycle Results

Values in (ML)	Precipitation	Water Demand	Infiltration	Wastewater	Evapotranspiration	Run Off
EXG	830.4	142.1	93.1	58.6	267.6	526.2
BAU	832.7	202.5	83.2	149.4	256.4	546.2
WSC	832.6	234.1	104.4	176.3	278.5	507.5
WSC-Green Streets	832.6	234.1	115.8	176.3	287.6	487
WSC - Storage	832.6	184	104.4	176.3	278.5	371.9

Attachment C – Technical report on overland flow

Greenslopes Catchment Overland Flow Study

Water Sensitive Typology Assessment

March 2021

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Executive Summary

Natural Environment, Water and Sustainability (NEWS) has engaged City Projects Office (CPO) to undertake an overland flow investigation within the Greenslopes stormwater catchment (part of the Norman Creek catchment). This study is part of a larger project, with objectives being defined in collaboration with the Corporative Research Centre for Water Sensitive Cities (CRCWSC).

The broader project aims to explore the impacts of urban infill development typologies on catchment hydrology, resource efficiency, liveability and amenity. To achieve this, the project will assess the following:

1. Changes to overland flow within the catchment from the adoption of the infill typologies developed by Nigel Bertram (Infill Typologies);
2. A range of scenarios for Existing, future 'Business as Usual' and future 'Water Sensitive Cities';
3. Water Sensitive Cities (WSC) scenarios, including the Infill Typologies, along with other possible interventions like bio-basins, RWT, passively watered street trees, local detention storage and by-pass drainage (relief drainage); and
4. Results from each of the steps above to provide guidance for planning outcomes sought by Council in the future.

Study Objectives

Stage 1:

In the context of the overall project objectives defined above, the primary objectives of this overland flow study were as follows:

- To assess the future development (land-use intensification) as per current City Plan (BCC, 2014) guidelines, on overland flow flooding within the Greenslopes catchment, and,
- To assess the impact of developed 'Water Sensitive' typologies on overland flow flooding within the Greenslopes catchment.

Stage 2:

Following the completion of the Stage 1 works, several amendments were made to the underlying future development scenarios that were investigated during the first stage. These amendments included revised building footprints (and types), and the incorporation of catchment storage (i.e. residential storage tanks).

The methodology and results for Stage 2 works is presented in an Addendum report, included in Appendix G.

Note: The overall project objectives remained the same between Stage 1 and Stage 2.

Note:

Model Development

A hydrologic (XP-RAFTS) and hydraulic (TUFLOW) model were developed for this assessment. In the absence of historical catchment flood data, the XP-RAFTS model was suitably verified against the Rational Method (QUDM) and checked against TUFLOW model discharges.

Stage 1:

Three catchment scenarios were simulated in the models for a range of flood magnitudes, from 63% AEP to 0.05% AEP. The three scenarios were:

- **NOW Scenario** – Existing catchment conditions: Based on the current waterway conditions as at the year 2020 (hydrology and hydraulic models);
- **NEW Scenario** – Fully developed catchment conditions under current Brisbane City Council (BCC) City Plan guidelines (land use only): Based on fully developed land-use assumptions (hydrology model), with existing catchment building footprints (hydraulic model);
- **NEXT Scenario:** is characterized by the type of development envisaged in the urban design scenarios developed for this project and is the development that would satisfy the vision for a Water Sensitive City. From a hydrologic/hydraulic modelling perspective, this has been assessed as follows -
    - Existing catchment conditions (hydrology model), with new typology building footprints within the overland flow conveyance corridor (hydraulic model), as per Appendix A.

Two sensitivity scenarios were also analysed. The first scenario considered the effects on catchment flows from a 'dry' tailwater boundary (all Scenarios). The second scenario looked at inclusion of rainwater tank storage into the catchment (NEXT Scenario).

Results from the TUFLOW modelling were used to assess changes in flood depths, discharges, timing, flood hazard (depth x velocity product) and hazard safety classifications (AEMI Hazard Classification).

Stage 2:

As part of the Stage 2 works, four scenarios were simulated in the models for the 39% AEP and 2% AEP flood events. The scenarios are described as follows:

- **Now Scenario** – Same as the 'Now Scenario', as modelled as part of the Stage 1 works.
- **BAU Scenario** – 'Business as Usual' Scenario. Fully developed catchment conditions under current Brisbane City Council (BCC) City Plan guidelines (land use intensification only).

  Like the 'NEW' Scenario in the Stage 1 works, the hydrology model has been updated with increased catchment impervious fractions to represent the 'land-use intensification' of selected residential parcels within the catchment.

  The hydraulic model (in the 'BauOF' scenario – Refer Table 1 of the Addendum report) was also modified with the inclusion of larger 'BAU' Scenario building footprints for these selected parcels (as developed by Monash).
- **WS Scenario** – 'Water Sensitive' Scenario. This scenario is characterized by the type of development envisaged in the urban design scenarios developed for this project and is the development that satisfies the vision for a 'Water Sensitive City'.

  Specifically, this includes the following amendments to the study models:

  - Hydrology model: reduced catchment impervious fractions to simulate the smaller WS Scenario building footprints (developed by Monash), and,
  - Hydraulic model ('DevOF' scenario – Refer Table 1): Introduction of reduced building footprints (and change in building types) within the overland flow conveyance corridor to represent WS building typologies (developed by Monash), as per Appendix A.
- **WS Storage Scenario -** 'Water Sensitive' Scenario with additional flood storage (10 kL storage tank for collecting rainwater for each WS dwelling).

  This is the same as the 'WS' Scenario's but includes the introduction of additional storage (represented as an increased initial loss), in the WS Scenario hydrology model.

Model Results

Stage 1:

Flood Depths

<u>NOW Scenario</u>

The existing stormwater drainage network within the catchment is undersized. In certain sections, the network is incapable of fully containing 39% AEP storm event flows, with excess floodwaters surcharging the network in these areas and beginning to flow overland. Overland flow depths in this event are mostly in the range of 10 – 100mm. In the 10% AEP event, the majority of the pipe network runs full, with overland flow depths in the typical range of 50 - 500mm (varying considerably across the catchment, with higher depths in localised areas). In the 2% AEP event, overland flow flood depths are generally in the range of 100 – 800mm, with higher depths in localised areas.

Note that these depths are taken from a hydraulic model that has not been calibrated (due to lack of historical flood data).

<u>NEW Scenario</u>

There is a general minor increase in depths (compared to NOW Scenario) across the catchment, for all AEP events analysed. Depth increases are generally within the range of 0 – 40 mm, with some isolated areas of higher increases. This is primarily due to higher peak discharges in the NOW Scenario, from an increase in catchment imperviousness resulting from development intensification.

<u>NEXT Scenario</u>

Minor increases in depths across most roads (between 0 – 100mm at the reporting locations in all AEPs analysed) are observed compared to the NOW Scenario. The exception to this is at Cedar Street and Denman Street, along the southern branch of the stormwater network (Locations 10 and 11), where moderate reductions in depths [up to 150mm (10% AEP) to 260 mm (0.5% AEP)] are observed.

Minor to moderate decreases in depths are observed across most 'open undercroft' residential lots within the overland flow path at the reporting locations analysed, with larger decreases in the vicinity of 30 Newdegate Street (40 – 450 mm decrease) and 85 Cedar Street (190 – 500mm decrease). Minor to moderate increases in flood depths are observed at several residential lots, mainly where the new building footprints in the NEXT Scenario create a barrier to floodwaters, or where buildings that create a blockage to flow are located directly downstream of 'open undercroft' buildings.

Flood Hazard

<u>NEW Scenario</u>

There is a general minor increase in flood hazard (depth x velocity product) in the NEW Scenario (compared to NOW Scenario) throughout the catchment. This is primarily due to minor increases in catchment imperviousness in the NEW Scenario, which result in marginally higher catchment peak discharges, depths and velocities. For all AEPs analysed, hazard increases are generally within the range of 0 – 0.1 m^2/s, with some isolated areas of up to 0.2 m^2/s observed in larger events (2% and 0.5% AEPs).

However, these flood hazard increases are relatively minor, compared to absolute hazard values in the NOW Scenario. As such, there are only minimal differences in flow hazard category (AEMI) mapping when comparing NOW and NEW Scenarios.

<u>NEXT Scenario</u>

Both minor to moderate decreases and increases in flood hazard (depth x velocity product) are observed throughout the catchment in the NEXT Scenario, compared to the NOW Scenario. Variability in flood hazard may be due to the apparent ‘straightening’ and ‘widening’ of the flowpaths (and lowering of average Manning’s n roughness) through residential lots in the NEXT Scenario, resulting in a higher concentration of flows, compared to the more braided nature of floodwaters (due to more blockages) in certain sections of the NOW Scenario catchment.

Flood hazard is typically higher in the NEXT Scenario in locations where flows are higher (i.e. - downstream areas) and more concentrated, where Manning’s n ground level roughness is lower, and where flows have been re-directed. Conversely, flood hazard is typically lower in the NEXT Scenario at locations where flows were previously highly constricted in the NOW Scenario (i.e. - between existing building blockages), and sometimes along existing flow paths that have subsequently been re-directed in the NEXT Scenario.

Flood Hazard Categories (AEMI Hazard Classification)

NEXT Scenario

For the 39% AEP event, flood hazard along the overland flow paths is similar between NOW and NEXT Scenarios. Hazard is generally in the lowest H1 category (safe for buildings, people and vehicles), with isolated pockets of higher category H2 hazard (unsafe for small vehicles).

For the 10% AEP event, higher hazard areas affecting vehicles, children and the elderly (H2 and H3 hazards) are ‘dampened’ out (i.e. – slightly lowered) in the upper catchment areas (compared to the NOW Scenario). Conversely, there are increases in higher hazard areas in the NEXT Scenario affecting all people and some buildings (H3-H5 hazards) in the lower catchment from Bunya Street to Pear Street.

The 2% AEP event comparison was similar to the 10% AEP event, with an exception being that there are now observed increases in the NEXT Scenario in higher hazard areas. These increases are affecting all people and some buildings (H3-H5 hazards) in the southern branch of the stormwater network (upper catchment) from Cedar Street to Ridge Street.

Flood Timing/Peak Discharge

Time to flood peak is marginally shorter (typically within 0-2 minutes) and overland flow peak discharge marginally higher (typically within 0-10%) in the NEW Scenario compared to the NOW scenario.

The NEXT Scenario is more hydraulically efficient than the NOW and NEW Scenarios, as it includes less floodplain blockage and generally lower Manning’s n roughness. This is reflected in reductions in time to flood peak (compared to the NOW Scenario) of 1.5 – 5.5 minutes and peak discharge increases between 10% and 60%, depending on location.

Sensitivity Testing

Two sensitivity scenarios were analysed in the hydrology and hydraulic models, as follows:

- Tailwater Boundary set to downstream wetland level; and
- Inclusion of rainwater tank storage, limited to the assumptions outlined in Section 5.6.2.

Lowering the tailwater level to the downstream wetland level reduced backwater effects in the downstream catchment between Bunya Street and the stormwater network outlet. Flood depths in the lower catchment were; therefore, observed to be more sensitive to changes in overland flow discharges in the NEW and NEXT Scenarios, compared to the simulations with a Norman Creek coincident flood tailwater level.

Inclusion of rainwater tank storage in the NEXT Scenario [equivalent of up to 1,826 m^3 volume removed from the TUFLOW model (depending on AEP)] resulted in a reduction in peak discharges across the catchment (compared to the NEXT Scenario with no storage included). At select key locations within the catchment, peak discharges in the NEXT Scenario were now generally similar or lower (compared to the NOW Scenario) for events up to the 10% AEP event. However, due to project time/budget limitations, it is noted that this sensitivity assessment is considered a rough estimation of catchment storage effects only, so it is recommended to develop a more detailed hydrology/hydraulic model for sizing/locating storage areas.

Potential Future Work

Based on the outcomes of this investigation and, in the context of the objectives of the overall project, the following recommendations are made for future work:

- Extend the scope of the NEW and NEXT Scenarios to the whole catchment and assess impacts to catchment hydrology/hydraulics. Changes made in these Scenarios (compared to the NOW Scenario) have only been applied within the main overland flow paths in this study;
- NEXT Scenario design refinement of building location/building type to alleviate areas of high blockage;
- Assess the impacts of inclusion of proposed relief drainage into the hydraulic model, on all Scenario results; and
- Refine the hydrology and/or hydraulic models to be fit-for-purpose for analysing a detailed 'rainwater tank' flood storage Scenario. The storage sensitivity scenario undertaken in this assessment is broad-based and is to be referenced as a guide only.

Stage 2:

Area of Inundation Comparison

The largest reduction in inundated area is observed in the WS scenario with WS typology building footprints/types (9.5% area reduction compared to the NOW Scenario). Inclusion of flood storage reduces the area of inundation by an additional approximate 1.8-2.6% (compared to the corresponding WS_ExOF and WS_DevOF scenarios without flood storage).

The largest increase in inundated area is observed in the BAU scenario with BAU typology building footprints/types (9.8% area increase compared to the NOW Scenario).

Flood Depths

A comparison of flood depth differences between scenarios indicates the following:

Catchment impervious changes

- *BAU_ExOF vs WS_ExOF*
- *BAU_ExOF vs NOW*

Minor decreases in catchment perviousness (BAU) results in slight increases in flood depths (~10-50mm) catchment wide. Localised increases greater than 50mm are also observed, particularly in the 39% AEP scenario.

- *WS_ExOF vs NOW*

Minor increases in catchment perviousness (WS Scenario) results in slight decreases in flood depths (~ 10-50mm) catchment wide. Localised decreases greater than 50mm are also observed, particularly in the 39% AEP scenario.

Catchment impervious changes plus changes to building footprint/type

BAU_BauOF vs WS_DevOF, BAU_BauOF vs WS_ExOF, BAU_BauOF vs BAU_ExOF, BAU_BauOF vs NOW, WS_DevOF vs NOW

The above comparisons show a mix of flood depth increases and decreases (in some areas over 0.5m increase/decrease). The larger differences appear to be less influenced by the minor catchment perviousness changes and are more to do with the change in building footprints/types, which causes localised changes in flood depths and velocities.

The Bau_BauOF Scenario (inclusive of intensified/larger footprints and increased imperviousness) was observed to create the highest flood depth increases on average compared to other scenarios.

The WS_DevOF Scenario (inclusive of smaller footprints and reduced imperviousness) generally resulted in flood level decreases throughout the catchment (compared to the NOW scenario). However, some larger flood level increases were observed in localised areas (typically around building footprint changes).

<u>Catchment impervious reduction and inclusion of storage</u>

- *WS_10kl_ExOF vs NOW*

Minor increases in catchment perviousness and inclusion of rainwater tank storage for over half of buildings within the catchment resulted in a general decrease in flood depths of between 10-200mm catchment wide.

<u>Catchment impervious reduction, inclusion of storage plus, and changes to building footprint/type</u>

- *WS_10kl_DevOF vs NOW*

Minor increases in catchment perviousness, inclusion of rainwater tank storage for over half of buildings within the catchment, and inclusion of smaller/modified building footprints in the overland flow path resulted in:

- an overall decrease (on average) of flood depths within the catchment. Depth decreases were generally in the range of 10-500mm
- some localised flood depth increases, generally in the range of 10-200mm.

Some flood level increases and decreases are localised and can be attributed to the change in building footprint areas/types, as described in the above section.

Flood Hazard/Hazard Classification

Result observations are typically in line with the depth comparison results described above. That is:

- Small decreases in catchment imperviousness slightly reduces hazard
- Small increases in catchment imperviousness slightly increases hazard
- Changing building types/footprints in the overland flow path can result in considerable localised increases/decreases in flood hazard
- Inclusion of flood storage (depending on volume) can go some way towards mitigating localised increases in flood depths/hazard

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Adopted Average Recurrence Interval (ARI) to AEP Conversion

The recently updated Australian Rainfall and Runoff 2016 edition (ARR 2016) utilises different terminology whereby, for the larger flood magnitudes, the term Annual Exceedance Probability (AEP) (%) is now preferred to Annual Recurrence Interval (ARI). Relationship between ARI and AEP can be expressed by the following equation:

AEP = 1 – exp (-1 / ARI)

Refer to Table 1-1 for ARI to AEP conversion for all events.

Table 1-1: ARI to AEP conversion

ARI (years)	Actual AEP (%)
1	63
1.4	50
2	39(1)
4.5	20
5	18(1)
10	10
20	5
50	2
100	1
200	0.5

List of Abbreviations

Abbreviation	Definition
1D	One dimensional, in the context of hydraulic modelling
2D	Two dimensional, in the context of hydraulic modelling
AEMI	Australian Emergency Management Institute
AEP	Annual Exceedance Probability
ALS	Airborne Laser Scanning
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
BCC	Brisbane City Council
BOM	Bureau of Meteorology
CRCWSC	Corporative Research Centre Water Sensitive Cities
DEM	Digital Elevation Model
FM	Flood Management
GIS	Geographic Information System
Ha	Hectares
IFD	Intensity Frequency Duration
LGA	Local government area
m AHD	metres above Australian Height Datum
NEWS	Natural Environment, Water and Sustainability
QUDM	Queensland Urban Drainage Manual (2016)
RM	Rational Method
RWT	Rainwater Tank
TOC	Time of Concentration
WMB	Water Mass Balance
WS	Water Sensitive

1.0 Introduction

1.1 Catchment Location

Greenslopes catchment is situated within the larger Norman Creek Catchment and is located approximately 5 kilometres (km) south of the Brisbane Central Business District (CBD). The catchment area is approximately 0.73 km^2 and is predominantly comprised of low to medium residential lots, with some commercial properties located in the upper catchment along Logan Road.

When the underground catchment stormwater network surcharges, floodwaters traverse overland and concentrate along two main upper catchment branches, before forming a single branch at Bunya Street. The stormwater network and overland flow then discharges into a wetland/basin downstream of Pear Street, where basin overflows traverse into Norman Creek.

Figure 1-1 shows the location of the catchment.

1.2 Study Background

Water is integral to almost every feature of an urban landscape. Our cities and towns are complex, ever evolving places and the way we interact with other people constantly changes. In a water sensitive city, the community interacts with the urban water (hydrological) cycle in ways that:

- provide the water security essential for economic prosperity through efficient use of diverse available resources;
- enhance and protect the health of waterways and wetlands, the river basins that surround them, and the coast and bays, thereby offering a range of social, ecological, and economic benefits;
- mitigate flood risk and damage; and
- create public spaces with better “blue and green” infrastructure, enhancing liveability.

Most major cities in Australia expect intensified infill development over the coming decades. Without significant intervention, 'business as usual' is expected to have considerable influence on the hydrology, resource efficiency, liveability and amenity of our cities.

‘Water sensitive outcomes for infill developments’ program (CRCWSC IRP4) aims to develop and apply a performance framework to understand infill impacts, create design options and processes through case studies, and identify improved governance options and arrangements. The project will also utilise a range of existing CRCWSC tools and products, such as the WSC Toolkit (Tools and Products (TAP) Water Sensitive Cities Modelling Toolkit).

Developing urban spaces, like Greenslopes, has significant potential impact on: (i) hydrological performance, (ii) resource efficiency and (iii) amenity and liveability. The water sensitive design approach aims to support higher density communities, while enhancing environmental performance. It recognises the substantial effect that intensified residential infill development has on metropolitan water performance and urban thermal comfort, given its scale and extent.

This report explores opportunities to improve environmental performance and liveability for smart higher density living in urban precincts. Different typological models enable high quality infill development that supports and encourages water sensitive urban intensification.

The project principally focuses on developments from individual lots through to the precinct scale. To achieve its objectives, the project will work closely with the TAP (Tools and Products) program, IRP3 (Evidence-based integrated urban planning across different scales) and IRP2 (Comprehensive economic evaluation framework). The work will be underpinned by strong stakeholder engagement, overseen and chaired by an end-user steering committee. Ultimately, the work is expected to contribute to improved infill governance.

1.3 Study Objectives

This overland flow study has been undertaken as part of the wider assessment of exploring 'water sensitive urban intensification' opportunities to improve environmental performance and liveability for higher density living.

Primary objectives of this study were as follows:

- To assess the impact of future development (land-use intensification) as per current City Plan (BCC, 2014) guidelines, on overland flow flooding within the Greenslopes catchment; and
- To assess the impact of developed 'Water Sensitive' infill typologies on overland flow flooding within the Greenslopes catchment.

Three catchment scenarios were simulated in the investigation for a range of flood magnitudes from 63% AEP to 0.05% AEP. The three scenarios were:

- **NOW Scenario** – Existing catchment conditions: Based on the current waterway conditions as at year 2020 (hydrology and hydraulic models);
- **NEW Scenario** – Fully developed catchment conditions under current BCC City Plan guidelines (land use only): Based on fully developed land-use assumptions (hydrology model), with existing catchment building footprints (hydraulic model);
- **NEXT Scenario:** is characterized by the type of development envisaged in the urban design scenarios developed in this project, which would satisfy the vision for a Water Sensitive City. From a hydrologic/hydraulic modelling perspective, this has been assessed as follows:
    - Existing catchment conditions (hydrology model), with new typology building footprints within the overland flow conveyance corridor (hydraulic model), as per Appendix A.

Two sensitivity scenarios were also analysed, to consider the effects on catchment flows from a 'dry' tailwater boundary (all Scenarios), and from inclusion of rainwater tank storage into the catchment (NEXT Scenario).

Figure 1-1 : Locality Plan

1.4 Study Scope

The following tasks were undertaken to achieve project objectives, as outlined in Section 1.3:

- Develop a RAFTS hydrologic model of the catchment;
- Validate hydrologic model discharges against Rational Method estimates at key locations;
- Develop a TUFLOW hydraulic model of the catchment;
- Check the TUFLOW hydraulic model discharges against RAFTS model and Rational Method estimates at key locations;
- Undertake Scenario and Sensitivity testing in the RAFTS and TUFLOW models; and
- Produce result statistics and mapping for a selected range of design events.

ARR 2016 guidelines were followed in the undertaking of design flood estimation for this assessment.

1.5 Study Limitations

In utilising the flood models, it is important to be aware of their limitations, which can be summarised as follows.

- The models have only been validated against the Rational Method for establishing design flows. This should be taken into account when considering the accuracy of results, particularly if absolute values (i.e., of depth, velocity, hazard etc) are used by the reader, other than for the purposes of comparing Scenarios in this impact assessment;
- The Scenarios analysed are concept-only, with the models also developed at a catchment scale. As a result, smaller more localised flooding characteristics may not be apparent in the results; and
- The accuracy of the model results is directly linked to the accuracy of the data used to develop the model (e.g. ALS survey, stormwater network data, building footprints etc.).

2.0 Catchment Description

Greenslopes catchment area is approximately 0.73 km^2 and is predominantly comprised of low to medium residential lots, with some commercial properties located in the upper catchment along Logan Road. In Council's *City Plan 2014*, several lots have recently been rezoned to medium residential land-use. The catchment is steeper in the upper reaches and relatively flat in the lower reaches, having an average slope of below 5% along the longest overland flow path length of 1.4 km, and average catchment impervious land cover of 60%, as of 2019.

When the underground catchment stormwater network surcharges, floodwaters traverse overland and concentrate along two main upper catchment branches, before forming a single branch at Bunya Street in Greenslopes. The stormwater network and overland flow then discharges into a wetland downstream of Pear Street, where basin overflows traverse into Norman Creek. Within the lower reaches of the overland flow path, the majority of residential properties are two-storey 'Queenslander' houses, with partially obstructed undercrofts. Lower reaches of the catchment can be affected by regional backwater flooding from Norman Creek, depending on the magnitude of the regional flood event.

3.0 Hydrologic model development and validation

3.1 Overview

The hydrologic model simulates the rainfall runoff routing process within the catchment. Hydrologic modelling for this study was performed using XPRAFTS software (Innovyze, version 2018.1.2). XPRAFTS allows the effects of development/urbanisation to be assessed, making it suitable for use in this assessment.

3.2 XPRAFTS Sub-catchment Data

3.2.1 General

This section describes the sub-catchment information used in the XPRAFTS model. XPRAFTS allows the user to define the sub-catchment with differing levels of detail depending on the type of catchment and requirements for the study. The adopted sub-catchment parameters for the XPRAFTS model are presented in Appendix C. A summary of the scenarios included in the hydrological model are as follows:

Scenario NOW – Existing (year 2020) sub-catchment conditions;

Scenario NEW – Future scenario with intensified catchment development, based on assumptions presented in Appendix A;

Scenario NEXT - Existing (year 2020) sub-catchment conditions; and

Scenario NEXT (Storage Sensitivity) – Scenario NEXT, with adjusted Impervious sub-catchment Initial Loss values.

3.2.2 Sub-catchment Delineation and Slope

Sub-catchment delineation was based on 2019 ALS contours and considered the location of major tributaries, property boundaries, stormwater drainage and roads. Sub-catchment delineation was the same for all scenarios and comprised 146 sub-catchments, with average sub-catchment area of 73 hectares (ha). Refer to Figure 3-1, which shows the XPRAFTS sub-catchment delineation.

Sub-catchment slopes were based on the Equal-Area method and are outlined in Appendix C.

3.2.3 Land-use and Impervious Area

Land use within the catchment is predominantly urban, low-density residential. Sub-catchment Total Impervious Area (TIA) fractions were calculated by digitizing the buildings, pavements and gardens in GIS software. The average total impervious fraction for the Greenslopes catchment was calculated as approximately 60%. This study did not consider the difference between Total Impervious Area and Effective Impervious Area (EIA).

PERN (Manning's n roughness) values were estimated at 0.045 for Pervious areas and 0.025 for Impervious areas.

3.2.4 Rainfall IFD (ARR 2016)

The following 2016 Bureau of Meteorology (BoM) Intensity-Frequency-Duration (IFD) information was adopted for use in this investigation (*http://www.bom.gov.au/water/designRainfalls/revised-ifd/).* Refer to Table 3-1 for the ARR 2016 rainfall IFD data for Greenslopes.

Table 3-1: Rainfall IFD data for Greenslopes (ARR 2016)

Duration (min)	AEP Rainfall Intensity (mm/hr)							
	63%	39%	18%	10%	5%	2%	1%	0.05%
10	15.3	17.4	23.6	27.8	31.9	37.1	41.1	46.2
15	19.5	22.1	30.1	35.4	40.5	47.1	52.2	58.7
20	22.6	25.6	34.9	41.1	47.1	54.9	60.7	68.4
25	25	28.4	38.7	45.7	52.4	61.1	67.8	76.4
30	27.1	30.7	41.9	49.4	56.8	66.4	73.7	83.2
45	31.6	35.8	49	58	66.8	78.5	87.5	98.9
60	34.8	39.4	54.2	64.3	74.2	87.6	97.9	111

Figure 3-1: Greenslopes RAFTS Model Sub-catchments

3.3 Validation procedure

3.3.1 General

Suitable calibration data for the catchment was not available due to an absence of gauges and historical surveyed flood levels. Therefore, the XPRAFTS model could only be validated against other engineering methods for estimating design discharges. For the NOW Scenario, peak flow comparisons were made with the Rational Method (QUDM, 2016) and later compared to the TUFLOW hydraulic model discharges.

3.3.2 Rational Method parameters

The process for undertaking Rational Method calculations is documented in QUDM (2016). Time of Concentration (TOC) estimates for the NOW Scenario were comprised of a combination of calculated overland flow and pipe flow times, with a standard inlet time of five minutes.

Rational Method parameters adopted in this assessment are shown in Table 3-2 below. Refer to Figure 3-2 for the defined Rational Method catchment areas.

Table 3-2: Rational Method Parameters

Parameter	Catchment ID							
	A	**B**	**C**	**D**	**E**	**F**	**O16037388**	**O17037611**
Catchment Area (ha)	7.5	17.1	15.6	34.6	30.2	73	0.676	1.116
Time of Concentration (min)	12	15	16	27	20	30	13	10
Fraction Impervious (fi)	0.6						0.57	0.78
I_{10} Intensity (mm/hr)	64.20							
C_{10} Runoff Coefficient	0.81	0.81	0.80	0.80	0.80	0.81	0.79	0.84

Figure 3-2 : Rational Method Catchments

3.4 Hydrologic model validation results

Table 3-3 provides a comparison between peak discharges from the XPRAFTS hydrology model and the Rational Method at six total flow and two local flow XPRAFTS locations. Comparisons were undertaken for the 63%, 10%, 2% and 1% AEPs; as these represent the AEPs most commonly applied in infrastructure design and planning, as well as being representative of other intermediate AEPs.

The following observations are made, when comparing the XPRAFTS results against Rational Method calculations (Table 3-3):

- XPRAFTS model discharges were within +/- 10% of Rational Method (RM) disharges at 14 out of 26 reporting points and within +/- 15% of RM disharges at 20 out of 26 reporting points;
- The largest observed differences in peak discharge between XPRAFTS and Rational Method results were 21% (Total Flow at two locations) and 37% (Local Flow at one location);
- For smaller events, XPRAFTS tended to predict higher peak discharges compared to RM. For larger events, XPRAFTS predicted similar or lower peak discharges compared to RM; and
- For larger events (10%, 2% and 1% AEPs), where flows are not generally confined to the stormwater network, XPRAFTS discharges were closer to RM discharges, being within +/- 15% of RM discharges at 17 out of 18 reporting points.

Table 3-3: XPRAFTS and Rational Method Peak Discharge Comparison

RM Catchment ID	RAFTS Node ID (Local/Total Flow)	AEP	RM Discharge (m^3/s)	RAFTS Mean Peak Discharge (m^3/s)	% Difference – RAFTS vs. RM
A	**O17037611 (Total)**	63	1.15	1.35	17.4%
		2	4.02	3.74	-7.0%
		1	4.65	4.22	-9.2%
B	**O17037436 (Total)**	63	2.37	2.60	9.7%
		2	8.28	7.33	-11.5%
		1	9.56	8.19	-14.3%
C	**O17037494 (Total)**	63	2.21	2.67	20.8%
		2	7.73	7.74	0.1%
		1	8.92	8.66	-2.9%
D	**O16037388 (Total)**	63	3.48	3.68	5.7%
		2	12.28	10.57	-13.9%
		1	14.23	11.81	-17.0%
E	**O16037534 (Total)**	63	3.64	4.31	18.4%
		2	12.76	12.42	-2.7%
		1	14.68	13.93	-5.1%
F	**O16037567 (Total)**	63	6.93	8.36	20.6%
		2	24.54	24.89	1.4%
		1	28.50	27.84	-2.3%
O16037388	**O16037388 (Local)**	63	0.10	0.11	10.0%
		10	0.23	0.22	-4.3%
		2	0.36	0.32	-11.1%
		1	0.41	0.36	-12.2%
O17037611	**O17037611 (Local)**	63	0.19	0.26	36.8%
		10	0.43	0.48	11.6%
		2	0.67	0.66	-1.5%
		1	0.77	0.74	-3.9%

3.5 Selected ARR Ensembles for Hydraulic Modelling

The following methodology was adopted for selection of ARR ensembles for simulation in the TUFLOW hydraulic model. The ‘ensemble’ design event approach is outlined in Australian Rainfall and Runoff (2019), and replaces the single design event approach (ARR, 1987). The methodology below is an interpretation of the ARR 2019 guidelines, is consistent with what was adopted for use in the recently completed Cabbage Tree Creek Flood Study (BCC, 2019), and is as follows:

- Select a number of key locations within the hydraulic model extents from which to determine the critical duration and the representative design flow;
- Run the XP-RAFTS model for all AEP/Storm Duration/Ensemble combinations, and determine the critical duration at the selected key locations, for each AEP;
- For the critical duration event, identify the ensemble (E1 to E10) that corresponds to Rank 6 and Rank 5 flow at each of the chosen locations, for each AEP.
- For each of the three temporal pattern groups (i.e. frequent (63% and 39% AEP), intermediate (10% AEP) and rare (2%, 1% and 0.5% AEP)), select up to two ensembles (per duration), which correspond to those that occur the most frequently as Rank 6 and Rank 5 flow;
- Check the XPRAFTS results to ensure that the chosen ensembles for other selected locations do not produce a higher flow than the adopted ensemble at that specific location;
- Run the chosen ensemble(s) through the XPRAFTS model to create inflow hydrographs for the TUFLOW model; and
- Run the TUFLOW model with the XPRAFTS inflow hydrographs.

Based on the methodology above, the ensembles selected for hydraulic analysis using the TUFLOW model are as follows:

10 minute storm duration

- Frequent: [1-yr ARI (63 % AEP) 2-yr ARI (39 % AEP)] - Ensemble 9 (of 10).

15 minute storm duration

- Frequent: [1-yr ARI (63 % AEP) 2-yr ARI (39 % AEP)] - Ensemble 1 (of 10);
- Intermediate: [10-yr ARI (10 % AEP)] - Ensemble 2 (of 10); and
- Rare: [50-yr ARI (2 % AEP), 100-yr ARI (1 % AEP) and 200-yr ARI (0.5 % AEP)] - Ensemble 3 (of 10).

20 minute storm duration

- Frequent: [1-yr ARI (63 % AEP) 2-yr ARI (39 % AEP)] - Ensemble 2 (of 10); and
- Intermediate: [10-yr ARI (10 % AEP)] - Ensemble 3 and 6 (of 10).

25 minute storm duration

- Rare: [50-yr ARI (2 % AEP), 100-yr ARI (1 % AEP) and 200-yr ARI (0.5 % AEP)] - Ensemble 9 (of 10).

4.0 Hydraulic model development

4.1 Overview

A combined one-dimensional/two-dimensional (1D/2D) TUFLOW hydraulic model was developed to assess hydraulic impacts of the scenarios. The following sections detail the source data and methodology adopted in the development of the NOW Scenario hydraulic model, including amendments to the NOW Scenario model for the purposes of assessing the NEXT and NEW scenarios.

Model Schematisation and Extent

The TUFLOW hydraulic model extent is shown in Figure 4-2. This hydraulic model is a fully two-dimensional model, with embedded 1D components representing the major pipe drainage network and associated manholes and gully inlet pits.

Model simulations were run with TUFLOW 2018-03-AE-w64 (BMT Group 2007-2018), using the 'HPC' solution scheme with CPU solver. The TUFLOW HPC software employs adaptive timestepping to ensure model stability and conservation of mass. For impact assessments, the utilisation of HPC (and adaptive timestepping) requires additional checks to make sure that it does not produce 'artificial impacts'.

Figure 4-2 to Figure 4-5 show the extent and schematisation of the NOW and NEXT Scenario TUFLOW models, including inflow locations, hydraulic structures, adopted Manning's n roughness values and building topography modifications.

Available data
The following data was utilised in the development of the TUFLOW model:

- Aerial photography – 2020 (NearMap);
- 2019 ALS data;
- Building footprint layer from Brisbane River Catchment Flood Study (BRCFS);
- Brisbane City Council stormwater pit and pipe data;
- QLD Digital Cadastre Database (DCDB);
- Council GIS databases; and
- Future development data from CRC WSC team in Monash University on typologies. Refer to Appendix B for a map showing NEXT scenario typologies and assumptions relating to structure flow conveyance within the hydraulic model.

Topography

ALS 2019 survey (1m resolution) was used as the base topography for the TUFLOW hydraulic model. A 2D model grid size of 1m was adopted for this assessment.

Topographical improvements were then included in the hydraulic model at select locations, including:

- Lowering of wetland ground level at the stormwater network outlet to below the outlet pipe invert level;
- Inclusion of typically impenetrable (i.e. brick) fencing as 2D 'z shape' adjustments, within the anticipated main flowpaths only;
- Representation of buildings within the TUFLOW model as follows -
    - **(NOW/NEW/NEXT Scenarios)** For buildings with an undercroft that allows partial conveyance, adopt a Manning's 'n' roughness coefficient of n = 1 for the building footprint
    - **(NOW/NEW/NEXT Scenarios)** For buildings that are slab on ground or that do not allow partial conveyance at ground level, adopt a 0.3m high blockage for the building footprint, along with a Manning's 'n' roughness coefficient of n = 1 for the building footprint when flow overtops the blockage.
    - **(NEXT Scenario)** For buildings with an undercroft and little to no obstruction, represent the building as a 2D Layered Flow Constriction (2d_lfcsh), with 20% blockage between

ground level and building underside, along with a Manning’s ‘n’ roughness coefficient of n = 0.035 for the building footprint. A 20% blockage factor is intended to represent the effects of building piers, staircases, vehicles and any personal items stored underneath the building.

Based on a review of Google Streetview, it was determined that all buildings within the main catchment flowpaths in the NOW Scenario were either slab on ground, or contained an undercroft allowing partial conveyance only.

The Manning’s ‘n’ roughness value of n = 1 adopted for the representation of buildings is consistent with that applied in a recently completed Council study, peer reviewed by BMT WBM (Pallara Catchment Flood Study, BCC, 2018).

A sensitivity check was undertaken, with buildings fully blocked to a height above maximum flood levels in the catchment, which is the recommended method described in *ARR Revision Project 15: Two Dimensional Simulations in Urban Areas - Representation of Buildings in 2D Numerical Flood Models* (Smith & Wasko, 2012).

The sensitivity check results showed high head-losses across buildings (of up to 1.5 - 2m) in areas where buildings were situated close together within the flow path, particularly in larger flood events. This was deemed to be overly conservative for a number of reasons, including: (i) many buildings within the floodplain have undercrofts that may allow partial conveyance; (ii) the model uses a 1m grid resolution, which may under-represent narrow flowpath widths between houses that are situated close together; and (iii) buildings are more likely to be permeable (to a minor degree) than impermeable. It was; therefore, considered more reasonable to adopt the high-manning’s method, with short impermeable slab heights (where necessary), as described above.

Land Use

Manning’s ‘n’ hydraulic roughness areas were digitised based on aerial photography, with coefficients based on industry accepted guidelines, including *Natural Chanel Design Guidelines* (BCC, 2003) and *Open-Channel Hydraulics* (Chow, 1959).

Mannings ‘n’ roughness coefficients that were adopted for each land use type are detailed in Table 4-1.

Table 4-1: Mannings ‘n’ rouphness cofficients

Land-Use Type	Manning’s ‘n’
Grass (urban areas)	0.035
Vegetation (backyards)	0.055
Asphalt (roads)	0.016
Pavement (incl. driveways)	0.02
Buildings (Slab-on-ground and ‘Closed Undercroft’)	1
Buildings (‘Open Undercroft’)	0.035
Stormwater (1D) channels	0.013

Hydraulic Structures

The major pipe drainage network within the model area was included as a network of 1D elements embedded into the 2D TUFLOW model domain. Pipe drainage data was sourced from Council’s spatial information database.

All stormwater drainage pipes of diameter greater than or equal to 450 mm were included in the hydraulic model. Manholes were also automatically applied at all pipe junctions, with manhole losses based on the ‘Engelund’ method.

Inflow pits were applied as 1D ‘Q’ pit elements, with a depth-discharge relationship applied to each pit. The same depth-discharge relationship was applied to each pit (regardless of pit type) and was based on the BCC standard design for a 3.6m Lintel Lip in Line Sag Gully (Type E Kerb and Channel). The vast majority of pits within the catchment did not have a ‘type’ attribute in Council’s GIS dataset, so the decision was made to represent each pit as a ‘medium-sized’ sag pit. Whilst this may potentially over predict the amount of flow captured into some pits (i.e. – pits that are ‘on-grade’ and/or of a smaller size), it was deemed to be fit-for-purpose, as the study is an impact assessment and the stormwater drainage network was not the critical focus.

Inflow pits that were not snapped to a drainage pipe, were automatically connected to the nearest pipe junction based on the 'Pit Search Distance' TUFLOW command.

Boundary Conditions

Boundary inflows (Q-T) for the Greenslopes catchment were extracted from the XPRAFTS hydrology model (outlined in Section 3.2) and applied via 2d 'sa' polygons within the TUFLOW hydraulic model at each XPRAFTS sub-catchment location. For sub-catchments that included pits, the inflows were applied directly over the pits using the 'Read GIS SA Pits' TUFLOW command.

As the catchment flows into Norman Creek, tailwater levels for the Greenslopes catchment were based on an analysis of coincident flooding with Norman Creek using the Quick IFD Method in QUDM (2017).

NEXT Scenario Building Types

The NEXT Scenario is based on a hypothetical 'future development' condition, as developed by the CRC WSC team at Monash University. The future development condition consists of the modification of existing buildings (footprint size, location within parcel, and building type) within the main overland flow paths to align with the aims of the overarching water sensitive study.

Refer to Appendix B for further detail.

The location of the building types is shown in Figure 4-1 below. A summary of the building types is as follows:

Apartment – Slab on Ground – New apartment building (replacing existing buildings on site), that is built at ground level.

Apartment – Undercroft – Part of the '*Apartment – Slab on Ground'* buildings, that is open underneath, and designed to let overland flow pass through.

Hover – Raised Building Above – New 'hover' type building (replacing existing buildings on site) that is raised above ground level and has an open, useable undercroft that is designed to allow overland flow to pass through.

New QLD – Raised Building Above – New 'Queenslander' type building that is raised above ground leel and has an open, useable undercroft that is designed to allow overland flow to pass through. The building is typically of a smaller footprint than the existing building on site, and is relocated within the parcel to reduce overland flow obstruction.

New QLD – Slab on Ground – A storage area built at ground level, that is part of the '*New Qld – Raised Building Above*' building.

Old QLD – Raised Building Above – Old 'Queenslander' type building that is raised above ground level, but has a closed undercroft that forms an obstruction to overland flow. The building is typically of a smaller footprint than the existing building on site.

Townhouse – Slab on Ground - New townhouse building (replacing existing buildings on site), that is built at ground level.

Townhouse – Open Undercroft – Ground floor area of the '*Townhouse – Slab on Ground'* building, that is designed to allow overland flow to pass through.

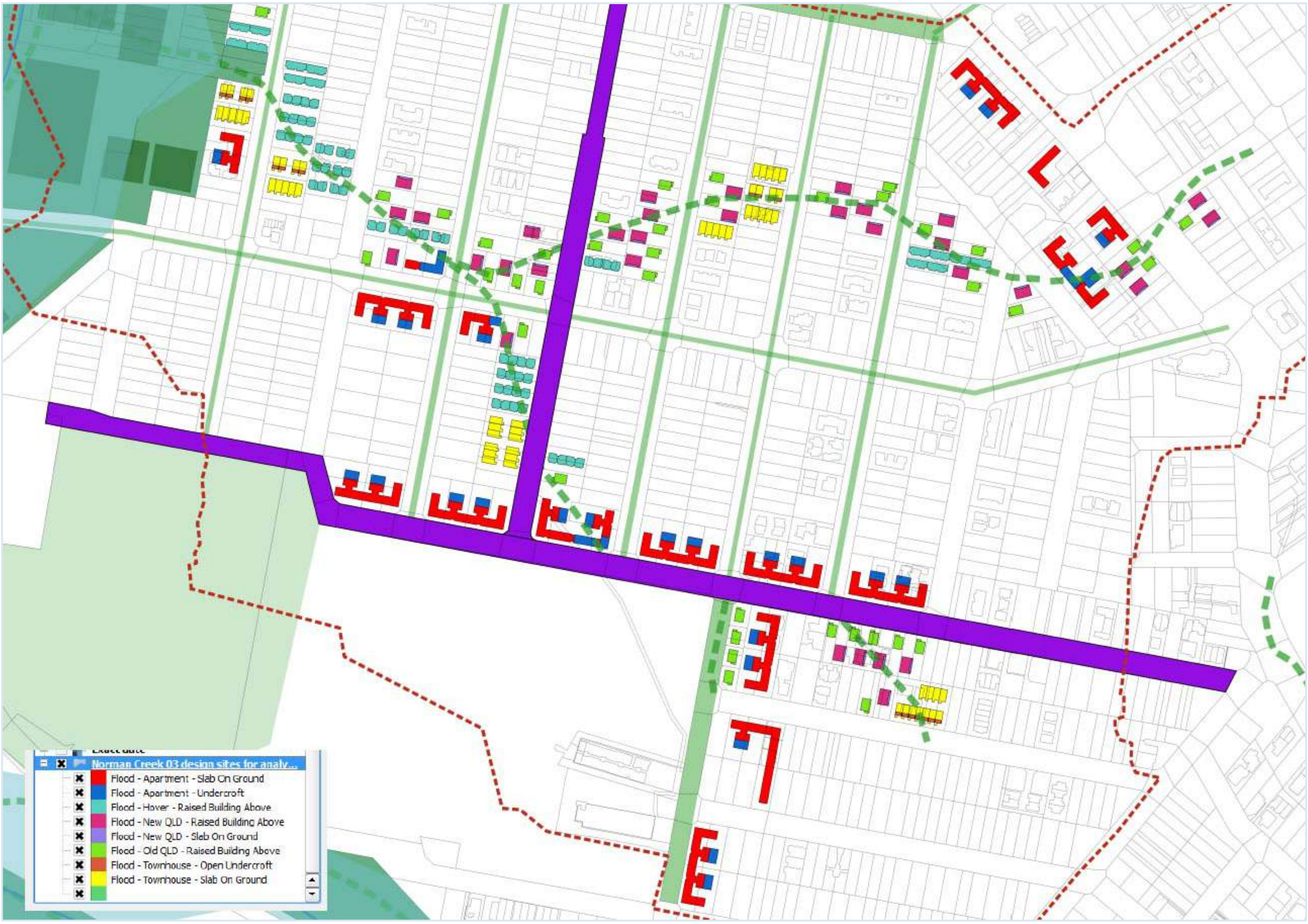
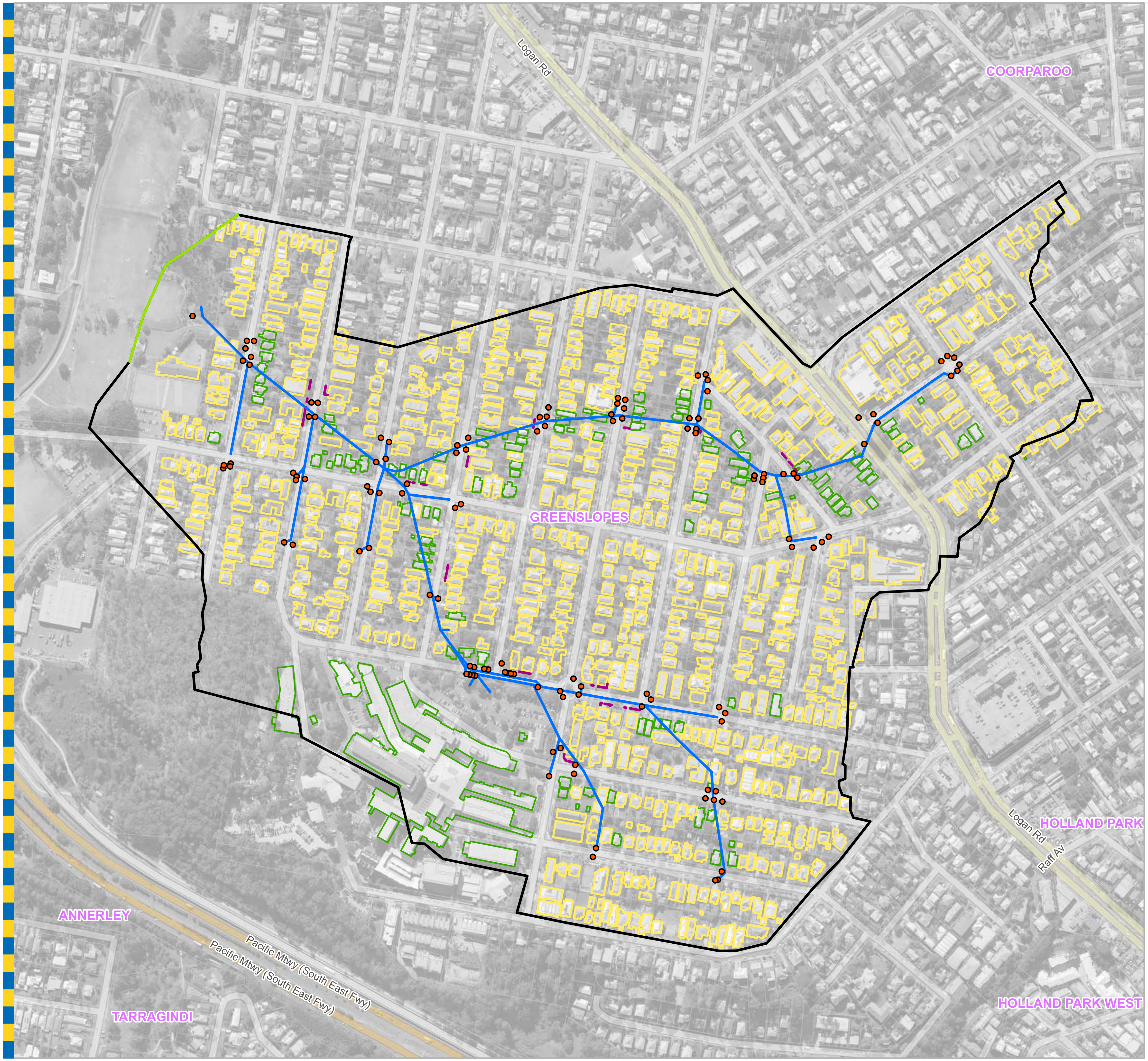


Figure 4-1: NEXT Scenario Building Types



Legend

- 1D Pits
- 1D Pipes
- 2D Tailwater Boundary
- 2D Fences
- 2D Model Boundary
- 2D Buildings - Closed Undercroft
- 2D Buildings - Slab on Ground
- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Property Holdings

N W E S

0 50 100 150
Metres

Prepared : 084836
Checked : NC
Revision : 0
Publication Date : 14 Apr 2021
Project Number : 200937

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_FlowArcGIS\GDS_200937_004_Figure4_2.mxd

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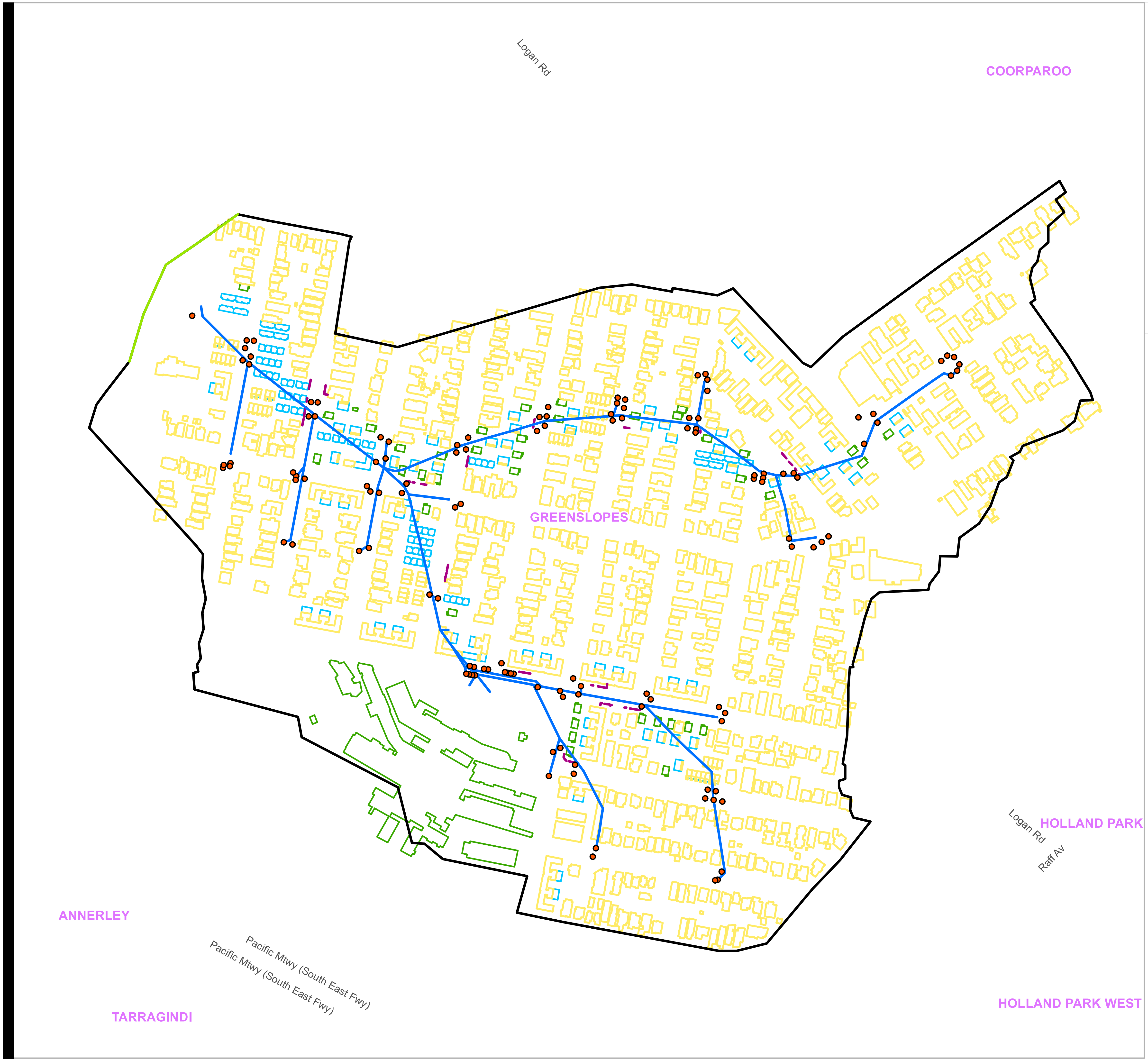
Figure 4.2 – TUFLOW NOW Scenario Model Schematisation

GDS - 200937 - 004



Legend

- 1D Pits
- 1D Pipes
- 2D Tailwater Boundary
- 2D Fences
- 2D Model Boundary
- 2D Buildings - Slab on Ground
- 2D Buildings - Open Undercroft
- 2D Buildings - Closed Undercroft
- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Property Holdings

N
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0 50 100 150
Metres

Prepared :	089958
Checked :	NC
Revision :	0
Publication Date :	04 Jun 2020
Project Number :	200937

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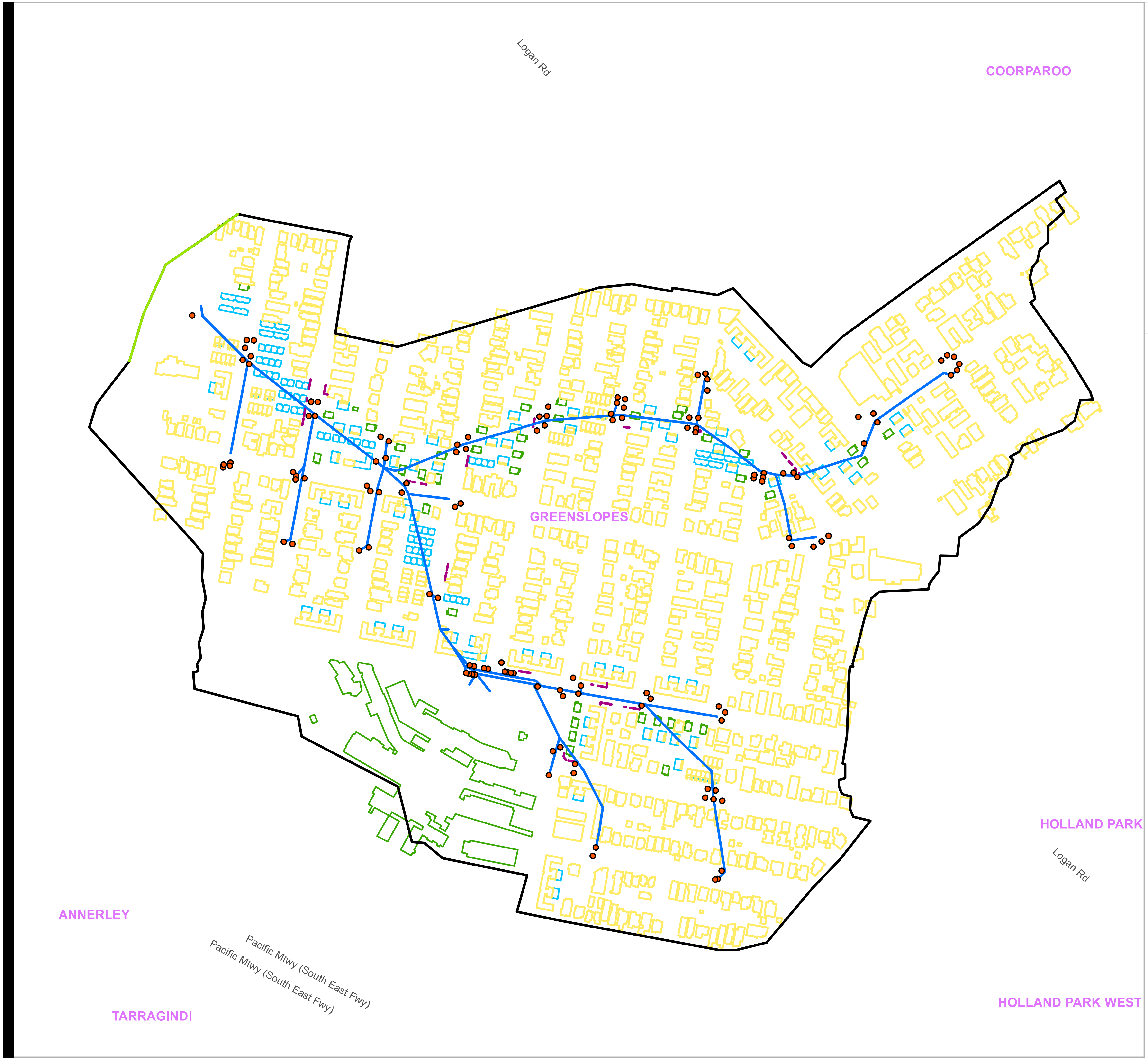
Figure 4.3 – TUFLOW NEXT Scenario Model Schematisation

GDS - 200937 - 006



Legend

- 1D Pits
- 1D Pipes
- 2D Tailwater Boundary
- 2D Fences
- 2D Model Boundary
- 2D Buildings - Slab on Ground
- 2D Buildings - Open Undercroft
- 2D Buildings - Closed Undercroft
- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Property Holdings

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Metres

Prepared :	089958
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Revision :	0
Publication Date :	30 Jun 2020
Project Number :	200937

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Figure 4.4 – TUFLOW NEXT Scenario Model Schematisation

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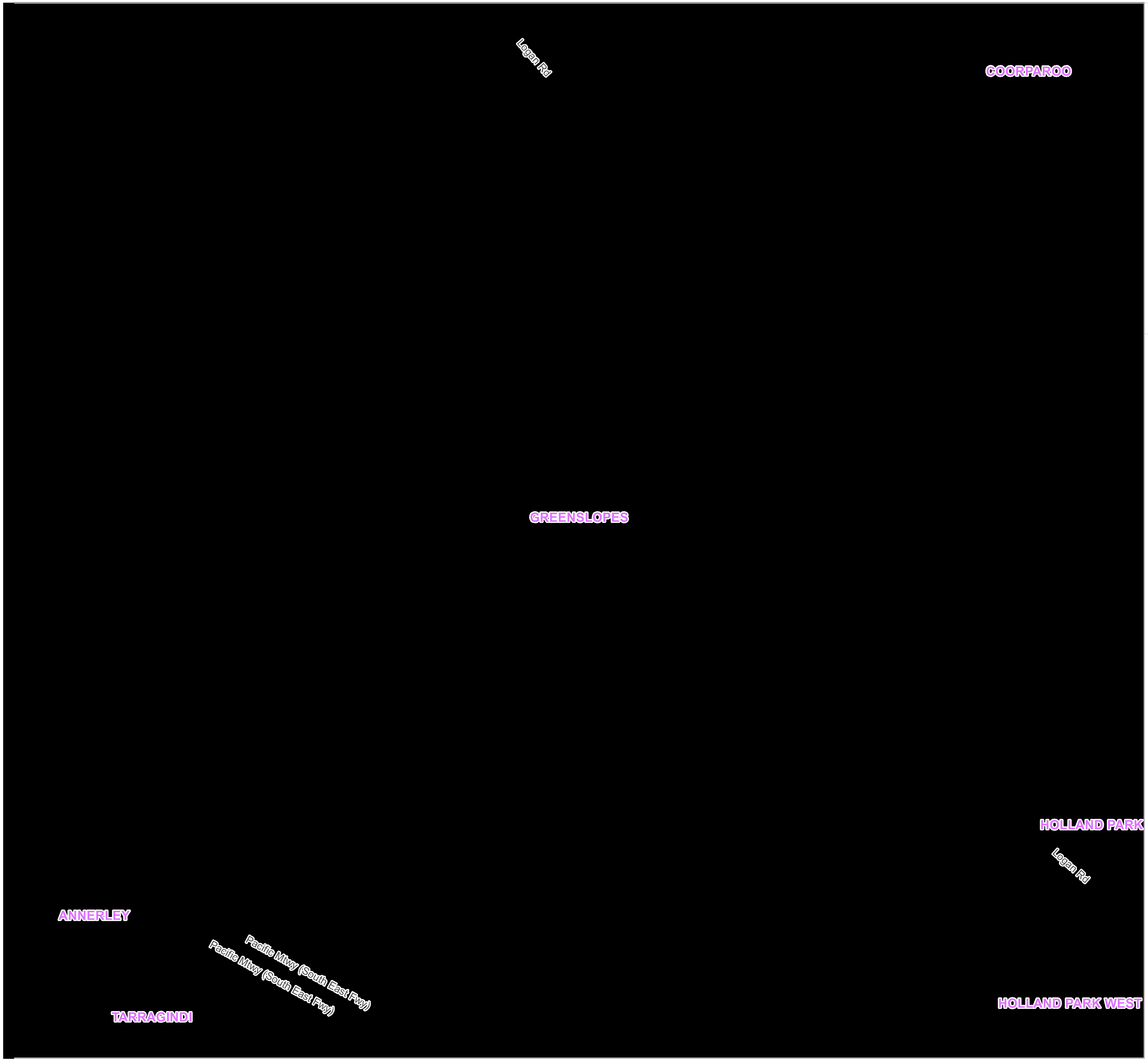

Legend

Freeways/Highways	**Surface**
Major Roads	Asphalt
Streets	Pavement
Tunnels	Buildings
2D Model Boundary	Grass
Property Holdings	Vegetation

N W E S

0 50 100 150

Metres

Prepared :	089958
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Figure 4.5 – TUFLOW NEXT Scenario Manning's n Roughness Map

GDS - 200937 - 007

4.2 Model Verification

Peak discharges from the TUFLOW model were compared to XPRAFTS and Rational Method discharges for selected events at six reporting locations. The peak discharge comparison is presented in Table 4-2.

Table 4-2: TUFLOW Peak Discharge Check

Rational Method Catchment ID	AEP	Rational Method Discharge (m^3/s)	RAFTS Mean Peak Discharge (m^3/s)	TUFLOW Peak Discharge (m^3/s)	% Difference TUFLOW vs. RAFTS	% Difference TUFLOW vs. RM
A	63	1.15	1.35	1.31	-3.0%	13.9%
	2	4.02	3.74	2.25	-39.8%	-44.0%
	1	4.65	4.22	2.73	-35.3%	-41.3%
B	63	2.37	2.60	2.25	-13.5%	-5.1%
	2	8.28	7.33	5.51	-24.8%	-33.5%
	1	9.56	8.19	6.07	-25.9%	-36.5%
C	63	2.21	2.67	2.37	-11.2%	7.2%
	2	7.73	7.74	6.62	-14.5%	-14.4%
	1	8.92	8.66	7.47	-13.7%	-16.3%
D	63	3.48	3.68	3.78	2.7%	8.6%
	2	12.28	10.57	12.22	15.6%	-0.5%
	1	14.23	11.81	14.81	25.4%	4.1%
E	63	3.64	4.31	4.07	-5.6%	11.8%
	2	12.76	12.42	10.67	-14.1%	-16.4%
	1	14.68	13.93	12.11	-13.1%	-17.5%
F	63	6.93	8.36	8.69	3.9%	25.4%
	2	24.54	24.89	19.41	-22.0%	-20.9%
	1	28.50	27.84	22.29	-19.9%	-21.8%

Comparison of peak discharges demonstrates the following:

- Peak discharges from TUFLOW generally compared well to RM and XPRAFTS for the 63% AEP event, which is typically confined to the stormwater drainage network;
- Peak discharges from TUFLOW generally under-predicted peak discharges compared to RM and XPRAFTS for the 2% AEP and 1% AEP events, which are a combination of stormwater drainage flow and overland flow. This was particularly evident in upstream catchment areas A and B;
- While not documented in this report**,** a better match of RM and XPRAFTS peak discharges to TUFLOW was achieved by adjusting 'time of concentration' (RM) and 'link lag' (RAFTS) sub-catchment routing parameters for larger AEP events. This enabled a better consideration of storage effects and obstructions within the overland flow floodplain that are included in the TUFLOW model.

It was; therefore, deemed prudent to apply local (and not total) sub-catchment inflows only from the XPRAFTS model into the TUFLOW model, as well as allowing hydraulic model routing of catchment flows. This was undertaken with consideration of the lack of historical gauged data for calibration, the favourable comparison of RM to XPRAFTS local sub-catchment discharges (for larger events – refer to Table 3-3), an understanding of potential deficiencies in adopted channel routing parameters for the RM calculations and XPRAFTS (as mentioned above) and the superiority of hydraulic modelling software (i.e. – TUFLOW) in routing flood flows.

4.3 Assumptions and Exclusions

1. Effects of climate variability and structure blockage have not been analysed as part of this assessment;
2. Assumptions relating to representation of buildings (Manning's n roughness parameters and blockages) in the NEXT scenario are based on discussions with the Client and have been applied at a broad catchment-scale;
3. Pit inlet capture capacities (as discussed above) have been generalised to a single level/depth relationship for all pits within the model, due to lack of available on-site data. No blockage of pit inlets has been assumed;
4. Minor piped drainage of diameter smaller than 450 mm has not been included within the hydraulic model; and
5. Pervious fence blockages have not been included in the hydraulic model.

5.0 TUFLOW Model Results

The TUFLOW hydraulic model was run for the 63%, 39%, 10%, 2%, 1% and 0.5% AEP events (all scenarios), for the selected ensembles/durations mentioned in Section 3.5. Model results were then analysed and compared for a range of outputs, including: depth, depth x velocity product (hazard), discharge and flood timing. Results of these comparisons are documented in the sections below.

5.1 Depth

Flood depth differences between modelled scenarios at selected reporting locations is detailed in Table 5-1. Refer to Figure 5-1 for a map showing the reporting locations.

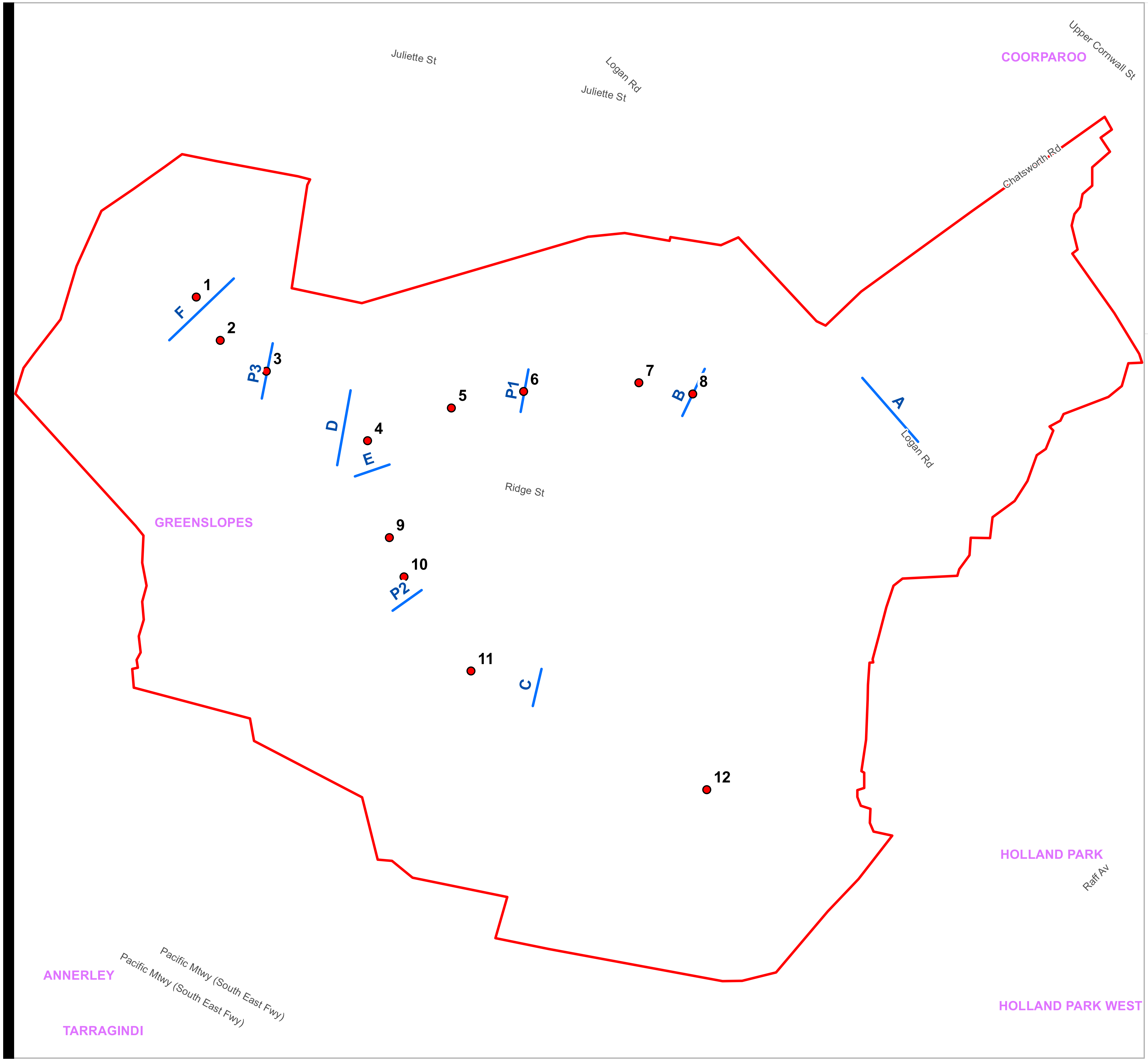
Results highlighted in bold denote a depth increase greater than 10 mm in the NEW/NEXT Scenarios (compared to NOW Scenario). Results within a shaded cell denote a depth decrease greater than 10 mm in the NEW/NEXT Scenarios (compared to NOW Scenario).

Flood depth mapping is presented in Appendix D and comprises:

- Peak flood depth mapping for the NOW/NEXT (39%, 10%, 2% and 0.5% AEP) and NEW (39%, 2% AEP) Scenarios; and
- Peak flood depth comparison mapping for NOW vs. NEW (39%, 2% AEP) and NOW vs. NEXT (39%,10%, 2% and 0.5% AEP) Scenarios.

Table 5-1: Flood Depth Differences at Key Reporting Locations

Reporting ID	Reporting Location (Greenslopes Suburb)	Flood Depth Difference (NEW minus NOW) (mm)				Flood Depth Difference (NEXT minus NOW) (mm)			
		39% AEP	10% AEP	2% AEP	0.5% AEP	39% AEP	10% AEP	2% AEP	0.5% AEP
1	Pear Street	2	4	9	**23**	0	**79**	**89**	**84**
2	60 Pear Street	**120**	7	**16**	**33**	-23	-20	-136	-229
3	Peach Street	**11**	7	**16**	**35**	-3	**106**	**62**	-7
4	89 Ridge Street	**45**	**17**	**24**	**35**	**18**	**67**	-10	-47
5	62 Cedar Street	6	**28**	**29**	**36**	-30	-22	-45	-53
6	Henry Street	-	**28**	**18**	**26**	-	**33**	**15**	**13**
7	30 Newdegate Street	**176**	**102**	**77**	**73**	-36	-220	-368	-451
8	Thomas Street	**29**	**20**	**16**	**17**	0	3	2	6
9	85 Cedar Street	**12**	2	-4	5	-185	-295	-467	-504
10	Cedar Street	9	2	-3	5	-15	**35**	-40	-64
11	Denman Street	**29**	4	-3	5	-1	-152	-224	-258
12	43 Hunter Street	0	-2	-3	0	**441**	**507**	**511**	**505**



Legend

- Reporting Points
- 2D PO Reporting Lines
- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

N / W / E / S

0 40 80 120
Metres

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Figure 5.1 – TUFLOW Model Result Reporting Locations

GDS - 200937 - 008

5.1.1 Depth Results Discussion

NEW Scenario

There is a general minor increase in depths in the NEW Scenario (compared to NOW Scenario) throughout the catchment, for all AEP events analysed. Minor increases in catchment imperviousness in the NEW Scenario result in marginally higher peak discharges throughout most of the catchment. Considering the basic assumption that Q = VA, the NEW Scenario typically experiences proportionally greater increases in overland flow discharge compared to increases in velocity, leading to increases in flow conveyance area and flood depths. For all AEPs, depth increases throughout the catchment in the NEW Scenario are generally within the range of 0 – 40 mm, with some isolated areas of higher increases. These higher increases are observed at Reporting Locations 2 and 7, and are rationalised as follows:

- **Location 2** (39% AEP only) – Storage related depth increases. Very shallow overland flow filling-up a minor storage area to a greater depth in the NEW Scenario; and
- **Location 7** (all AEP's) – Conveyance related depth increases. Higher peak discharges (in the NEW Scenario) upstream of three residential buildings spaced very closely together results in 'backing-up' of floodwaters upstream of these buildings. Re-running the hydraulic model at a smaller grid resolution (to better represent flowpath widths between buildings) may alleviate some of the modelled increases at this location.

NEXT Scenario

The NEXT Scenario, with the inclusion of 'open undercroft' buildings, along with smaller, repositioned buildings within the overland flow path, results in less residential building blockage and lower flow resistance at these locations, compared to the NOW Scenario. General trends in depth changes in the NEXT Scenario (compared to NOW Scenario) are as follows:

- Roads – Minor increases in depths across most roads (between 0 – 100mm at the reporting locations for all AEPs analysed). The exception to this is at Cedar Street and Denman Street, along the southern stormwater branch (Locations 10 and 11), where moderate reductions in depths are observed, particularly at Denman Street, where there is a depth decrease between 150mm (10% AEP) and 260 mm (0.5% AEP);
- Residential lots – Minor to moderate decreases in depths across most 'open undercroft' residential lots within the overland flow path at the reporting locations analysed, with moderate decreases in the vicinity of 30 Newdegate Street (40 – 450 mm decrease) and 85 Cedar Street (190 – 500mm). Minor to moderate increases in flood depths are observed at several residential lots, mainly where the new building footprints in the NEXT Scenario create a barrier to floodwaters and where buildings that create a blockage to flow are located directly downstream of 'open undercroft' buidings. For example, this is evident at Reporting Location 12 (43 Hunter Street), where the NEXT Scenario typology buildings create flow blockages and subsequent depth increases of up to 450 - 500mm in all events, and at Reporting Location 4 (89 Ridge Street), which is a complex region of multiple residential building types.

5.2 Hazard (Depth x Velocity Product)

Flood hazard (depth x velocity product) differences at selected reporting locations is detailed in Table 5-2 below. Refer to Figure 5-1 for a map showing the reporting locations.

Results highlighted in bold denote a depth x velocity product increase greater than 0.1 m^2/s in the NEW/NEXT Scenarios (compared to NOW Scenario). Results within a shaded cell denote a depth x velocity product decrease greater than 0.1 m^2/s in the NEW/NEXT Scenarios (compared to NOW Scenario).

Flood hazard mapping is presented in Appendix E and comprises:

- Peak flood hazard comparison mapping for NOW vs. NEXT (39%,10%, 2% and 0.5% AEP) Scenarios.

Table 5-2: Flood Depth x Velocity Product Differences at Key Reporting Locations

Reporting ID	Reporting Location (Greenslopes Suburb)	Flood Depth x Velocity Difference (NEW minus NOW) (m^2/s)				Flood Depth x Velocity Difference (NEXT minus NOW) (m^2/s)			
		39% AEP	10% AEP	2% AEP	0.5% AEP	39% AEP	10% AEP	2% AEP	0.5% AEP
1	Pear Street	0	0.01	0.02	0.05	0	0.09	**0.11**	0.09
2	60 Pear Street	0.01	0	0.02	0.06	-0.06	**0.23**	**0.71**	**0.96**
3	Peach Street	0.01	0.01	0.02	0.01	0	**0.16**	**0.26**	**0.45**
4	89 Ridge Street	0	0	0	0.01	0	0.01	0.02	0.02
5	62 Cedar Street	0	0	0.01	0.01	0.01	**0.12**	**0.28**	**0.40**
6	Henry Street	-	0.04	0.04	0.06	-	0.05	0.03	0.02
7	30 Newdegate Street	0.02	0.05	0.05	0.05	0	0.04	0.03	0.02
8	Thomas Street	0.03	0.04	0.04	0.05	0	0	0.01	0.02
9	85 Cedar Street	0	0	0	0	0.04	**0.38**	**0.57**	**0.74**
10	Cedar Street	0	0	-0.01	0	0	0.05	0.06	0.08
11	Denman Street	0.01	0	0	0.01	0	-0.01	-0.04	-0.03
12	43 Hunter Street	0	0	0	0	-0.13	-0.20	-0.25	-0.32

5.2.1 Depth x Velocity Product Results Discussion

NEW Scenario

There is a general minor increase in flood hazard (depth x velocity product) in the NEW Scenario (compared to NOW Scenario) throughout the catchment, for all AEP events analysed. This is primarily due to minor increases in catchment imperviousness in the NEW Scenario, which result in marginally higher catchment peak discharges, depths and velocities. For all AEPs, increases in the NEW Scenario are generally within the range of 0 – 0.1 m^2/s, with some isolated areas of up to 0.2 m^2/s observed in larger events (2% and 0.5% AEP).

Refer to Figure 5-2 below for a long-section profile comparison of flood hazard between the NOW (blue), NEW (orange) and NEXT (green) Scenarios for the 50yr event, from Pear Street to Thomas Street. This long section plot provides some context to the changes in flood hazard in the NEW Scenario. The plot demonstrates that increases in flood hazard in the NEW Scenario are consistently minor, compared to the absolute flood hazard values observed in the NOW Scenario.

NEXT Scenario

As per Table 5-2 and Appendix F, there are minor to moderate decreases and increases in flood hazard throughout the catchment in the NEXT Scenario, compared to the NOW Scenario. Figures in Appendix E show that there is both a 'straightening' and 'widening' of the flowpaths through residential lots in the NEXT Scenario. The NEXT Scenario results in a higher concentration of flows into a single main flowpath, compared to the more braided nature of floodwaters (due to more blockages) in certain sections of the NOW Scenario catchment. As a result of this 'modification' and the lower overall flowpath resistance in this scenario, peak hazard values vary considerably at most locations throughout the catchment, compared to the NOW Scenario. Flood hazard differences also appear to increase with increasing flood magnitude.

Flood hazard is typically higher in the NEXT Scenario in locations where discharges are higher (i.e. downstream areas) and more concentrated, where Manning's n ground level roughness is lower and where flows have been re-directed. Conversely, flood hazard is typically lower in the NEXT Scenario, in locations where flows were previously highly constricted in the NOW Scenario (i.e. - between existing building blockages) and sometimes along existing NOW Scenario flow paths, which were then re-directed in the NEXT Scenario. Note: This is not an exhaustive list of reasons as to the differences in hazard between the NOW and NEXT Scenarios.

In Figure 5-3 and Figure 5-4, two examples are provided to demonstrate the observations described above. These figures show the variability in flood hazard for the three Scenarios, along two cross-sections at Reporting Locations 2 and 5, for the 2% AEP event.

In Figure 5-2 below, a long-section profile comparison of flood hazard between the NOW (blue), NEW (orange) and NEXT (green) Scenarios is provided for the 50yr event, from Pear Street to Thomas Street. This further demonstrates the flood hazard similarities of the NEW Scenario and the NOW Scenario, and variability of the NEXT Scenario to the NOW Scenario. The plot also puts into context the variability in absolute hazard values compared to the NOW Scenario.

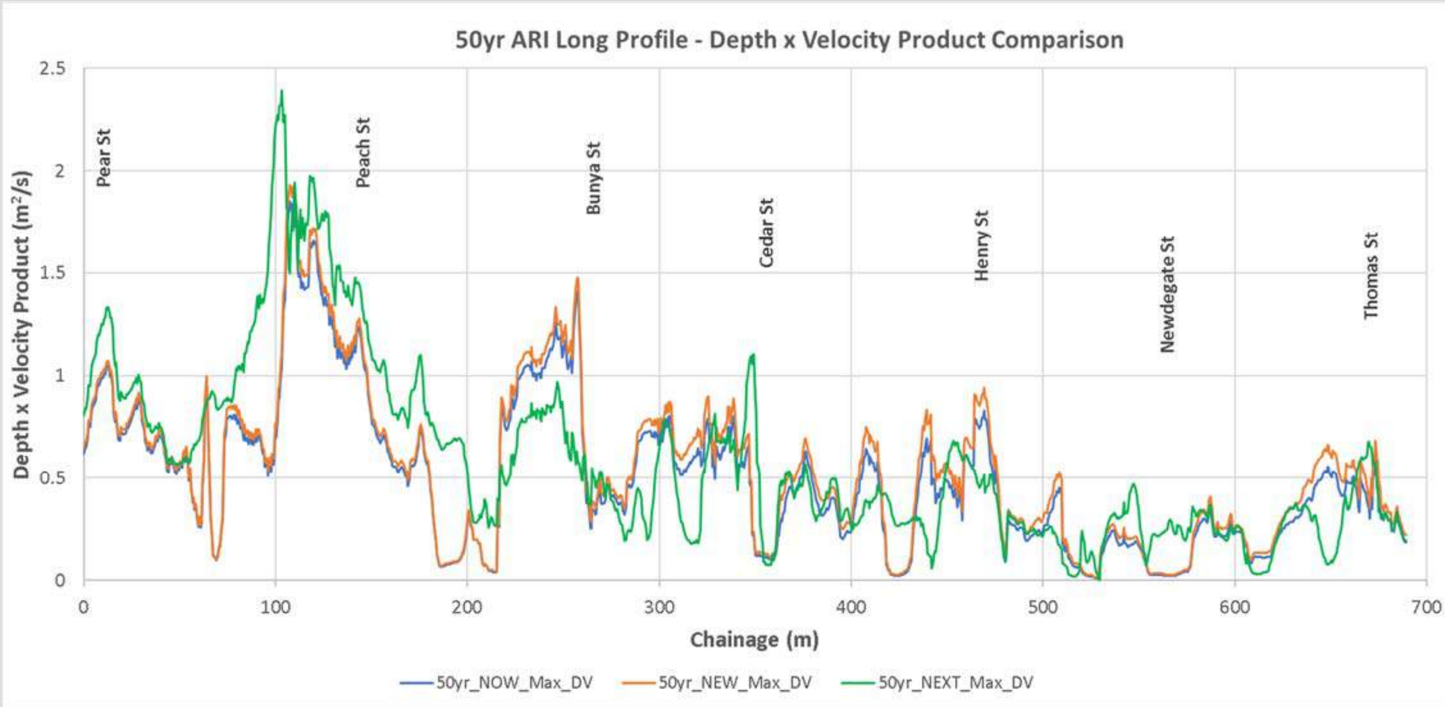


Figure 5-2: 2% AEP Profile Comparison – Depth x Velocity Product – Pear St to Thomas St

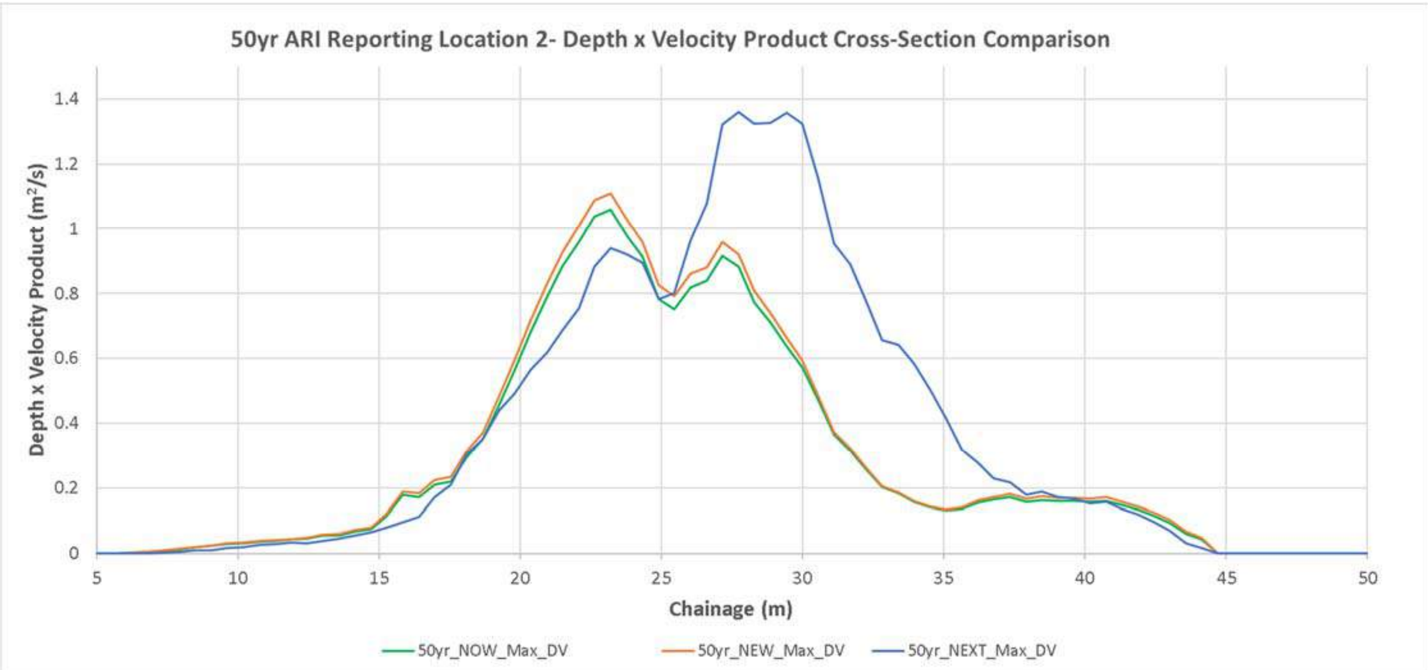


Figure 5-3: 2% AEP Section Comparison – Depth x Velocity Product – Reporting Location 2

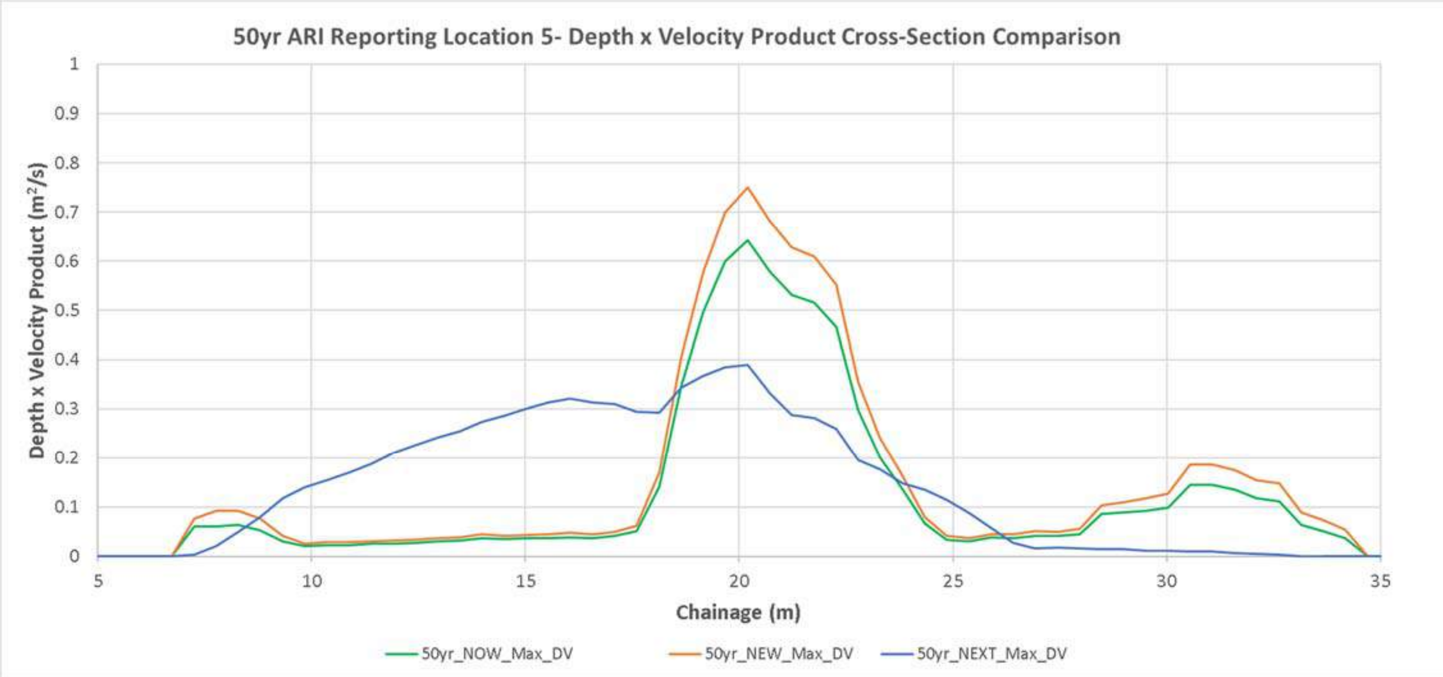


Figure 5-4: 2% AEP Section Comparison – Depth x Velocity Product – Reporting Location 5

5.3 Hazard (AEMI Classification)

The Australian Emergency Management Institute (AEMI) Hazard Classification curves (Smith *et al*., 2014) are shown in Figure 5-5 and described in Table 5-3 below. These curves are also referenced in ARR Book 6 Chapter 7 (ARR 2019, *Safety Design Criteria*).

This hazard classification is based on Depth, Velocity, and Depth x Velocity product values, and describes flood hazard safety thresholds for people, vehicles and buildings.

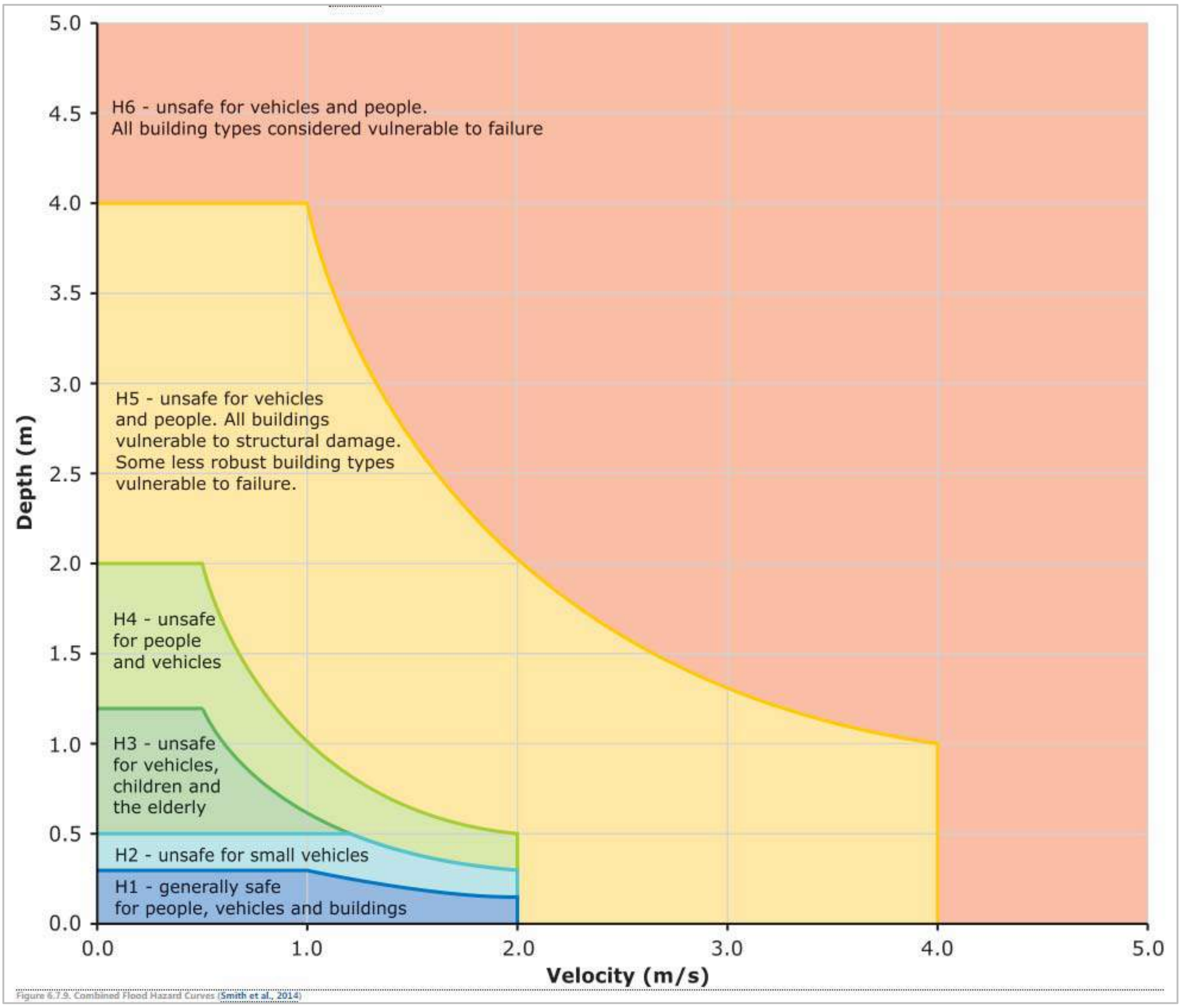


Figure 5-5: AEMI Combined Flood Hazard Curves (Smith *et al*., 2014)

Table 5-3: AEMI Combined Flood Hazard Curves – Threshold Limits (Smith *et al.*, 2014)

Hazard Vulnerability Classification	Classification Limit (D and V in combination)	Limiting Still Water Depth (D)	Limiting Velocity (V)
H1	D*V ≤ 0.3	0.3	2.0
H2	D*V ≤ 0.6	0.5	2.0
H3	D*V ≤ 0.6	1.2	2.0
H4	D*V ≤ 1.0	2.0	2.0
H5	D*V ≤ 4.0	4.0	4.0
H6	D*V > 4.0	-	-

Flood Hazard Category (AEMI) mapping is presented in Appendix F and comprises:

- Peak flood hazard category mapping for NOW and NEXT Scenarios (39%, 10%, 2%, 0.5% AEPs); and
- Peak flood hazard category difference mapping for NOW vs. NEXT Scenarios (39%, 10%, 2%, 0.5% AEPs).

5.3.1 Hazard Classification Results Discussion

Differences in Hazard Category mapping between the NOW and NEXT Scenarios is generally as per the trends described in Section 5.2.1. For the 39% AEP event, flood hazards along the overland flow paths are similar between NOW and NEXT Scenarios and are generally within the lowest H1 category (safe for buildings, people and vehicles), with isolated pockets of higher category H2 hazard (unsafe for small vehicles).

For the 10% AEP event, higher hazard areas affecting vehicles, children and the elderly (H2 and H3 hazards) are 'dampened' out in the upper catchment areas (compared to the NOW Scenario). Conversely, there are increases in higher hazard areas in the NEXT Scenario affecting all people and some buildings (H3-H5 hazards) in the lower catchment from Bunya Street to Pear Street.

The 2% AEP event comparison shows similar results to the 10% AEP comparison. An exception is that there are now observed increases in the NEXT Scenario, in higher hazard areas affecting all people and some buildings (H3-H5 hazards) in the southern stormwater branch (upper catchment) from Cedar Street to Ridge Street.

Flood hazard (AEMI) categories at selected reporting locations are detailed in Table 5-4 below. Results within a shaded cell denote a Hazard Category increase in that Scenario (compared to the other).

Table 5-4 : AEMI Combined Flood Hazard Curves – Threshold Limits (Smith *et al.*, 2014)

Reporting ID	Reporting Location (Greenslopes Suburb)	Flood Hazard Category (AEMI Classification) – NOW Scenario			Flood Hazard Category (AEMI Classification) – NEXT Scenario		
		39% AEP	10% AEP	2% AEP	39% AEP	10% AEP	2% AEP
1	Pear Street	1	1	4	1	2	4
2	60 Pear Street	2	3	4	2	3	5
3	Peach Street	1	2	4	1	2	4
4	89 Ridge Street	1	2	3	1	2	3
5	62 Cedar Street	1	1	2	1	1	2
6	Henry Street	-	1	1	-	1	1
7	30 Newdegate Street	1	3	3	1	2	3
8	Thomas Street	1	1	1	1	1	1
9	85 Cedar Street	1	3	3	1	2	4
10	Cedar Street	1	2	3	1	2	3
11	Denman Street	1	3	3	1	2	3
12	43 Hunter Street	1	3	4	3	3	3

5.4 Timing and Peak Discharge

Minor overall increases in sub-catchment fraction imperviousness in the NEW scenario means that time to flood peak is marginally shorter (by 0-2 minutes, particularly in upstream catchments) and overland flow peak discharge marginally higher compared to the NOW scenario. Time to flood peak in the NEXT scenario is typically shorter (and overland flow peak discharge considerably higher) throughout the catchment compared to the NOW scenario. This is predominantly due to changes in floodplain building types and location in the NEXT scenario, which allow more efficient conveyance of floodwaters.

A comparison of the 2% AEP time to flood peak and peak discharge at four key reporting locations for all Scenarios is provided in Table 5-5 and Table 5-6 below.

A discharge hydrograph comparison at Reporting Location 1 (downstream catchment) for the 50yr ARI 25 min Ensemble 9 simulation is shown in Figure 5-6. The comparison demonstrates differences in peak discharges and timing at this location for all Scenarios.

Table 5-5: 2% AEP Peak Discharge and Time to Peak Comparison – NOW/NEXT Scenarios

Reporting ID	Location	NOW Scenario – Time to Peak Q (mins)		Change in Time to Peak – NEXT vs. NOW scenario (mins)		Change in OLF Peak Discharge - NEXT vs. NOW scenario (%)	
		2% AEP 15m E3	2% AEP 25m E9	2% AEP 15m E3	2% AEP 25m E9	2% AEP 15m E3	2% AEP 25m E9
1	Pear Street	28.5	36	-5.5	-5.5	+56%	+40%
4	Ridge Street (adjacent No. 89)	24.5	31.5	-3.5	-2.5	+55%	+31%
6	Henry Street	22	29.5	-3	-2.5	+58%	+23%
10	Cedar Street	20	27	-3	-1.5	+10%	+9%

Table 5-6: 2% AEP Peak Discharge Comparison – NOW/NEW Scenarios

Reporting ID	Location	Change in OLF Peak Discharge – NEW vs. NOW scenario (%)	
		2% AEP 15m E3	2% AEP 25m E9
1	Pear Street	+3%	+4%
4	Ridge Street (adjacent No. 89)	+8%	+7%
6	Henry Street	+28%	+26%
10	Cedar Street	0%	0%

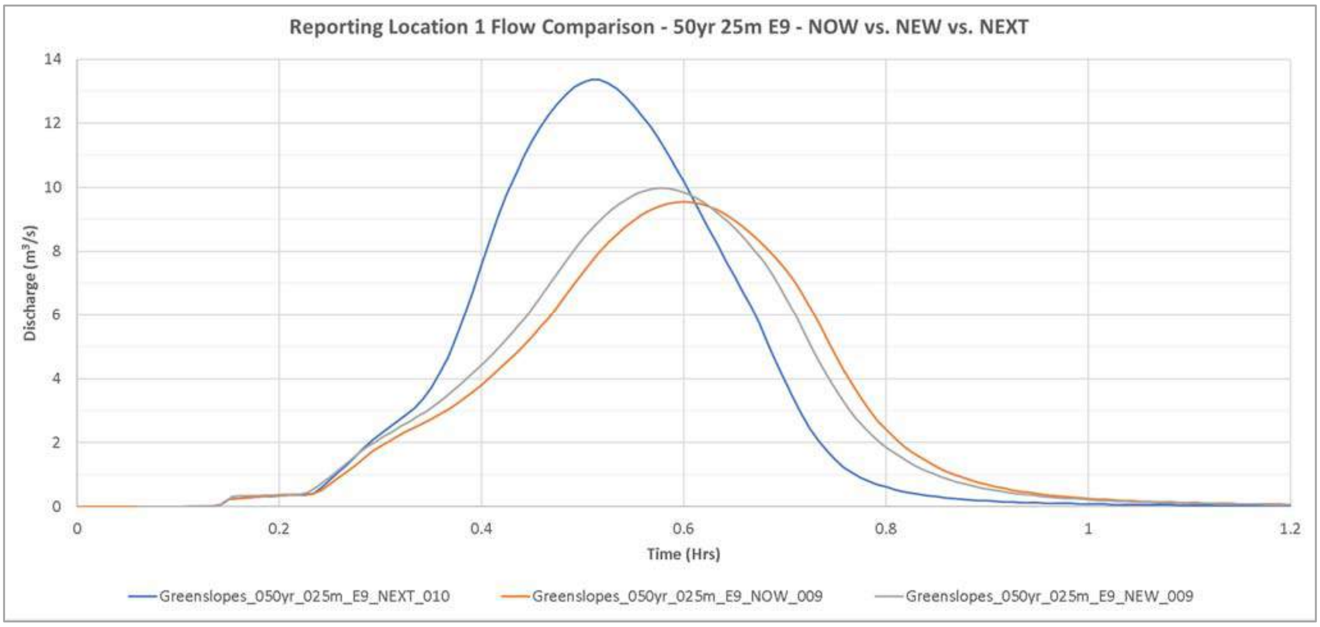


Figure 5-6 : Reporting Location 1 Discharge Comparison – 2% AEP 25min Ensemble 9

5.4.1 Timing and Peak Discharge Results Discussion

For the 2% AEP event, the time to flood peak was typically in the region of 20 to 36 minutes for the NOW scenario, depending on location within the catchment. The NEW scenario, which includes increased fraction impervious (compared to the NOW Scenario), resulted in a typical reduction in time to flood peak of approximately 0 – 2 minutes, with increases in peak discharge of typically between 0 – 10%, depending on location.

The NEXT Scenario is more hydraulically efficient than the NOW and NEW Scenarios, as it includes less floodplain blockage and generally lower Manning's n roughness. This is reflected in reductions in time to flood peak (compared to the NOW Scenario) of 1.5 – 5.5 minutes, with peak discharge increases between 10% and 60% in the 2% AEP event, depending on location.

It is worth noting that differences in time to peak between the NOW and NEXT Scenario for other AEPs are generally similar to the 2% AEP, meaning that the NEXT Scenario hydrographs typically peak 0 – 6 minutes earlier (compared to the NOW Scenario) for each AEP, depending on location.

Putting these times to peak into an evacuation context, BCC's *Flood Planning Scheme Policy* (BCC City Plan, 2014) recommends a minimum of 10 hours or more warning to effectively implement an evacuation. Evacuation is; therefore, not a primary consideration in the context of mitigating flood risk, for any of the three events analysed. Instead, other forms of flood preparedness, awareness and response may be required to mitigate risks during these short-duration events.

5.5 Flowpaths

No new additional flowpaths are formed in the NEW and NEXT scenarios, compared to the NOW Scenario. However, localised changes in flowpath widths are observed in larger events in the NEXT Scenario (compared to NOW Scenario), in the upstream catchment (southern branch) along Hunter Street. This is primarily due to changes in building types at (and in the vicinity of) 43 and 64 Hunter Street in the NEXT Scenario. Figure 5-7 and Figure 5-8 below provide a maximum flood extent comparison between the NOW (red) and NEXT (blue) Scenarios for the 2% AEP event at this location. Flood extents are shown only where depths are greater than 50mm.

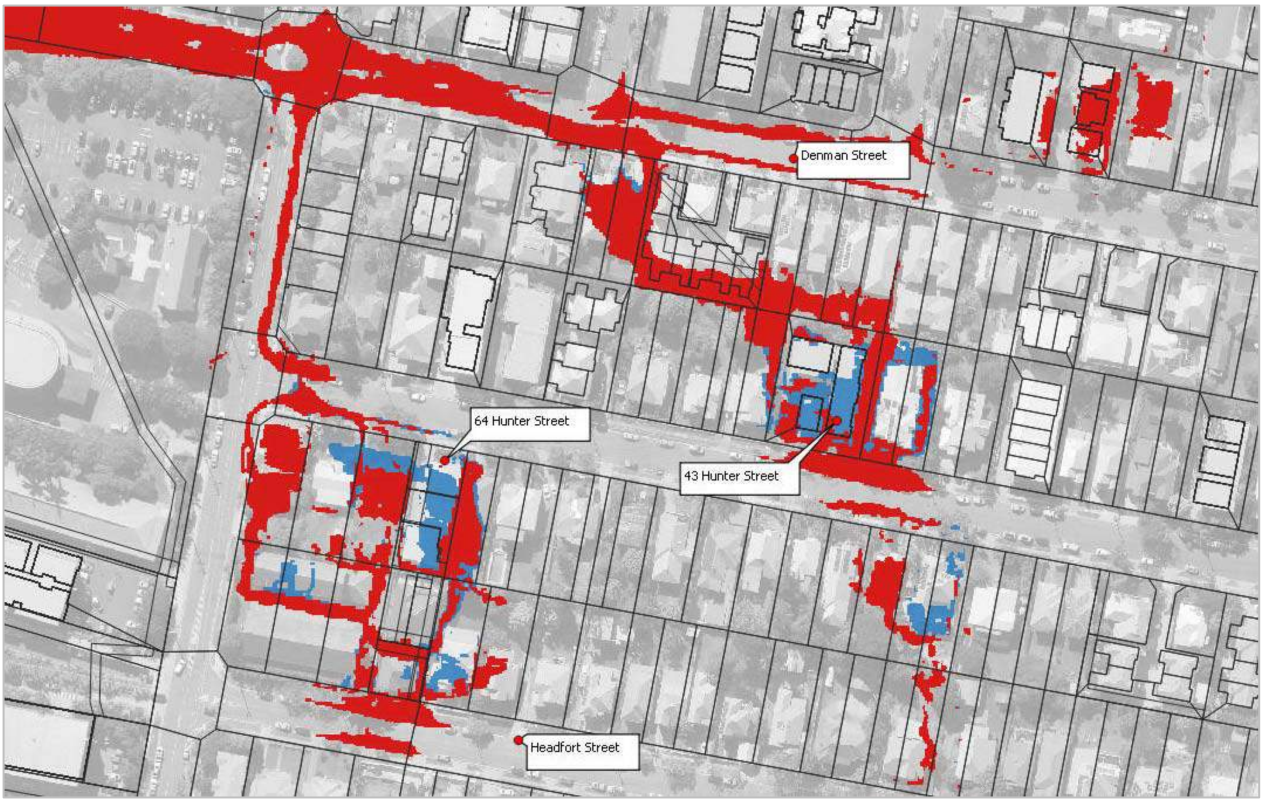


Figure 5-7: 2% AEP extent – Hunter Street – NOW Scenario (red) overlaid on NEXT Scenario (blue)

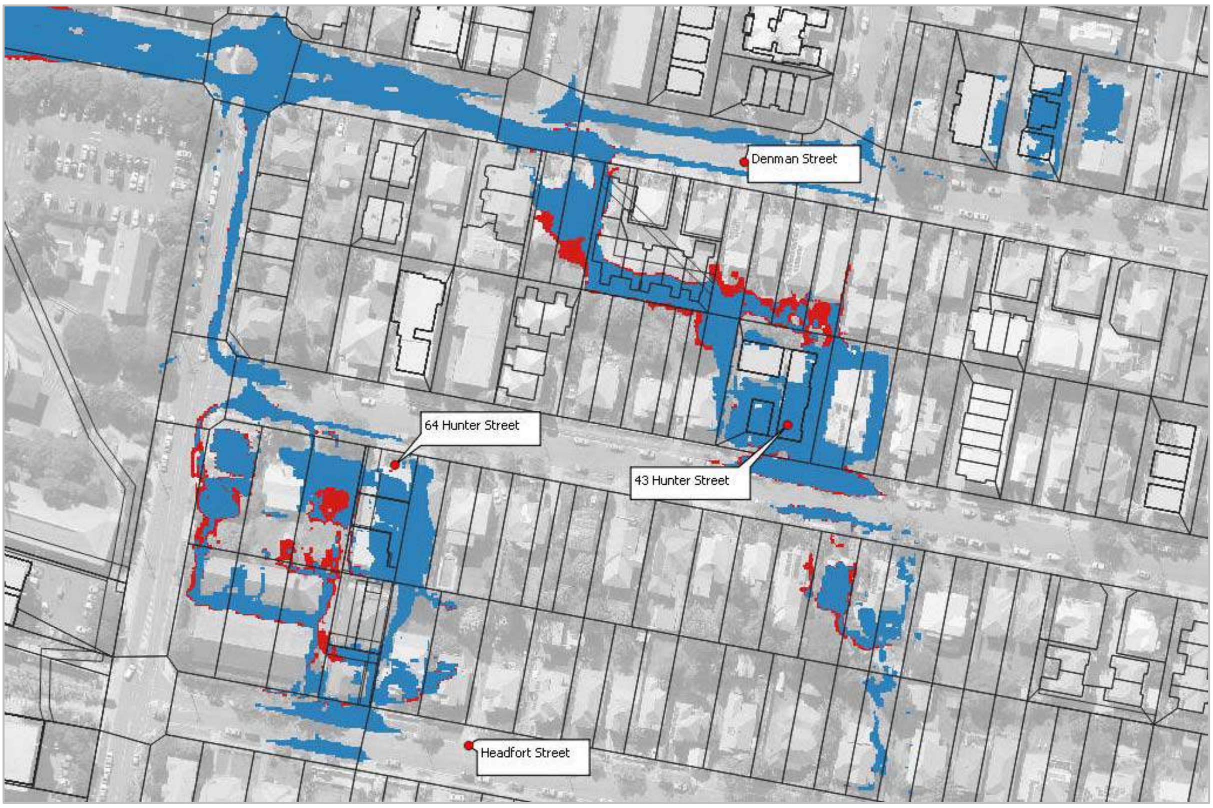


Figure 5-8: 2% AEP extent – Hunter Street – NEXT Scenario (blue) overlaid on NOW Scenario (red)

5.6 Sensitivity Assessment

5.6.1 Existing Wetland Level (Dry) Tailwater Boundary

A sensitivity scenario was simulated in the hydraulic model to assess the impacts of a 'dry' tailwater boundary. For all simulated AEPs, the TUFLOW 2d_bc tailwater boundary file was amended to a level equivalent to the existing downstream wetland level. This level is approximately 3m AHD and is the wetland level where excess floodwaters begin to drain through the outlet culvert. This sensitivity scenario was assessed for the 39%, 10% and 2% AEP events only, for all three scenarios.

Observations from this sensitivity run are as follows:

- The adopted tailwater level has a very minimal backwater effect on pipe and overland flow discharges in the lower catchment between Bunya Street and the stormwater network outlet. Flood depths in the lower catchment in this sensitivity run are; therefore, more sensitive to changes in overland flow discharges;
- For the 39% AEP event, all flows are now confined within the underground pipes in the NOW, NEW and NEXT Scenarios between Peach Street and the downstream outlet into the wetland; and
- For the 10% and 2% AEP events between Bunya Street and the downstream pipe outlet, flood depth increases in the NEW/NEXT Scenarios (compared to the NOW Scenario) are now slightly higher compared to those observed in the simulations with a coincident tailwater boundary.

5.6.2 NEXT Scenario –Rainwater Tank Storage

A sensitivity scenario was simulated in the hydraulic model to assess the impacts of lot-scale flood storage. Flood storage was incorporated into the NEXT Scenario (called 'NEXT+Storage'), on the assumption that all new/reconfigured buildings within the floodplain have rainwater tanks installed.

The following assumptions were made when determining volume and location of flood storage to be incorporated into the NEXT Scenario model:

- Only new and reconfigured buildings within the floodplain were considered for rainwater tank inclusion. This was therefore limited to buildings in 43 sub-catchments (out of 146 total sub-catchments), generally located within the overland flow path conveyance area;
- Rainwater tank storage was calculated for each building, based on building type. Adopted tank volumes were as follows -
    - Unit - 2000L
    - Townhouse – 3000L
    - House – 5000L
- A 100% efficiency of rainwater collection was assumed from the roof into the tank. The typical efficiency of collection is approximately 80-85%, as per Australian Government Department of Health guidelines (*Guidance on Use of Rainwater Tanks,* Environmental Health Standing Committee, March 2011). This only affects events where the total volume of design event rainfall (falling onto a building roof) is similar or less than the total available tank storage; and
- Tanks were assumed to be empty prior to an event, in order to simulate a 'best case' storage scenario.

Due to project time and budget limitations, a preferred rainfall-on-grid hydraulic modelling approach (or separated-storage hydrology modelling) for assessment of lot-scale rainwater tanks was not possible. Instead, rainwater tank storage was incorporated into the XPRAFTS model, as follows:

- Identify the total number and type of new and reconfigured buildings within the catchment;

- Calculate the total assumed rainwater tank storage for these buildings within the catchment, based on proposed building type and applicable tank volume, as defined above;
- Calculate the total building roof area and, for the downstream catchment critical duration event rainfall depth, calculate the total volume captured into the rainwater tanks, in each AEP event;
- Where total captured volume exceeds total available storage volume, cap to the total available storage volume;
- Calculate the depth (mm) of this captured volume, if it were to be applied uniformly over the impervious area portion of the XPRAFTS sub-catchments that contain at least one new/reconfigured building; and
- Apply this depth as an additional Initial Loss in the XPRAFTS model for the Impervious area portion of the XPRAFTS sub-catchments.

Based on the above methodology, total available tank storage was estimated to be 1,826m^3 and total applied additional initial loss was calculated as approximately 29.7 mm (2% AEP), 21.4 mm (10% AEP) and 14.6 mm (39% AEP).

This sensitivity run was assessed for the NEXT Scenario only, for the 39%, 10% and 2% AEP events. Observations from the sensitivity run are as follows:

- Prior to running this sensitivity check, hand calculations were undertaken to estimate volume differences between NOW and NEXT Scenario discharge hydrographs at key downstream locations in the catchment, for the 39%, 10% and 2% AEP events. Total volume differences were calculated from the hydrographs, where NEXT Scenario discharges are higher than NOW Scenario discharges, to provide a rough indication of the total storage volume to be added into catchment to reduce NEXT Scenario peak flows down to NOW Scenario peak flows. A table summarising AEP event vs. Reporting Location vs. Hydrograph volume difference in shown in Table 5-7. Volumes reported at Location F are approximately equivalent to the volume required to be detained within the whole catchment; and
- Based on these calculations, it is assumed that the inclusion of 1,826m^3 of rainwater tank storage into the TUFLOW model should roughly result in no increase to peak discharges in the catchment, in events up to and including the 10% AEP event (but less than the 2% AEP event).

Table 5-7: Discharge Hydrograph Volume Differences

AEP (Duration, Ensemble)[1]	Reporting Location	Volume difference (NEXT vs. NOW) (m^3) (Coincident Flood TWL)	Volume difference (NEXT vs. NOW) (m^3) (Dry TWL Sensitivity Run)	Approx. total event detained roof volume (based on critical IFD, applicable roof area and tank volume) (m^3)
39% (15m, E1)	P3	-5	0	900
39% (15m, E1)	F	-1	0	
10% (20m, E3)	D	573	528	1300
10% (20m, E3)	F	650	710	
2% (25m, E9)	D	1659	1677	1826[2]
2% (25m, E9)	F	2356	2323	

[1] Critical duration checked at each Reporting Location only.
[2] Total detained roof volume has been capped to total available tank volume

TUFLOW Model Results

TUFLOW model peak discharges between the NOW, NEXT and NEXT+Storage Scenario at downstream reporting locations is shown in Table 5-8. The changes to peak discharges in the NEXT scenario, when rainwater tank storage is included, generally aligns with the hand calculation observations described above. That is, peak discharges in the NEXT+Storage Scenario are lowered to approximately at or below NOW Scenario peak flows in downstream areas of the catchment, in the 39% and 10% AEP events. Peak discharges are lowered in the NEXT+Storage Scenario in the 2% AEP event, but are still higher than NOW Scenario peak discharges at the reporting locations analysed.

A comparison of flood depths in the 10% AEP event for the NOW Scenario and the NEXT+Storage scenario shows that there are still some isolated pockets of higher depths in the NEXT+Storage Scenario (compared to NOW Scenario).

This storage sensitivity assessment should provide the reader with a rough estimate of changes in catchment peak discharges at selected locations only. A more detailed hydrology model or rainfall-on-grid hydraulic model is recommended to obtain more reliable estimates for sizing and locating of storage areas.

Table 5-8: Storage Sensitivity Peak Discharge Comparison

AEP (Duration, Ensemble)	Reporting Location	Peak Discharge (NOW)	Peak Discharge (NEXT)	Peak Discharge (NEXT+ Storage)
39% (15m, E1)	P3	0.5	0.5	0.25
39% (15m, E1)	F	0.13	0.13	0.11
10% (20m, E3)	D	1.86	3.7	1.94
10% (20m, E3)	P3	2.2	4.25	2.1
10% (20m, E3)	F	2.9	4.9	2.65
2% (25m, E9)	D	8.3	10.9	10.4
2% (25m, E9)	F	9.55	13.4	12.6

6.0 Conclusions

This study has been undertaken as part of a wider assessment of exploring 'water sensitive urban intensification' opportunities to improve environmental performance and liveability for higher density living. The purpose of this study was two-fold:

- To assess the impact of future development with no intervention (land-use intensification) on overland flow flooding within the Greenslopes catchment in Brisbane; and
- To assess the impact of developed 'Water Sensitive' typologies on overland flow flooding within the Greenslopes catchment.

Three catchment scenarios were simulated in the investigation for a range of flood magnitudes, from 63% AEP to 0.05% AEP. The three scenarios were:

- NOW Scenario – Existing catchment conditions. Based on the current waterway conditions as at year 2020 (hydrology and hydraulic models);
- NEW Scenario – Fully developed catchment conditions (land use only). Based on fully developed land-use assumptions (hydrology model), with existing catchment building footprints (hydraulic model); and
- NEXT Scenario – Existing catchment conditions (hydrology model), with new typology building footprints within the overland flow conveyance corridor (hydraulic model), as per Appendix B.

Two sensitivity scenarios were also analysed, to consider the effects on catchment flows from a 'dry' tailwater boundary (all Scenarios) and from inclusion of rainwater tank storage into the catchment (NEXT Scenario). General observations from the simulation of these scenarios are as follows:

Flood Depths

<u>NOW Scenario</u>

The existing stormwater drainage network within the catchment is undersized. In certain sections, the network is incapable of fully containing 39% AEP storm event flows, with excess floodwaters surcharging the network in these areas and beginning to flow overland. Overland flow depths in this event are mostly in the range of 10 – 100mm. In the 10% AEP event, the majority of the pipe network runs full, with overland flow depths in the typical range of 50 - 500mm (varying considerably across the catchment, with higher depths in localised areas). In the 2% AEP event, overland flow flood depths are generally in the range of 100 – 800mm, with higher depths in localised areas.

<u>NEW Scenario</u>

There is a general minor increase in depths (compared to NOW Scenario) across the catchment, for all AEP events analysed. Depth increases across the catchment are generally within the range of 0 – 40 mm, with some isolated areas of higher increases. This is primarily due to higher peak discharges in the NOW Scenario, resulting from an increase in catchment imperviousness during development intensification.

<u>NEXT Scenario</u>

Minor increases in depths across most roads (of between 0 – 100mm at the reporting locations in all AEPs analysed) are observed compared to the NOW Scenario. The exception to this is at Cedar Street and Denman Street, along the southern stormwater branch (Locations 10 and 11), where moderate reductions in depths (of up to 150mm (10% AEPI) to 260 mm (0.5% AEP)) are observed.

Minor to moderate decreases in depths are observed across most ‘open undercroft’ residential lots within the overland flow path at the reporting locations analysed, with larger decreases in the vicinity of 30 Newdegate Street (40 – 450 mm decrease) and 85 Cedar Street (190 – 500mm decrease). Some minor to moderate increases in flood depths are observed at several residential lots, mainly where the new building footprints in the NEXT Scenario create a barrier to floodwaters and where buildings that create a blockage to flow are located directly downstream of ‘open undercroft’ buildings.

Flood Hazard

<u>NEW Scenario</u>

There is a general minor increase in flood hazard (depth x velocity product) in the NEW Scenario (compared to NOW Scenario) across the catchment. This is primarily due to minor increases in catchment imperviousness in the NEW Scenario, which result in marginally higher catchment peak discharges, depths and velocities. For all AEPs analysed, hazard increases are generally within the range of 0 – 0.1 m^2/s, with some isolated areas of up to 0.2 m^2/s observed in larger events (2% and 0.5% AEPs). However, these flood hazard increases are relatively minor, compared to absolute hazard values in the NOW Scenario.

<u>NEXT Scenario</u>

Both minor to moderate decreases and increases in flood hazard (depth x velocity product) are observed throughout the catchment in the NEXT Scenario, compared to the NOW Scenario.

Flood hazard is typically higher in the NEXT Scenario, in locations where flows are higher (i.e. - downstream areas) and more concentrated, where Manning’s n ground level roughness is lower and where flows have been re-directed. Conversely, flood hazard is typically lower in the NEXT Scenario at locations where flows were previously highly constricted in the NOW Scenario (i.e. - between existing building blockages) and sometimes along existing flow paths that have subsequently been re-directed in the NEXT Scenario.

This variability in flood hazard may be due to the apparent ‘straightening’ and ‘widening’ of the flowpaths (and lowering of average Manning’s n roughness) through residential lots in the NEXT Scenario, resulting in a higher concentration of flows, compared to the more braided nature of floodwaters (due to more blockages) in certain sections of the NOW Scenario catchment.

Flood Hazard Categories (AEMI)

<u>NEW Scenario</u>

Flood hazard increases are relatively minor in the NEXT Scenario, compared to absolute hazard values in the NOW Scenario, so there are only minimal differences in flow hazard category (AEMI) mapping when comparing NOW and NEW Scenarios.

<u>NEXT Scenario</u>

For the 39% AEP event, flood hazard along the overland flow paths is similar between NOW and NEXT Scenarios and is generally in the lowest H1 category (safe for buildings, people and vehicles), with isolated pockets of higher category H2 hazard (unsafe for small vehicles).

For the 10% AEP event, higher hazard areas affecting vehicles, children and the elderly (H2 and H3 hazards) are ‘dampened’ out (i.e. – slightly lowered) in the upper catchment areas (compared to the NOW Scenario). Conversely, there are increases in higher hazard areas in the NEXT Scenario, affecting all people and some buildings (H3-H5 hazards), in the lower catchment from Bunya Street to Pear Street.

The 2% AEP event comparison was similar to the 10% AEP event, with an exception being that there are now observed increases in the NEXT Scenario in higher hazard areas, affecting all people and some buildings (H3-H5 hazards) in the southern stormwater branch (upper catchment) from Cedar Street to Ridge Street.

Flood Timing/Peak Discharge

Time to flood peak is marginally shorter (typically within 0-2 minutes) and overland flow peak discharge marginally higher (typically within 0-10%) in the NEW Scenario, compared to the NOW scenario.

The NEXT Scenario is more hydraulically efficient than the NOW and NEW Scenarios, as it includes less floodplain blockage and generally lower Manning's n roughness. This is reflected in reductions in time to flood peak (compared to the NOW Scenario) of 1.5 – 5.5 minutes and peak discharge increases between 10% and 60%, depending on location.

Sensitivity Testing

Two sensitivity scenarios were analysed in the hydrology and hydraulic models:

- Tailwater Boundary set to downstream wetland level; and
- Inclusion of rainwater tank storage, limited to the assumptions outlined in Section 5.6.2.

Lowering the tailwater level to the downstream wetland level reduced backwater effects in the downstream catchment between Bunya Street and the stormwater network outlet. Flood depths in the lower catchment were; therefore, more sensitive to changes in overland flow discharges in the NEW and NEXT Scenarios, compared to the simulations with a Norman Creek coincident flood tailwater level.

Inclusion of rainwater tank storage in the NEXT Scenario [equivalent of up to 1,826 m^3 volume removed from TUFLOW model (depending on AEP)] resulted in the reduction in peak discharges throughout the catchment (compared to the NEXT Scenario with no storage included). At select key locations within the catchment, peak discharges in the NEXT Scenario were now generally similar or lower (compared to the NOW Scenario) for events up to the 10% AEP event. However, due to project time/budget limitations, this sensitivity assessment is a rough estimation of catchment storage effects only. It is recommended to develop a more detailed hydrology/hydraulic model for sizing/locating storage areas.

Potential Future Work

- Extend the scope of the NEW and NEXT Scenarios to the whole catchment and assess impacts to catchment hydrology/hydraulics. Changes made in these Scenarios (compared to the NOW Scenario) have only been applied within the main overland flow paths in this study;
- NEXT Scenario design refinement of building location/building type to alleviate areas of high blockage;
- Assess the impacts of inclusion of proposed relief drainage into the hydraulic model, on all Scenario results; and
- Refine the hydrology and/or hydraulic models to be fit-for-purpose for analysing a detailed 'rainwater tank' flood storage Scenario. The storage sensitivity scenario undertaken in this assessment is broad-based and is to be referenced as a guide only.

APPENDICES

Appendix A – NEW Scenario Land-Use Intensification

Appendix B – NEXT Scenario Building Typologies

Table 1 Built cover Ratio

	Now	New
Total Area (sq.m)	7120	7120
Roof (%)	22	42
Garden (%)	73	41
Pavement (%)	5	17

The comparison between now and new shows the roof area's and pavement increased by 20 and 12% respectively however the garden areas reduced by 32%.

CASE 2

Now Scenario

This scenario reflects the 2009 spatial arrangement. In this scenario the site comprised of 9 lots with a large backyard and a higher proportion of unpaved pavements. This site is located between Latimer street and Plimsoll Street, Greenslopes. Figure 3: now scenario. This image is sourced from nearmap image.

Figure 3: now scenario

NEW Scenario:

This scenario is based on 2019 spatial representation. Due to infill development the number of sites increased from 9 to 15 in next scenario.

Table 2: build over ratio

	NOW	NEW
Total Area (sq.m)	3545	3545
Roof (%)	28	39
Garden (%)	69	48
Pavement (%)	3	13

The comparison between now and new shows the roof area's and pavement increased by 11 and 10% respectively however the garden areas reduced by 21%.

In summary Table 3 present the increase in the new scenario is approximately around 26%.

Table 3: summary table of the two case studies

	NOW	NEW
imp	29	55.5
per	71	44.5

NEXT Scenario

From the typologies that Monash university developed, the roof, garden and pavement have been measured for the CAD layout plan provided. There are 4 typologies. refer to Appendix A document for further details on the typologies. the summary of the finding is captured in table Table 4 and Table 5.

Table 4: NEXT - typology surface ratios

	Garden	Roof	Pavement
Type-A	50%	32%	18%
Type-B1	40%	34%	26%
Type-B2	61%	31%	8%
Type-C	38%	40%	22%
Average	**50%**	**33%**	**17%**

Table 5: NOW – surface ratio's

	Garden	Roof	Pavement
Type-A	48%	39%	14%
Type-B1	50%	39%	11%
Type-B2	54%	35%	17%
Type-C	40%	43%	13%
Average	**49%**	**38%**	**13%**

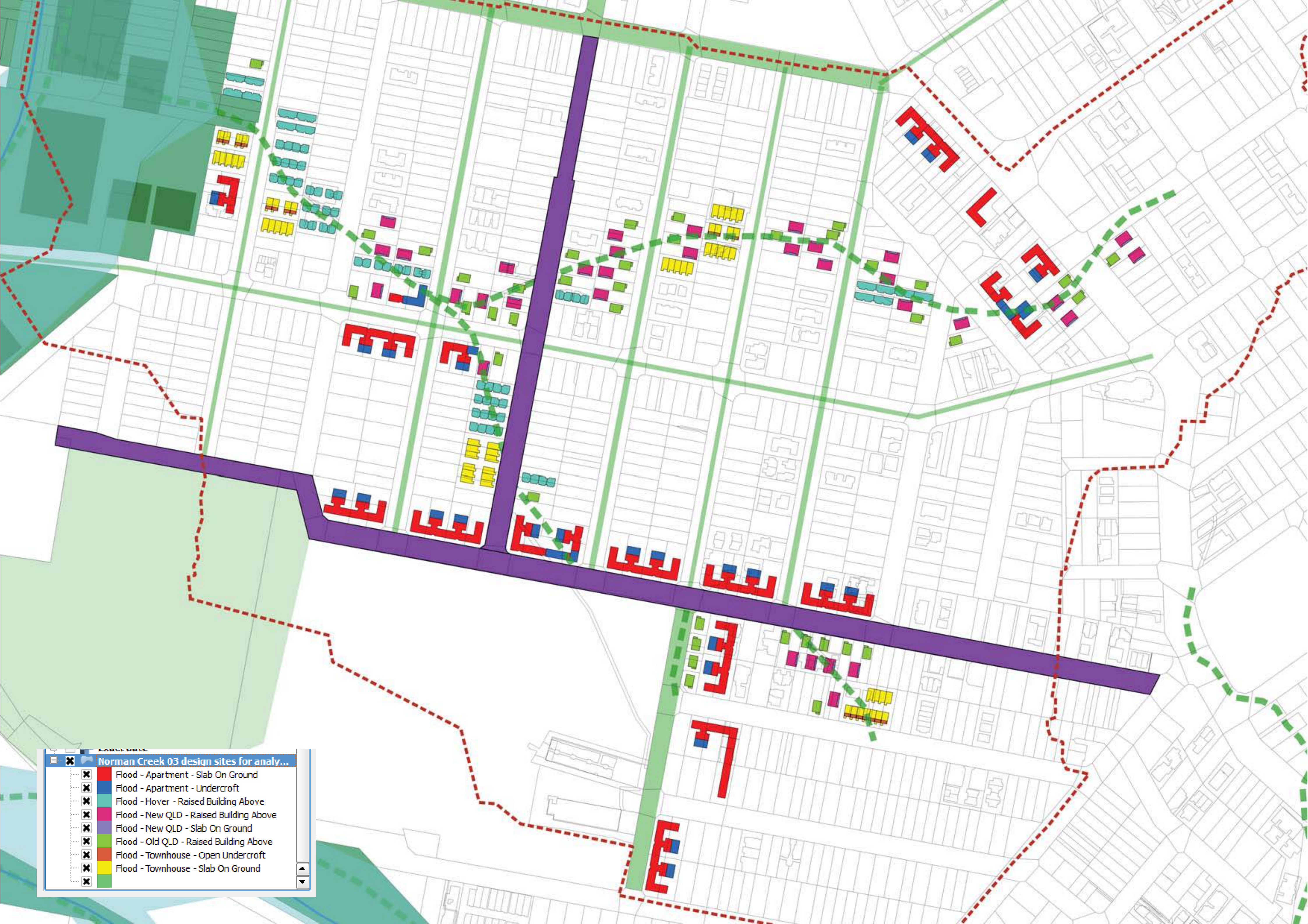
It should be noted that the pavement area proposed in the typologies is assumed to be porous pavement and it the modelling is has been assumed to have 50% imperviousness.

In the hydrology modelling in XPrafts for Table 6 provide a summary of the setting for NOW, NEW and NEXT scenario. Due to the small nature of changes in imperviousness ratio between NOW and NEXT scenario, the hydrology for these two scenarios remains unchanged.

Table 6: summary table for hydrology model with XPrafts mode

Surface Type	Now (%)	NEW (%)	NEXT
Pervious (Garden)	GIS calculated value for each catchment	100 – (NOW+26%)	Now
Impervious (roof and pavement)	GIS calculated value for each catchment	NOW+ 26%	Now

Appendix B – NEXT Scenario Building Typologies


Norman Creek 03 design sites for analy...
Flood - Apartment - Slab On Ground
Flood - Apartment - Undercroft
Flood - Hover - Raised Building Above
Flood - New QLD - Raised Building Above
Flood - New QLD - Slab On Ground
Flood - Old QLD - Raised Building Above
Flood - Townhouse - Open Undercroft
Flood - Townhouse - Slab On Ground

XP-RAFTS - NOW Scenario Subcatchment Parameters			
Subcatchment Name	Percentage Impervious [%]	Total Area [ha]	Vectored Slope [%]
O17037418	100	0.0783	5.9
O17037427	100	0.0513	5.7
NT1	59	0.20461	6.4
O17037428	70	0.4542	9
O17037692	60	0.7486	6
O17036719	61.99	1.2425	13
O17037693	75.3	0.7805	4.9
O17037611	78.53	1.1166	4.8
O17037772	84.47	0.776	4.3
O17036724	100	0.0237	7.8
O17036718	79.75	0.2454	10.4
O17036725	87.1	0.17	15.5
O17036723	100	0.0482	13.5
O17036726	100	0.0701	16.3
O17037425	65.87	0.20461	8.3
O17036729	64.18	0.3213	7.6
O17036720	73	0.0189	13.5
O17037438	86	0.1287	6.1
O17037419	72.03	0.8452	6.3
O17037420	80.48	0.2091	7.9
O170370641	84.78	0.7246	5.6
O17037421	70	1.0101	6.4
GO17037064	69.74	0.3228	6.4
O17037064	69.74	0.3228	7
O17037066	67.62	0.4889	14.6
O17036728	99.22	0.0845	7
O17037524	68	0.3776	5.5
O17037610	68.45	0.248	4.9
O16037386	86	0.1287	9.2
O16037481	59.66	0.7131	6.2
O16037482	51	1.6145	4.3
O17037490	77	0.0089	4.4
O17037433	71	0.7818	6.6
O17037434	100	0.1526	6.5
O16037491	54	1.7065	5.7
O17037489	52	0.1547	8.1
O16037488	69	0.4302	8.5
O16037487	100	0.0611	6.7
O16037483	96	0.1185	8.8
O16037388	57	0.6761	3.5
O17037527	54	0.342	6.2
O17037525	57	0.7634	6.4
O17037543	54.29	0.8965	5.2
O17037528	100	0.0392	3.5
O17037541	60	1.6233	4.5
O17037539	67.47	0.54	7.7
O17037426	100	0.0919	7.4
O17037441	100	0.1875	6.8

XP-RAFTS - NOW Scenario Subcatchment Parameters			
Subcatchment Name	**Percentage Impervious [%]**	**Total Area [ha]**	**Vectored Slope [%]**
O16037389	100	0.0561	3.5
O16037387	73.33	0.3323	10
O17037436	86	0.1287	5.6
O17037435	43	0.7341	5.9
O17037429	99	0.0681	8.4
O17037542	75.38	0.6126	5.1
O17037540	71.91	0.3575	7.7
O17037526	100	0.0613	6.1
O17037595	100	0.1373	2.9
O17037529	67	0.9947	5.4
O17037538	56.23	0.7524	6
P17002608	100	0.0915	8.2
O17037594	61.25	0.9073	7.5
O17037589	100	0.0797	0.8
O17037545	63	0.4469	5.1
O17037590	61.76	0.759	6.5
O17037593	55.9	1.2659	9
O17037494	58	1.2151	5.5
O17037591	52.93	0.6532	4.4
O17037592	52.39	0.2516	5.3
O17037544	88	0.5909	4.3
O17037846	100	0.0726	8.2
O16037549	62.39	0.1045	8.4
O16037548	59	0.7521	6.4
O17037560	63	0.0995	4
O17037586	74	0.2469	9
O17037562	54	0.1195	7.2
O17037597	100	0.0851	3.7
O16037556	80	2.85	6.4
O17037588	100	0.0707	7.6
O17037561	81.7	0.3023	8.6
O17037587	58.8	1.3322	5.3
O17037596	62	1.9667	5.6
NT4	69.5	4.1578	10.6
O16037534	52.69	1.546	3.5
O16037843	55	0.3826	7.9
O16037553	39	0.3189	4.4
O16037547	54	0.0816	3.5
O17037546	59	0.7521	6.2
O16037552	100	0.0622	6
O16037478	54	0.7173	7.5
O16037479	76.65	0.2268	7.5
O16037480	68.19	0.6635	7.3
O17037530	74.69	0.3625	2.5
O17037422	94	1.111	6.9
O17037423	100	0.0136	6.9
O16037522	100	0.2142	5.6
O17037531	65.2	0.3124	2.4

XP-RAFTS - NOW Scenario Subcatchment Parameters			
Subcatchment Name	**Percentage Impervious [%]**	**Total Area [ha]**	**Vectored Slope [%]**
O16037492	71.9	0.0364	8.6
O16037533	54	0.6912	8.2
O17037532	100	0.612	5.5
O16037397	58.75	0.9771	7.1
O16037477	78	0.0933	5
O16037390	100	0.0665	6.5
O16037476	100	0.073	6.2
NT3	100	0.1812	3
O16037399	48.7	0.9649	3.9
O16037401	55	0.6053	7.6
O16037398	100	0.0309	2.4
O16037563	42	0.6917	13.4
O16037400	100	0.0531	3.9
O16037568	58	1.2938	2.9
O16037567	97	0.1111	4.4
O16037396	70	0.3236	9.3
O16037373	100	0.0794	4.4
O16037566	100	0.1431	10.7
O16037845	100	0.0575	10.2
O16037394	100	0.064	11.1
O17037415	68	0.7228	5.9
O16037393	20	1.0692	13.7
O16037391	100	0.0506	6.6
O16037392	57	0.8	11.6
O16037374	100	0.0142	2.4
O16037375	100	0.0849	2.5
O16037395	100	0.0529	10.4
O16037493	68	0.4321	8.3
O16037554	98	0.001	4.3
O16178525	90	0.0705	4.3
O17037523	100	0.0639	2.7
NT2	0.39	0.5503	7.9
O17037773	100	0.1242	14.1

Appendix D – Flood Depth Mapping

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
Greater than 1

N W E S

0 40 80 120
Metres

Prepared : 089958
Checked : NC
Revision : 0
Publication Date : 02 Jun 2020
Project Number : 200937

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Figure D1 - 2yr ARI – NOW Scenario Flood Depth Map

GDS - 200937 - 009

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Depth (m)

- 0.1 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1
- Greater than 1

N E S W

0 40 80 120
Metres

Prepared : 089958
Checked : NC
Revision : 0
Publication Date : 03 Jun 2020
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Figure D2 - 10yr ARI – NOW Scenario Flood Depth Map

GDS - 200937 - 010

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)

- 0.1 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1
- Greater than 1

N
W E
S

0 40 80 120
Metres

Prepared : 089958
Checked : NC
Revision : 0
Publication Date : 03 Jun 2020
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Figure D3 - 50yr ARI – NOW Scenario Flood Depth Map

GDS - 200937 - 011

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Depth (m)

- 0.1 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1
- Greater than 1

N W E S

0 40 80 120

Metres

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Figure D4 - 200yr ARI - NOW Scenario Flood Depth Map

GDS - 200937 - 012

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
Greater than 1

N
W E
S

0 40 80 120
Metres

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Figure D5 - 2yr ARI – NEW Scenario Flood Depth Map

GDS - 200937 - 013

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
Greater than 1

N E S W

0 40 80 120
Metres

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Figure D6 - 50yr ARI – NEW Scenario Flood Depth Map

GDS - 200937 - 014

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
Greater than 1

N W E S

0 40 80 120
Metres

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Figure D7 - 2yr ARI – NEXT Scenario Flood Depth Map

GDS - 200937 - 015

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)

- 0.1 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1
- Greater than 1

N
W E
S

0 40 80 120
Metres

Prepared : 089958
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Figure D8 - 10yr ARI – NEXT Scenario Flood Depth Map

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GDS - 200937 - 016

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
Greater than 1

N
W E
S

0 40 80 120
Metres

Prepared : 089958
Checked : NC
Revision : 0
Publication Date : 03 Jun 2020
Project Number : 200937

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Figure D9 - 50yr ARI – NEXT Scenario Flood Depth Map

GDS - 200937 - 017

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Depth (m)
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
Greater than 1

N W E S

0 40 80 120
Metres

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Figure D10 - 200yr ARI - NEXT Scenario Flood Depth Map

GDS - 200937 - 018

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Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Afflux (m)

- Less than -0.5
- -0.5 to -0.2
- -0.2 to -0.05
- -0.05 to -0.01
- 0.01 to 0.05
- 0.05 to 0.2
- 0.2 to 0.5
- Greater than 0.5

N
W E
S

0 40 80 120
Metres

Prepared :	089958
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Revision :	0
Publication Date :	03 Jun 2020
Project Number :	200937

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Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_019_FigureD11.mxd

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Figure D11 - 2yr ARI NEW vs NOW Scenario Flood Depth Comparison Map

GDS - 200937 - 019

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Afflux (m)

- Less than -0.5
- -0.5 to -0.2
- -0.2 to -0.05
- -0.05 to -0.01
- 0.01 to 0.05
- 0.05 to 0.2
- 0.2 to 0.5
- Greater than 0.5

N W E S

0 40 80 120
Metres

Prepared : 089958
Checked : NC
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Figure D12 - 50yr ARI NEW vs NOW Scenario Flood Depth Comparison Map

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_020_FigureD12.mxd

GDS - 200937 - 020

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Afflux (m)

- Less than -0.5
- -0.5 to -0.2
- -0.2 to -0.05
- -0.05 to -0.01
- 0.01 to 0.05
- 0.05 to 0.2
- 0.2 to 0.5
- Greater than 0.5

N W E S

0 40 80 120
Metres

Prepared : 089958
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Figure D13 - 2yr ARI NEXT vs NOW Scenario Flood Depth Comparison Map

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_021_FigureD13.mxd

GDS - 200937 - 021

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Afflux (m)

- Less than -0.5
- -0.5 to -0.2
- -0.2 to -0.05
- -0.05 to -0.01
- 0.01 to 0.05
- 0.05 to 0.2
- 0.2 to 0.5
- Greater than 0.5

N W E S

0 40 80 120
Metres

Prepared : 089958
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Figure D14 - 10yr ARI NEXT vs NOW Scenario Flood Depth Comparison Map

GDS - 200937 - 022

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_022_FigureD14.mxd

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Afflux (m)

- Less than -0.5
- -0.5 to -0.2
- -0.2 to -0.05
- -0.05 to -0.01
- 0.01 to 0.05
- 0.05 to 0.2
- 0.2 to 0.5
- Greater than 0.5

N W E S

0 40 80 120
Metres

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Figure D15 - 50yr ARI NEXT vs NOW Scenario Flood Depth Comparison Map

GDS - 200937 - 023

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Afflux (m)

- Less than -0.5
- -0.5 to -0.2
- -0.2 to -0.05
- -0.05 to -0.01
- 0.01 to 0.05
- 0.05 to 0.2
- 0.2 to 0.5
- Greater than 0.5

N W E S

0 40 80 120
Metres

Prepared : 089958
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Figure D16 - 200yr ARI NEXT vs NOW Scenario Flood Depth Comparison Map

GDS - 200937 - 024

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N / W / E / S

0 40 80 120
Metres

Prepared :	089958
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Figure E1 - 2yr ARI – NOW Scenario Flood Hazard Map

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_025_FigureE1.mxd

GDS - 200937 - 025

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N E S W

0 40 80 120
Metres

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Figure E2 - 10yr ARI – NOW Scenario Flood Hazard Map

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_026_FigureE2.mxd

GDS - 200937 - 026

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N W E S

0 40 80 120
Metres

Prepared : 089958
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Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_027_FigureE3.mxd

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Figure E3 - 50yr ARI – NOW Scenario Flood Hazard Map

GDS - 200937 - 027

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N W E S

0 40 80 120
Metres

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Figure E4 - 200yr ARI – NOW Scenario Flood Hazard Map

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GDS - 200937 - 028

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N W E S

0 40 80 120
Metres

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Figure E5 - 2yr ARI – NEXT Scenario Flood Hazard Map

GDS - 200937 - 029

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_029_FigureE5.mxd

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N
W E
S

0 40 80 120
Metres

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Figure E6 - 10yr ARI – NEXT Scenario Flood Hazard Map

Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_030_FigureE6.mxd

GDS - 200937 - 030

Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N E S W

0 40 80 120
Metres

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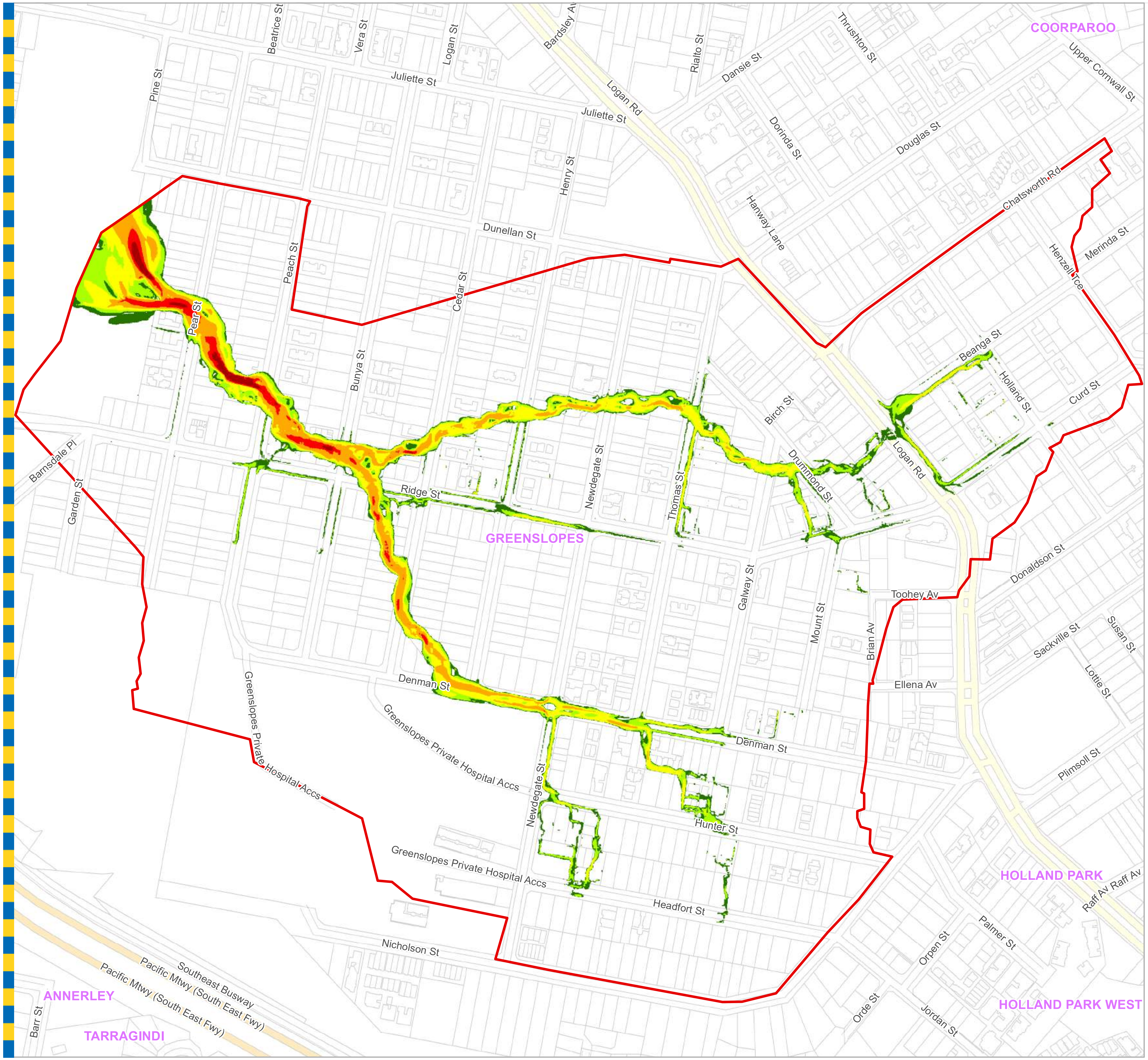
Figure E7 - 50yr ARI – NEXT Scenario Flood Hazard Map

GDS - 200937 - 031



Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

Flood Hazard (m2/s)

- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- 1 to 1.5
- Greater than 1.5

N W E S

0 40 80 120
Metres

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Figure E8 - 200yr ARI – NEXT Scenario Flood Hazard Map

GDS - 200937 - 032

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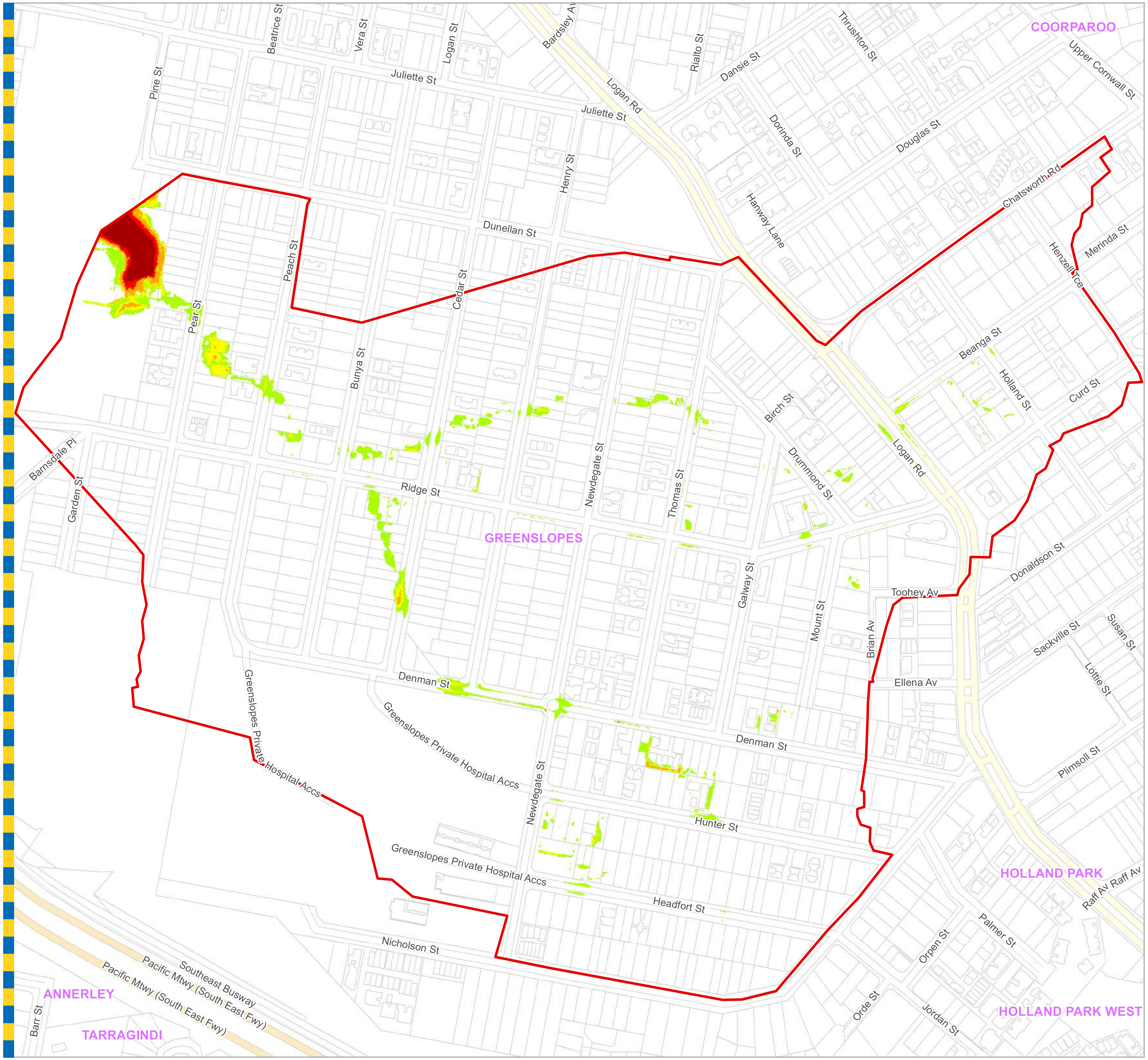
Appendix F – Flood Hazard Classification Mapping



Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Classification

- 1
- 2
- 3
- 4
- 5
- 6

N
W E
S

0 40 80 120
Metres

Prepared : 089958
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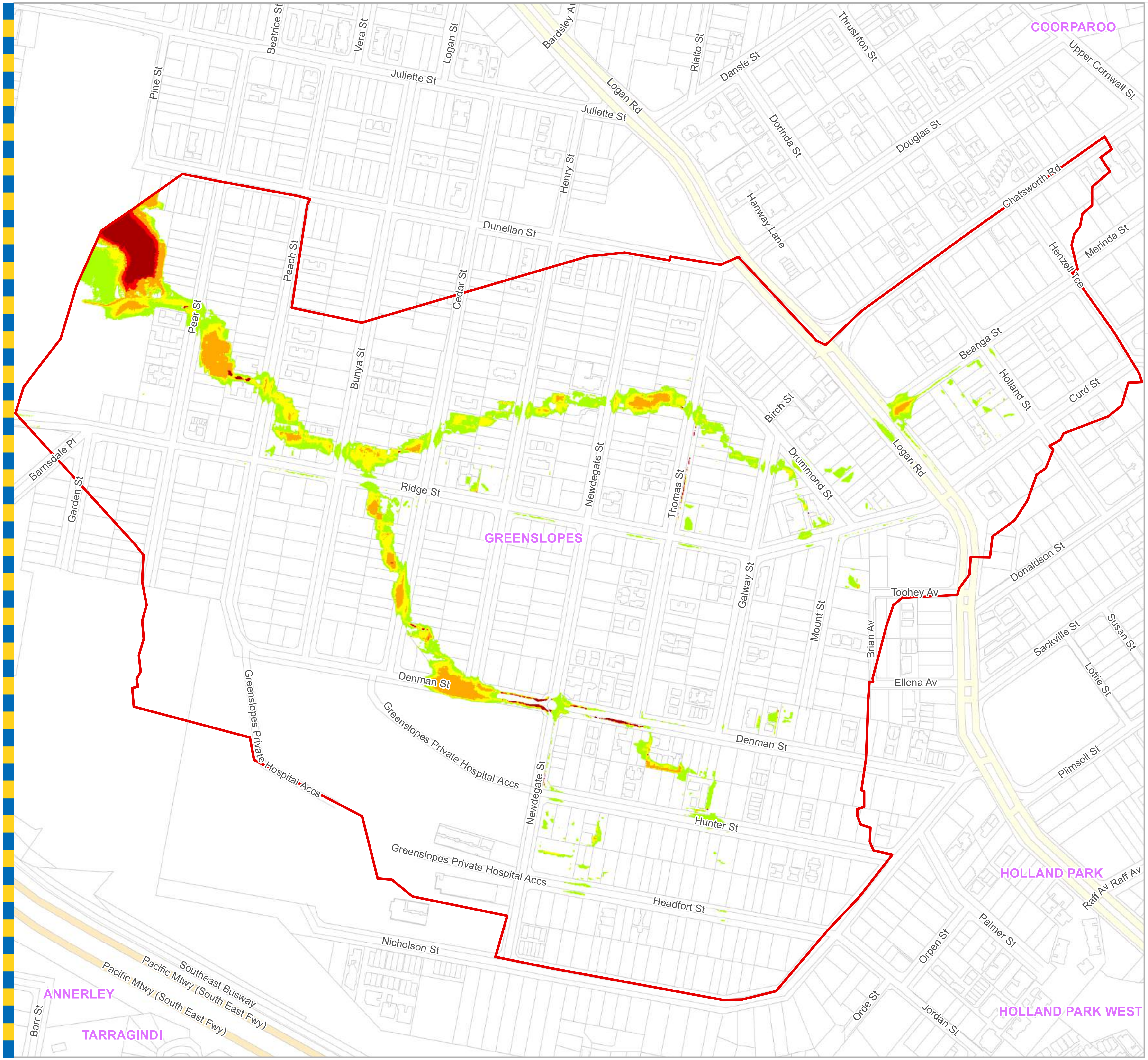
Figure F1 - 2yr ARI – NOW Scenario Flood Hazard Classification Map

GDS - 200937 - 033



Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Classification

- 1
- 2
- 3
- 4
- 5
- 6

N
W E
S

0 40 80 120
Metres

Prepared : 089958
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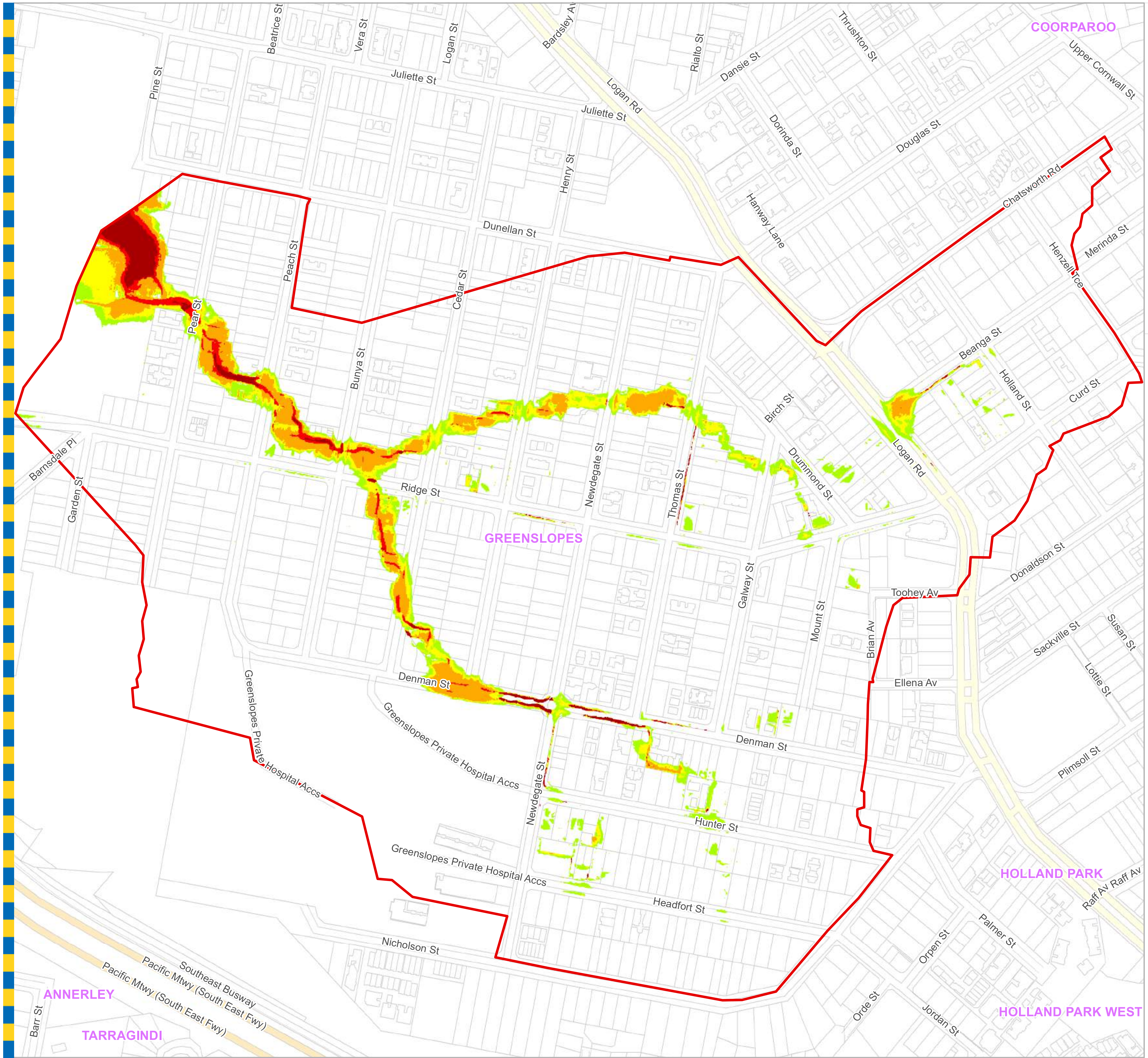
Figure F2 - 10yr ARI – NOW Scenario Flood Hazard Classification Map

GDS - 200937 - 034



Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Classification

1, 2, 3, 4, 5, 6

N, W, E, S

0 40 80 120
Metres

Prepared : 089958
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Publication Date : 04 Jun 2020
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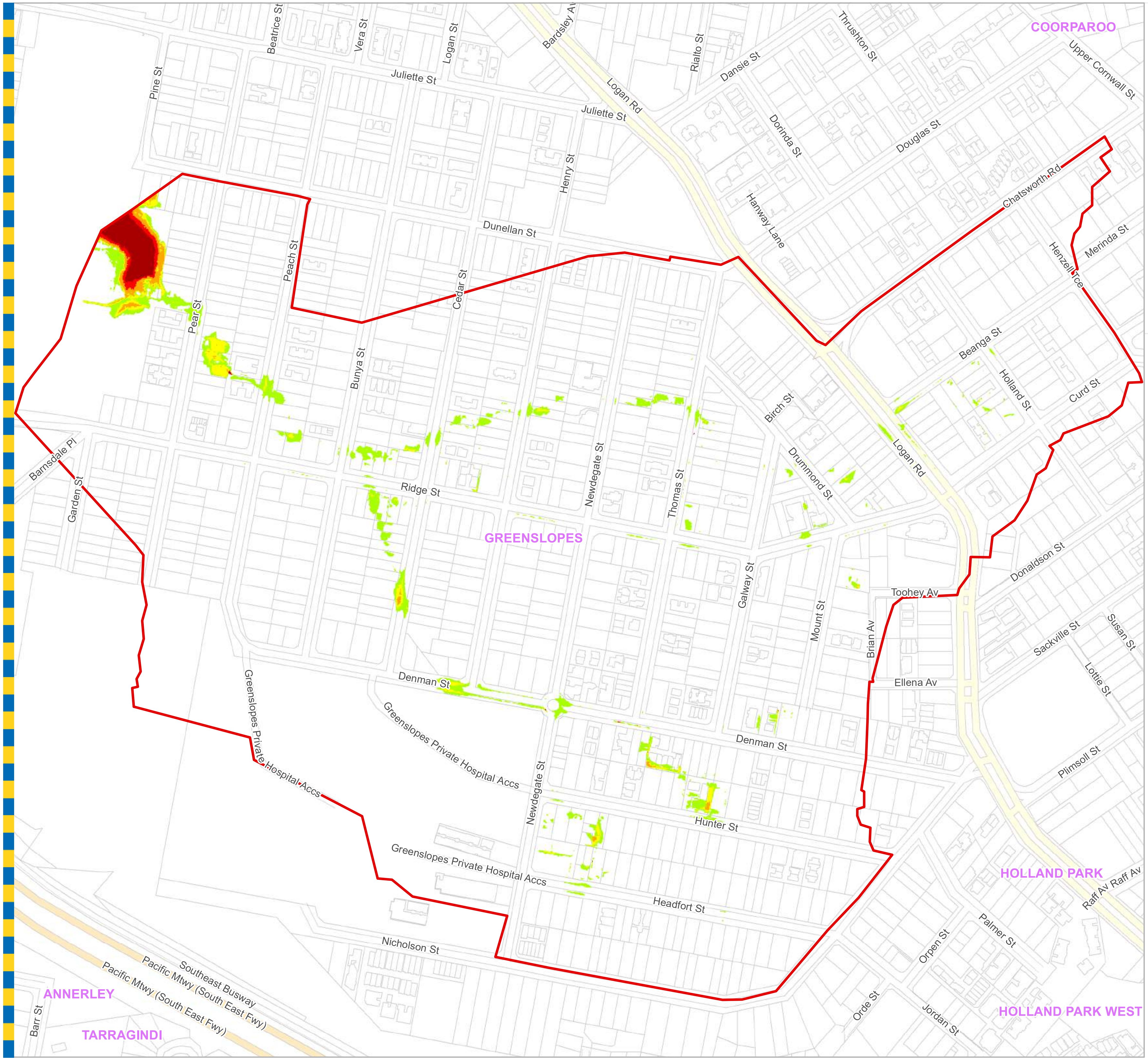
Figure F3 - 50yr ARI – NOW Scenario Flood Hazard Classification Map

GDS - 200937 - 035



Legend

	Freeways/Highways
	Major Roads
	Streets
	Tunnels
	Model Boundary
	Property Holdings

AEMI Hazard Classification

	1
	2
	3
	4
	5
	6

N W E S

0 40 80 120
Metres

Prepared : 089958
Checked : NC
Revision : 0
Publication Date : 04 Jun 2020
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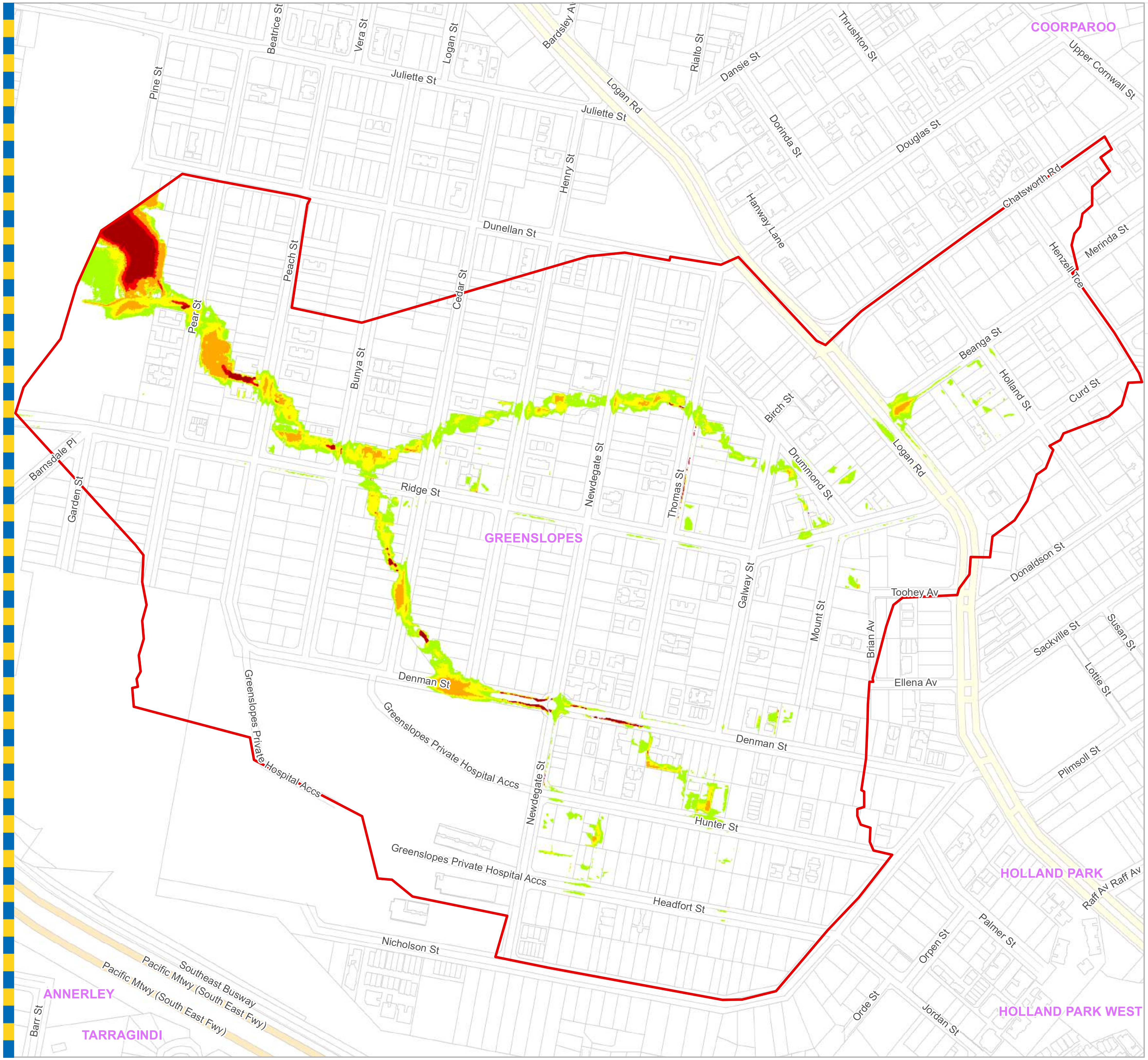
Figure F4 - 2yr ARI – NEXT Scenario Flood Hazard Classification Map

GDS - 200937 - 036



Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Classification

- 1
- 2
- 3
- 4
- 5
- 6

N E S W

0 40 80 120
Metres

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Figure F5 - 10yr ARI – NEXT Scenario Flood Hazard Classification Map

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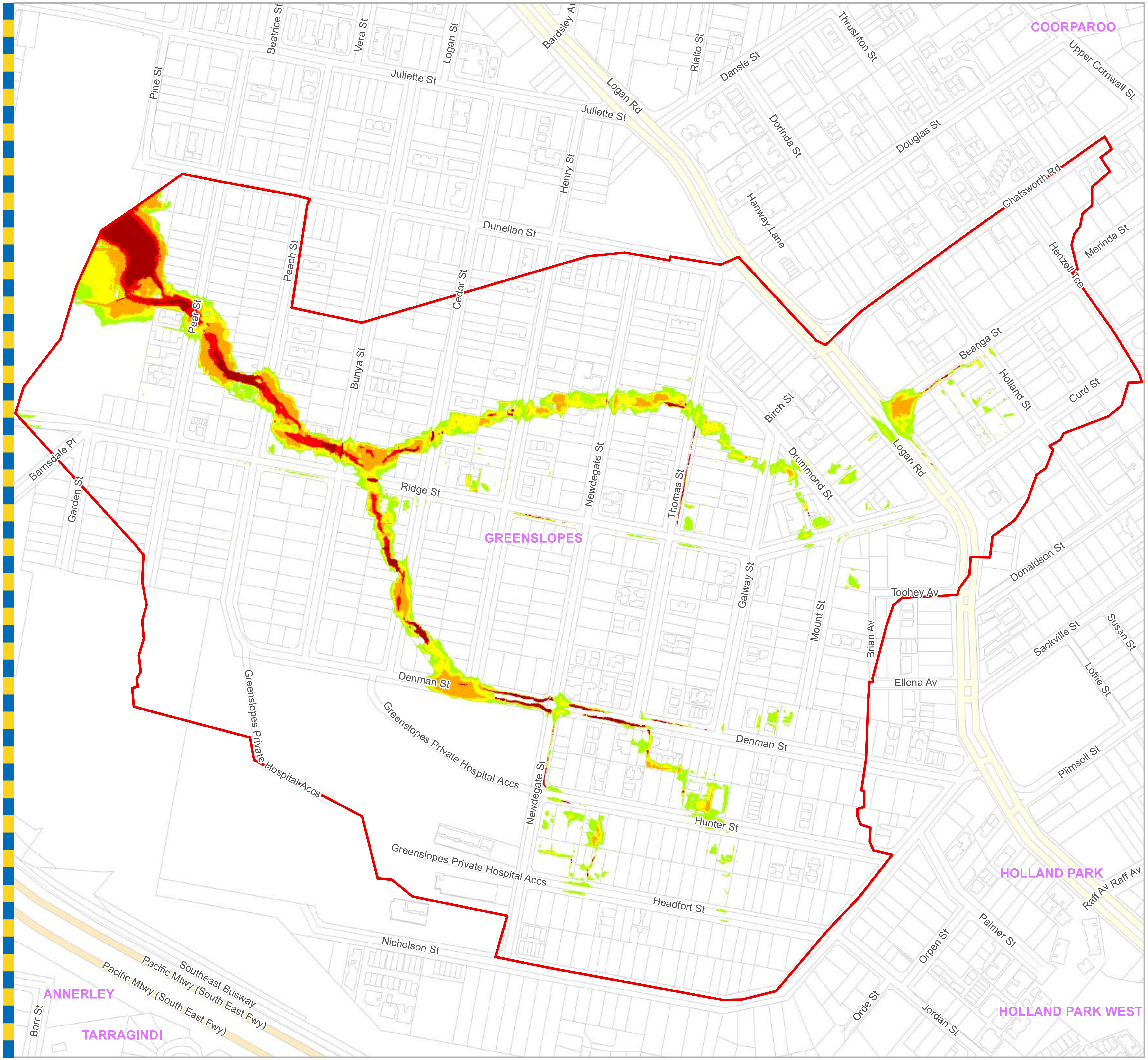

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Classification

- 1
- 2
- 3
- 4
- 5
- 6

N W E S

0 40 80 120
Metres

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Figure F6 - 50yr ARI – NEXT Scenario Flood Hazard Classification Map

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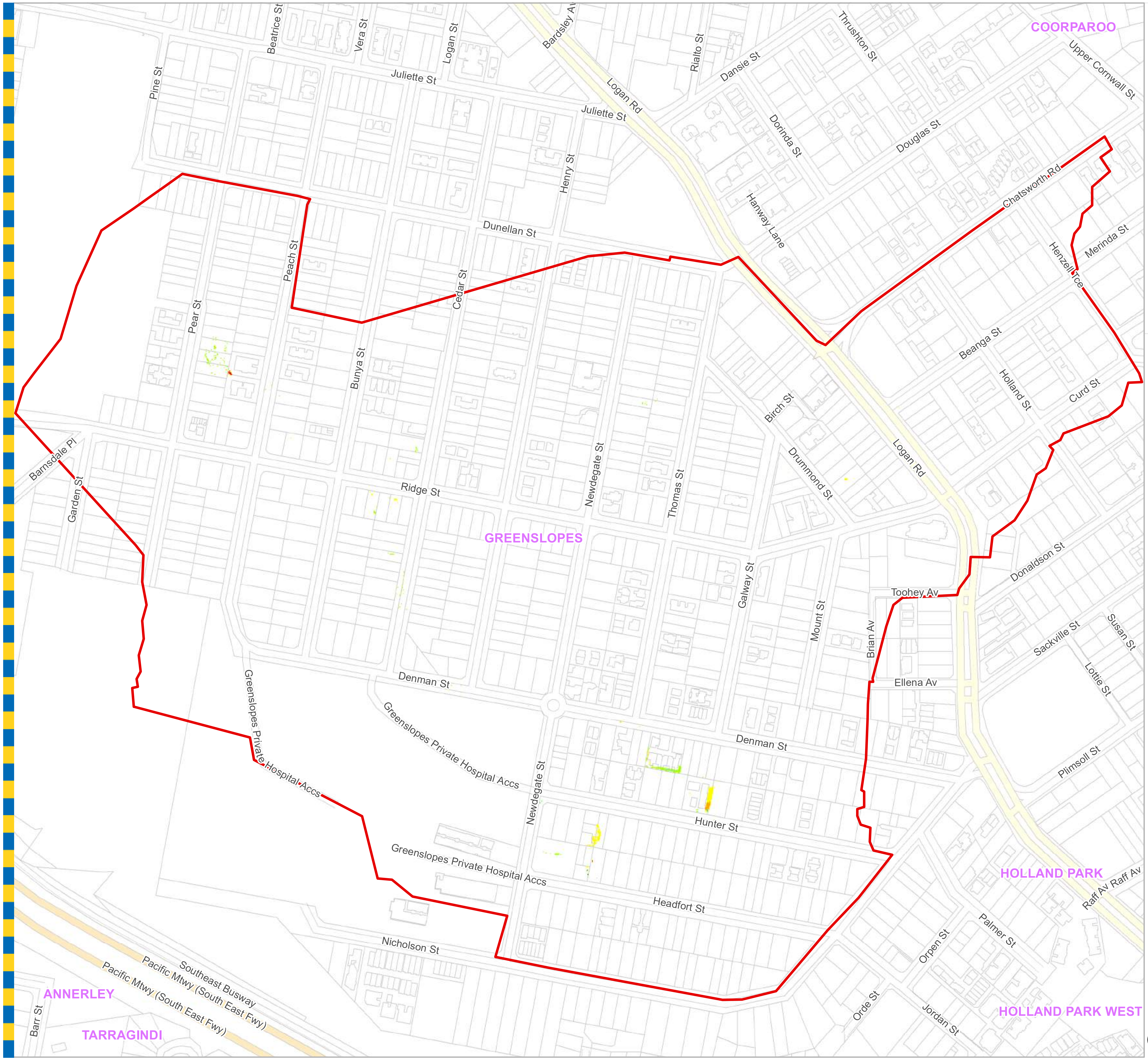
Location: G:\BI\CD\proj20\200937_Greenslopes_Overland_Flow\ArcGIS\GDS_200937_038_FigureF6.mxd



Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Class. Difference

- -3
- -2
- -1
- 1
- 2
- 3

N W E S

0 40 80 120
Metres

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Figure F7 - 2yr ARI – NEXT vs NOW Scenario Flood Hazard Classification Comparison Map

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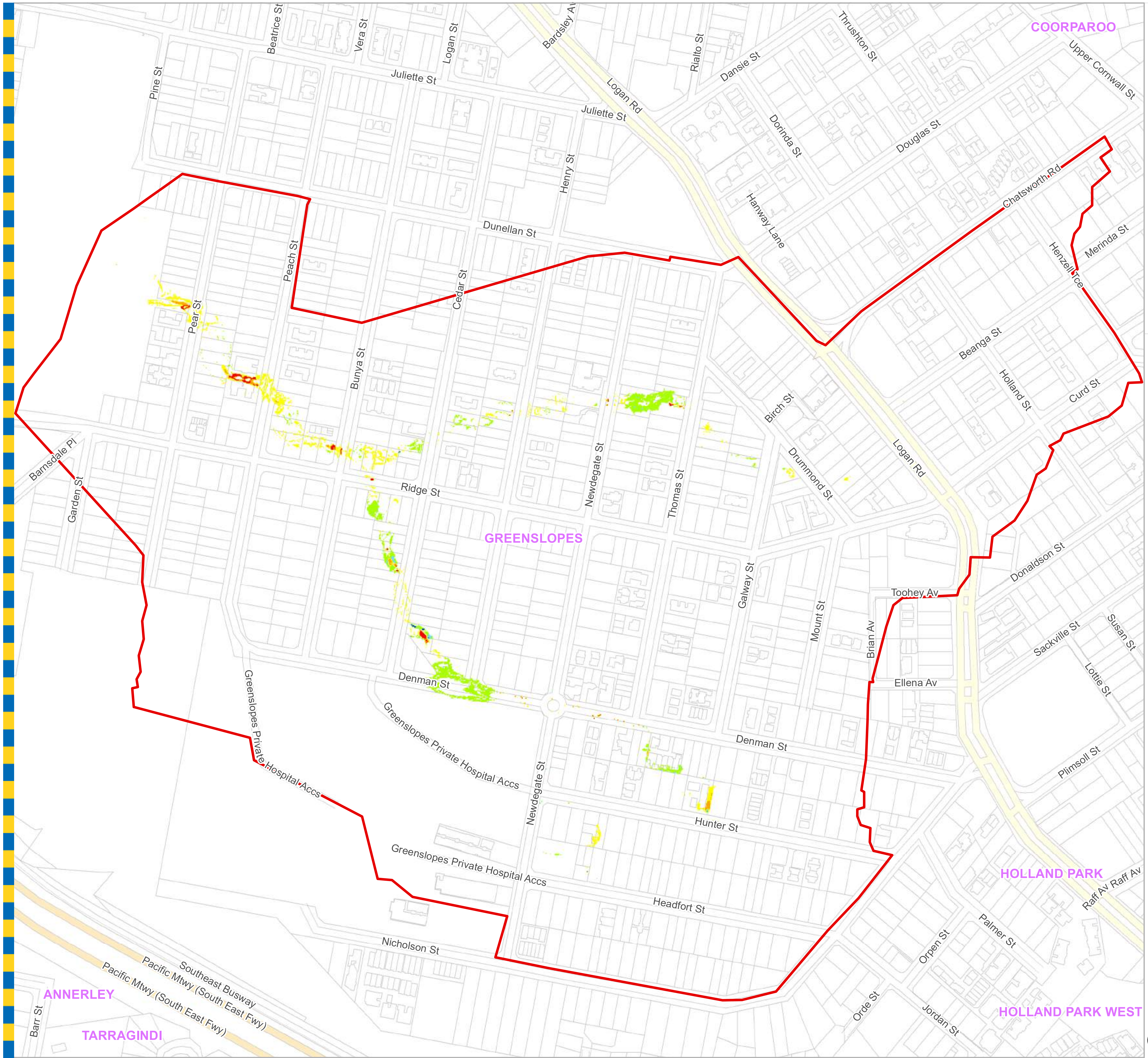
GDS - 200937 - 039



Legend

Freeways/Highways	
Major Roads	
Streets	
Tunnels	
Model Boundary	
Property Holdings	

AEMI Hazard Class. Difference

- -3
- -2
- -1
- 1
- 2
- 3

N W E S

0 40 80 120 Metres

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Figure F8 - 10yr ARI – NEXT vs NOW Scenario Flood Hazard Classification Comparison Map

GDS - 200937 - 040

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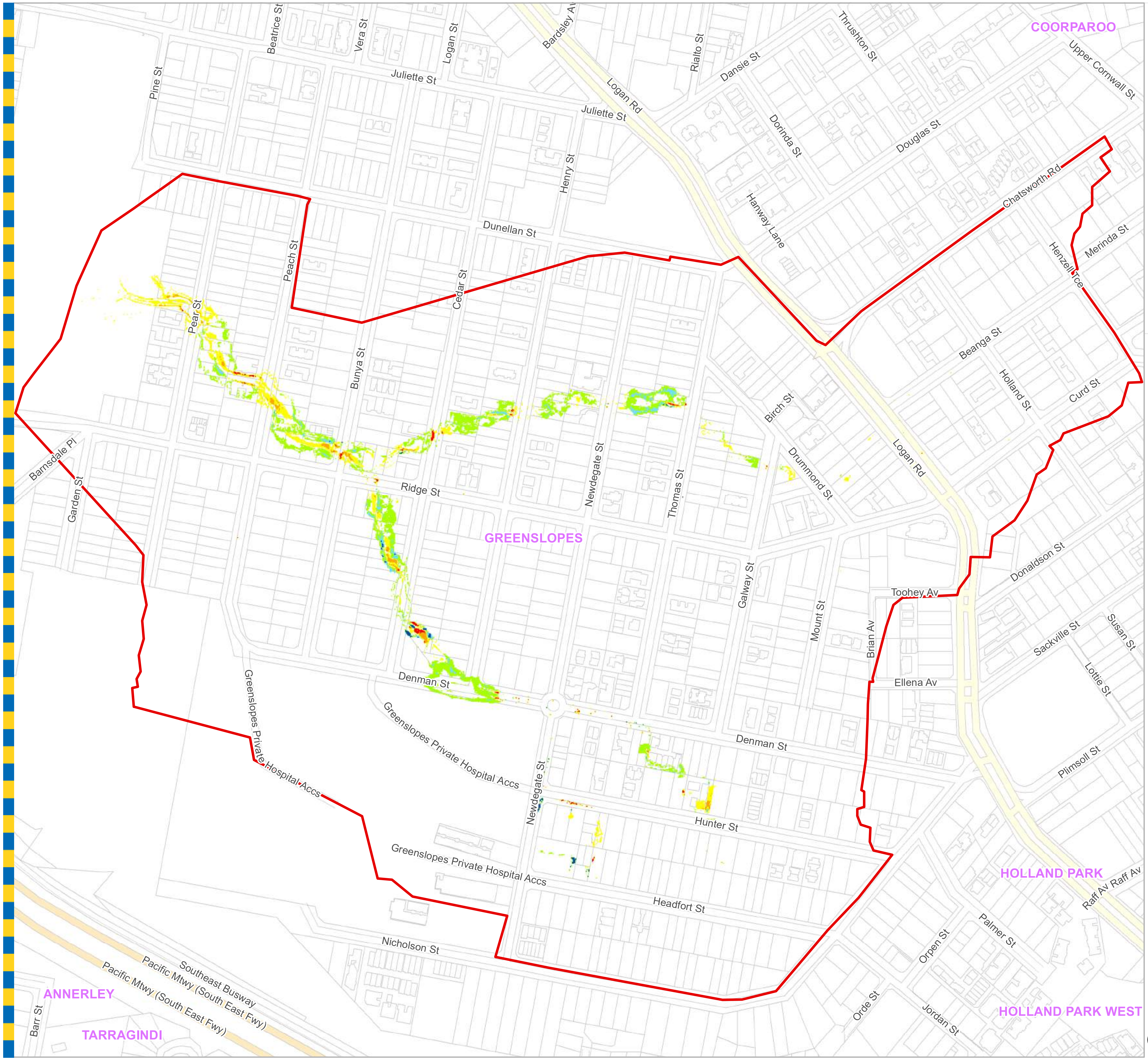

Legend

- Freeways/Highways
- Major Roads
- Streets
- Tunnels
- Model Boundary
- Property Holdings

AEMI Hazard Class. Difference

- -3
- -2
- -1
- 1
- 2
- 3

N E S W

0 40 80 120
Metres

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Figure F9 - 50yr ARI – NEXT vs NOW Scenario Flood Hazard Classification Comparison Map

GDS - 200937 - 041

Appendix G – Norman Creek – Overland flow assessment

1- Background

In June 2020, a report was delivered that assessed water sensitive outcomes for infill development (*Greenslopes Catchment Overland Flow Study Water Sensitive Typology Assessment* (BCC,2020)). This study was undertaken as a collaboration between Brisbane City Council and the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) IRP4 project - *Water Sensitive Outcomes for Infill Development*. This work used the Greenslopes subcatchment (within the greater Norman Creek catchment) as a pilot study area and investigated the effects of different development typologies, with the aim to minimise impacts of infill development on the environment.

Following the initial iteration of this work (finalised in June 2020), several amendments were made to the underlying assumptions and datasets. These changes were then simulated in the existing hydrology and hydraulic models to understand the effects on the Greenslopes catchment, and are documented in this addendum report.

In this addendum report, the original work finalised in June 2020 will be referred to as the Stage 1 works, while the additional modelling undertaken thereafter will be referred to as the Stage 2 works.

2- Modelling Methodology

A hydrologic (XP-RAFTS) and hydraulic (TUFLOW) model was developed for Stage One of the project.

As part of the Stage 2 works, four scenarios were simulated in the models for the 39% AEP and 2% AEP flood events. The scenarios are described as follows:

- **Now Scenario** – Existing catchment conditions. Based on the current waterway conditions as at the year 2020 (simulated in both the hydrology and hydraulic models). Note that this is the same as the 'Now Scenario' as modelled as part of the Stage 1 works.
- **BAU Scenario** – 'Business as Usual' Scenario. Fully developed catchment conditions under current Brisbane City Council (BCC) City Plan guidelines (land use intensification only).

  Like the 'NEW' Scenario in the Stage 1 works, the hydrology model has been updated with increased catchment impervious fractions to represent the 'land-use intensification' of selected residential parcels within the catchment.

  The hydraulic model (in the 'BauOF' scenario – Refer Table 1) was also modified with the inclusion of larger 'BAU' Scenario building footprints these selected parcels (as developed by Monash), with hydraulic model inflows from the BAU Scenario hydrology model.
- **WS Scenario** – 'Water Sensitive' Scenario. This scenario is characterized by the type of development envisaged in the urban design scenarios developed for this project and is the development that satisfies the vision for a 'Water Sensitive City'.

  Specifically, this includes the following amendments to the study models:

- Hydrology model: reduced catchment impervious fractions to simulate the smaller WS Scenario building footprints (developed by Monash), and,
- Hydraulic model ('DevOF' scenario – Refer Table 1): Introduction of reduced building footprints (and change in building types) within the overland flow conveyance corridor to represent WS building typologies (developed by Monash), as per Appendix A. Hydraulic model inflows are from the WS Scenario hydrology model.

- **WS Storage Scenario -** 'Water Sensitive' Scenario with additional flood storage (10 kL storage tank for collecting rainwater for each WS dwelling).

  From a modelling perspective, this is the same as the 'WS' Scenario's but includes the introduction of additional storage (represented as an increased initial loss), in the WS Scenario hydrology model.

The BAU/WS typology maps is included in Appendix A of this report.

A summary of the Stage 2 scenarios is detailed in Table 1.

Table 1: Stage 2 Works - Summary of Scenarios

<table>
<tr><th>Scenario</th><th>Hydrology</th><th colspan="2">Hydraulic (scenario name in bold)</th><th>Events Simulated</th></tr>
<tr><td>NOW</td><td>Existing catchment conditions</td><td colspan="2">(NOW) Existing catchment conditions and building footprints</td><td rowspan="4">39% AEP (2yr ARI)
2% AEP (50yr ARI)</td></tr>
<tr><td>- BAU_ExOF
- BAU_BauOF</td><td>Impervious fraction increase (based on intensification of 335 residential lots)</td><td>(BAU_ExOF)
Existing catchment conditions and building footprints</td><td>(BAU_DevOF)
Increased building footprints on 335 residential lots</td></tr>
<tr><td>- WS_ExOF
- WS_DevOF</td><td>Impervious fraction reduction (based on reduced building footprints on 405 residential lots)</td><td>(WS_ExOF)
Existing catchment conditions and building footprints</td><td>(WS_DevOF)
Decreased building footprints on 405 residential lots. Modification of building types.</td></tr>
<tr><td>- WS_10kl_ExOF
- WS_10kl_DevOF</td><td>WS Scenario plus increased initial subcatchment initial losses to simulate 10kl storage (per lot) on 405 residential lots</td><td>(WS_10kl_DevOF)
Existing catchment conditions and building footprints</td><td>(WS_10kl_DevOF)
Decreased building footprints on 405 residential lots. Modification of building types.</td></tr>
</table>

The XP-Rafts hydrology model scenario impervious fractions and modified land parcel information is shown in Table 2 below.

Table 2 – Scenario characteristics

<table>
<tr><th>Scenario</th><th>Catchment Impervious fraction (%)</th><th>No. of land parcels</th><th>No. of modified land parcels (building footprint/type)</th></tr>
<tr><td>NOW</td><td>61%</td><td rowspan="3">875</td><td>-</td></tr>
<tr><td>BAU</td><td>64%</td><td>0 (ExOF Scenario)
335 (BauOF Scenario)</td></tr>
<tr><td>WS</td><td>55%</td><td>0 (ExOF Scenario)
405 (DevOF Scenario)</td></tr>
</table>

The scenarios outlined in Table 1 were simulated in the hydrology and hydraulic models for the 39% and 2% AEP events. Results from the TUFLOW (hydraulic) modelling were then used to assess changes in scenario flood depths, flood hazard (depth x velocity product) and hazard safety classifications (AEMI Hazard Classification).

3- Results

The following section discusses the results of the simulated scenarios. Specifically, scenario comparisons are made for areas of inundation, flood depths, flood hazard, and flood hazard classification (AEMI).

3.1 Area of Inundation

Areas of inundation within the catchment were calculated for each scenario (for the 2% AEP event) and compared to the NOW (Existing) Scenario. Results are shown in Table 3.

Table 3 – Inundated Area Comparison

Scenario	Area of Inundation (Property and Road (m^2))	Inundation area difference (vs. NOW Scenario) (%)
NOW	34147	-
WS_ExOF	33192	-2.8%
WS_DevOF	30891	-9.5%
WS_10kl_ExOF	32291	-5.4%
WS_10kl_DevOF	30295	-11.3%
BAU_ExOF	34729	1.7%
BAU_BauOF	37501	9.8%

Differences in areas of inundation are due to a combination of factors including changes in footprint area/distribution, number of slab-on-ground buildings, inclusion of storage and changes in catchment imperviousness.

The largest reduction in inundated area is observed in the WS scenario (with WS typology building footprints/types). Inclusion of flood storage reduces the area of inundation by an additional approximate 1.8-2.6% (compared to the corresponding WS_ExOF and WS_DevOF scenarios without flood storage).

The largest increase in inundated area is observed in the BAU scenario (with BAU typology building footprints/types).

3.2 Flood Depths

A comparison of flood depth differences at key reporting locations is documented in Table 4. Results highlighted in bold denote a depth increase greater than 10 mm in the alternate Scenarios (compared to NOW Scenario). Results within a shaded cell denote a depth decrease greater than 10 mm in the alternate Scenarios (compared to NOW Scenario). Refer to the Stage One report for a map showing the reporting locations.

Refer to Section 4 in this addendum report for flood depth difference mapping for selected scenarios, for the 39% AEP and 2% AEP events.

Observations from these comparisons indicate the following:

<u>Hydrologic model impervious changes</u>

- BAU_ExOF vs WS_ExOF
- BAU_ExOF vs NOW

Minor decreases in catchment perviousness (BAU) results in slight increases in flood depths (~10-50mm) catchment wide. Localised increases greater than 50mm are also observed, particularly in the 39% AEP scenario.

- WS_ExOF vs NOW

Minor increases in catchment perviousness (WS Scenario) results in slight decreases in flood depths (~ 10-50mm) catchment wide. Localised decreases greater than 50mm are also observed, particularly in the 39% AEP scenario.

Hydrologic model impervious changes plus hydraulic model building footprint/type changes

- BAU_BauOF vs WS_DevOF
- BAU_BauOF vs WS_ExOF
- BAU_BauOF vs BAU_ExOF
- BAU_BauOF vs NOW
- WS_DevOF vs NOW

The above comparisons show a mix of flood depth increases and decreases (in some areas over 0.5m increase/decrease). The larger differences appear to be less influenced by the minor catchment perviousness changes and are more to do with the change in building footprints/types, which causes localised changes in flood depths and velocities.

The Bau_BauOF Scenario (inclusive of intensified/larger footprints and increased imperviousness) was observed to create the highest flood depth increases on average (and largest area of increases) compared to other scenarios.

The WS_DevOF Scenario (inclusive of smaller footprints and reduced imperviousness) generally resulted in flood level decreases throughout the catchment (compared to the NOW scenario). However, some larger flood level increases were observed in localised areas (typically around building footprint changes).

Hydrologic model impervious reduction and inclusion of storage (initial loss reduction)

- WS_10kl_ExOF vs NOW

Minor increases in catchment perviousness and inclusion of rainwater tank storage for over half of buildings within the catchment resulted in a general decrease in flood depths of between 10-200mm catchment wide.

Hydrologic model impervious reduction and inclusion of storage (initial loss reduction) plus hydraulic model building footprint/type changes

- WS_10kl_DevOF vs NOW

Minor increases in catchment perviousness, inclusion of rainwater tank storage for over half of buildings within the catchment, and inclusion of smaller/modified building footprints in the overland flow path resulted in:

- an overall decrease (on average) of flood depths within the catchment. Depth decreases were generally in the range of 10-500mm
- some localised flood depth increases, generally in the range of 10-200mm.

Some flood level increases and decreases are localised and can be attributed to the change in building footprint areas/types, as described in the above section.

3.3 Flood Hazard Classifications (AEMI)

A comparison of AEMI hazard classification differences at key reporting locations is documented in Table 5. Results highlighted in bold denote an AEMI increase in the alternate Scenarios (compared to NOW Scenario). Results within a shaded cell denote an AEMI decrease in the alternate Scenarios (compared to NOW Scenario). Refer to the Stage One report for a map showing the reporting locations.

Refer to Section 4 in this addendum report forss AEMI classification difference mapping for selected scenarios, for the 39% AEP and 2% AEP events.

Result observations are typically in line with the depth comparison results described above. That is:

- Small decreases in catchment imperviousness slightly reduces hazard
- Small increases in catchment imperviousness slightly increases hazard
- Changing building types/footprints in the overland flow path can result in considerable localised increases/decreases in flood hazard
- Inclusion of flood storage (depending on volume) can go some way towards mitigating localised increases in flood depths/hazard

3.4 Flood Hazard (Depth x Velocity)

Refer to Section 4 for flood hazard difference mapping for selected scenarios, for the 39% AEP and 2% AEP events.

Observations from these comparisons are in line with those described in Section 3.3 above.

Table 4 – Flood Depth Differences at Key Reporting Locations

Reporting ID	Reporting Location (Greenslopes)	Flood Depth Difference (mm)											
		BAU_BauOF minus NOW		WS_DevOF minus NOW		WS_10kl_DevOF minus NOW		BAU_ExOF minus NOW		WS_ExOF minus NOW		WS_10kl_ExOF minus NOW	
		39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP
1	Pear Street	6	-42	-3	**76**	-7	**62**	3	7	-3	-12	-7	-30
2	60 Pear Street	3	**218**	-71	-91	-258	-107	**155**	**13**	-87	-21	-261	-48
3	Peach Street	**107**	**211**	-19	**41**	-54	**26**	**20**	**13**	-17	-21	-46	-49
4	89 Ridge Street	-18	-70	-48	-45	-73	-56	**41**	**12**	-39	-21	-55	-45
5	62 Cedar Street	8	0	-23	-34	-26	-39	4	4	-1	-13	-7	-27
6	Henry Street	**18**	-8	-	**10**	-	8	**17**	2	-	-8	-	-14
7	30 Newdegate Street	**62**	-25	-72	-388	-87	-392	**70**	4	-66	-20	-93	-33
8	Thomas Street	6	0	-27	-2	-63	-4	8	4	-27	-5	-63	-7
9	85 Cedar Street	-178	-261	-207	-451	-211	-458	**15**	**12**	-6	-14	-15	-28
10	Cedar Street	**31**	**17**	-20	-50	-25	-57	**10**	9	-3	-10	-10	-20
11	Denman Street	**86**	**141**	13	-186	-10	-193	**89**	**11**	**14**	-13	-8	-23
12	43 Hunter Street	**223**	**270**	**313**	**378**	**295**	**368**	4	6	-7	-5	-22	-15

Table 5 – Flood Hazard Classification (AEMI) Differences at Key Reporting Locations

Reporting ID	Reporting Location (Greenslopes)	AEMI Hazard Class Difference											
		BAU_BauOF minus NOW		WS_DevOF minus NOW		WS_10kl_DevOF minus NOW		BAU_ExOF minus NOW		WS_ExOF minus NOW		WS_10kl_ExOF minus NOW	
		39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP	39% AEP	2% AEP
1	Pear Street	0	-2	0	0	0	0	0	0	0	0	0	-1
2	60 Pear Street	0	0	0	0	-1	0	**1**	0	0	-1	-1	-1
3	Peach Street	**1**	-1	0	0	0	0	0	0	0	0	0	-1
4	89 Ridge Street	0	0	0	0	-1	0	0	0	0	0	0	0
5	62 Cedar Street	0	0	0	0	0	0	0	0	0	0	0	0
6	Henry Street	**1**	0	0	0	0	0	**1**	0	-	0	-	0
7	30 Newdegate Street	0	0	0	0	0	0	0	0	0	0	0	0
8	Thomas Street	0	0	0	0	-1	0	0	0	0	0	-1	0
9	85 Cedar Street	0	**1**	0	**1**	0	**1**	0	0	0	0	0	0
10	Cedar Street	0	0	0	0	0	0	0	0	0	0	0	0
11	Denman Street	0	0	0	0	0	0	0	0	0	0	0	0
12	43 Hunter Street	**1**	-2	**2**	-1	**2**	-1	0	0	0	0	0	0

4- Flood Mapping

The following flood comparison mapping has been provided:

39% AEP - Flood Depth difference

BAU vs BAU

BAU_BauOF minus BAU_ExOF

BAU vs. WS

BAU_ExOF minus WS_ExOF

BAU_BauOF minus WS_ExOF

BAU vs. NOW

BAU_ExOF minus NOW

BAU_BauOF minus NOW

WS vs. NOW

WS_ExOF minus NOW

WS_10kl_ExOF minus NOW

WS_10kl_DevOF minus NOW

2% AEP - Flood Depth difference

BAU vs BAU

BAU_BauOF minus BAU_ExOF

BAU vs. WS

BAU_BauOF minus WS_ExOF

BAU_ExOF minus WS_ExOF

BAU_BauOF minus WS_DevOF

BAU vs. NOW

BAU_BauOF minus NOW

BAU_ExOF minus NOW

WS vs. NOW

WS_10kl_ExOF minus NOW

WS_10kl_DevOF minus NOW

WS_ExOF minus NOW

WS_ExOF minus NOW

39% AEP - Flood Hazard difference

BAU vs BAU

BAU_BauOF minus BAU_ExOF

BAU vs. WS

BAU_ExOF minus WS_ExOF

BAU_BauOF minus WS_ExOF

BAU vs. NOW

BAU_ExOF minus NOW

BAU_BauOF minus NOW

WS vs. NOW

WS_ExOF minus NOW

WS_10kl_ExOF minus NOW

WS_10kl_DevOF minus NOW

2% AEP - Flood Hazard difference

BAU vs BAU

BAU_BauOF minus BAU_ExOF

BAU vs. WS

BAU_BauOF minus WS_ExOF

BAU_ExOF minus WS_ExOF

BAU_BauOF minus WS_DevOF

BAU vs. NOW

BAU_BauOF minus NOW

BAU_ExOF minus NOW

WS vs. NOW

WS_10kl_ExOF minus NOW

WS_10kl_DevOF minus NOW

WS_ExOF minus NOW

2% AEP - Flood Hazard Classification (AEMI) difference

BAU vs BAU

BAU_BauOF minus BAU_ExOF

BAU vs. WS

BAU_BauOF minus WS_ExOF

BAU_ExOF minus WS_ExOF

BAU_BauOF minus WS_DevOF

BAU vs. NOW

BAU_BauOF minus NOW

BAU_ExOF minus NOW

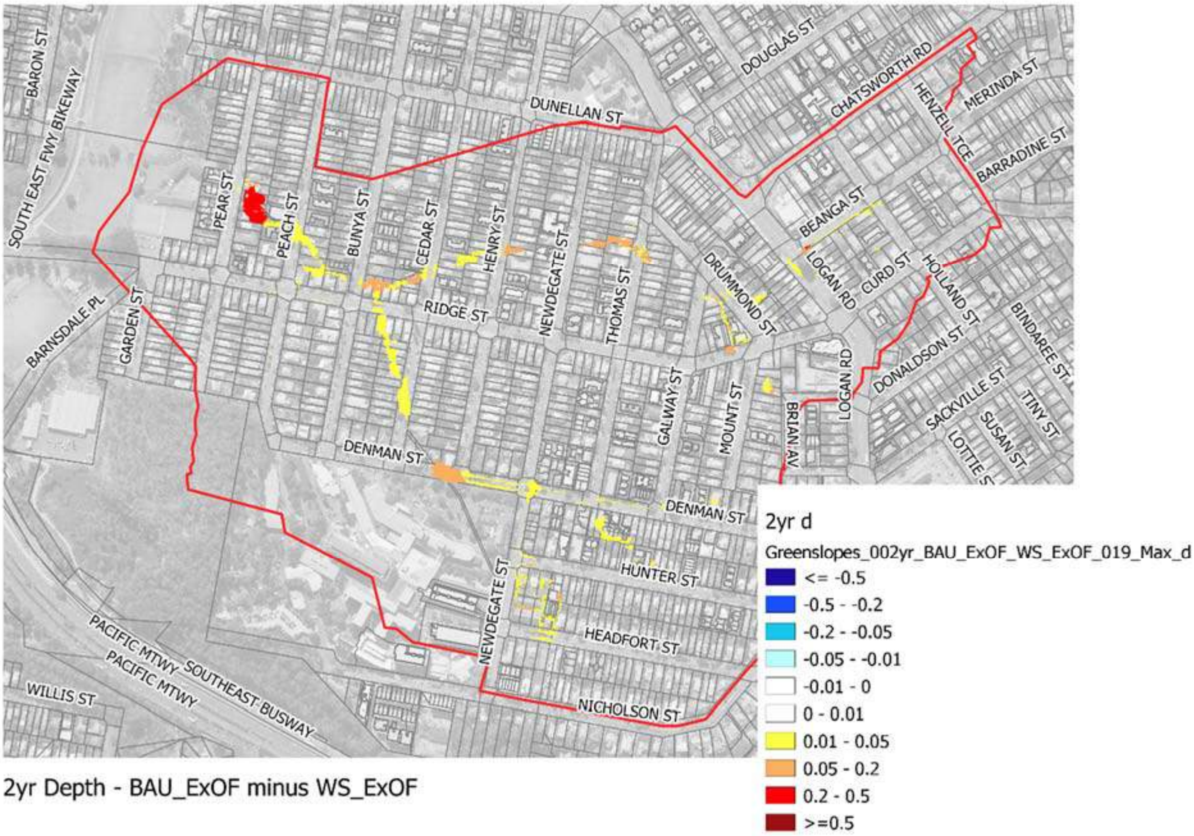
WS vs. NOW

WS_10kl_ExOF minus NOW

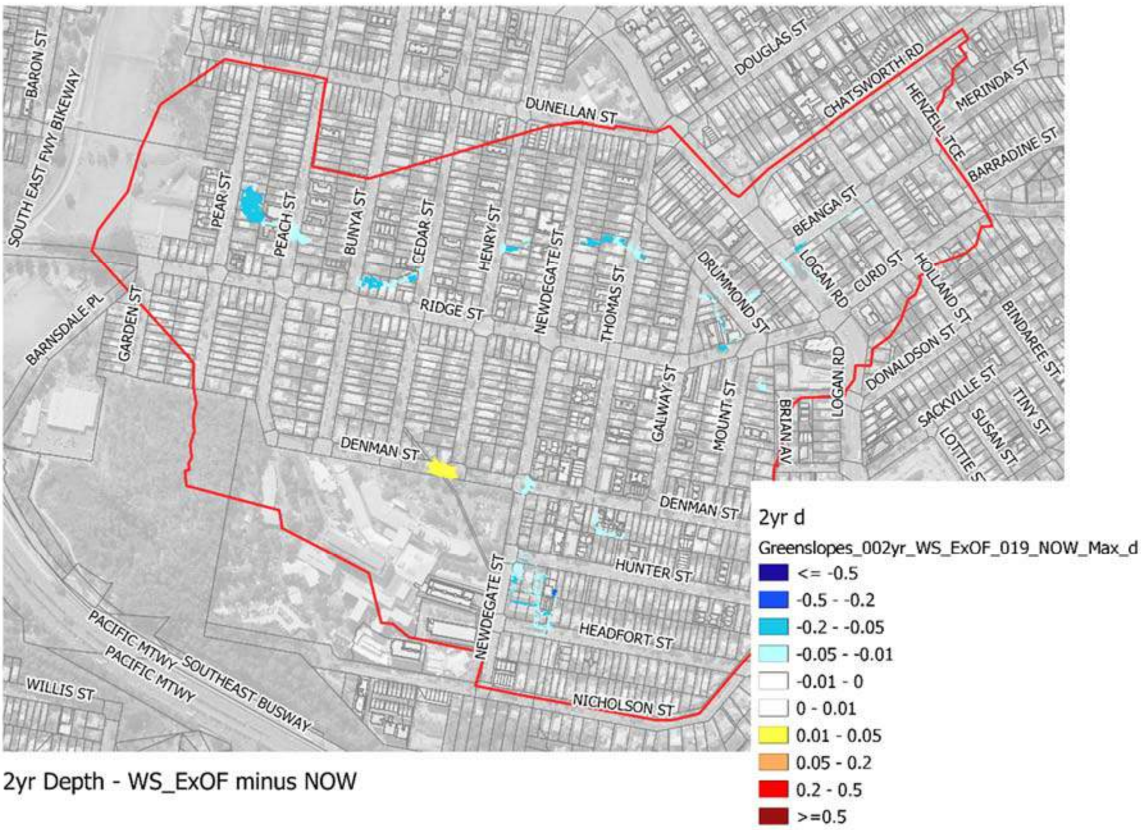
WS_10kl_DevOF minus NOW

WS_ExOF minus NOW

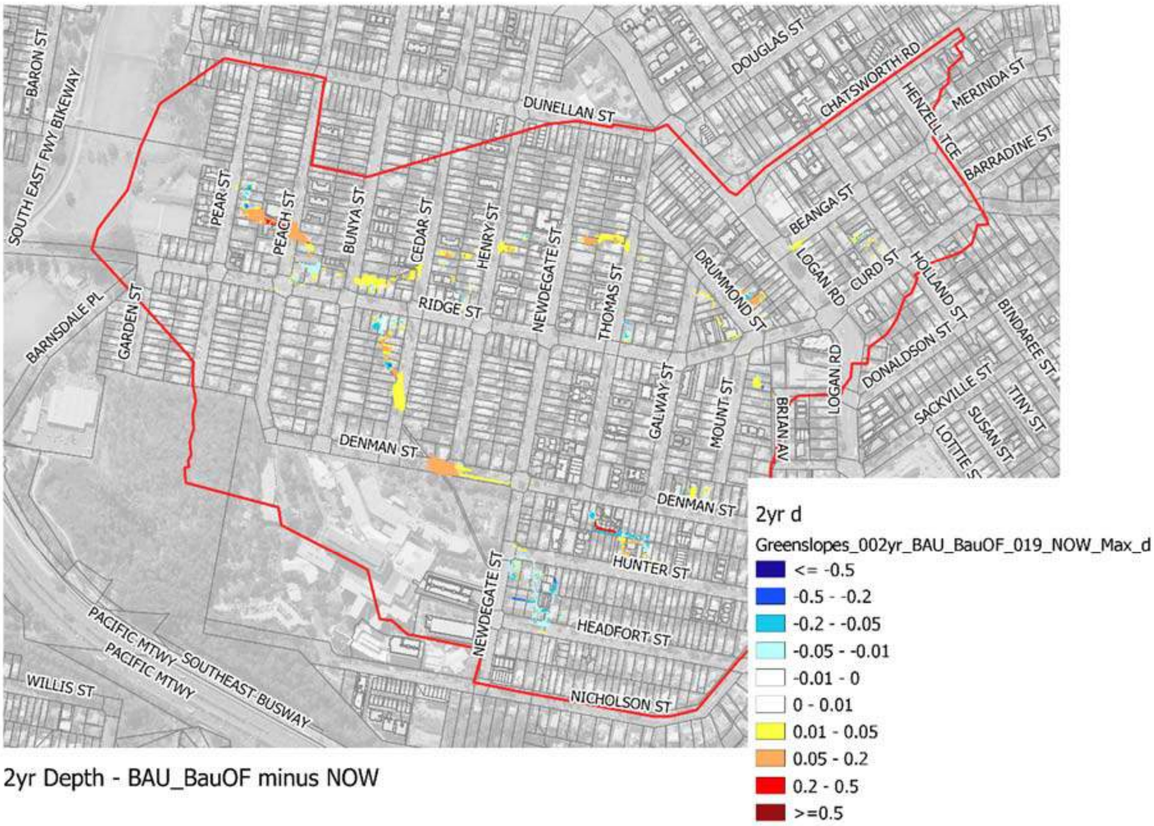
39% AEP - Flood Depth difference mapping (m)



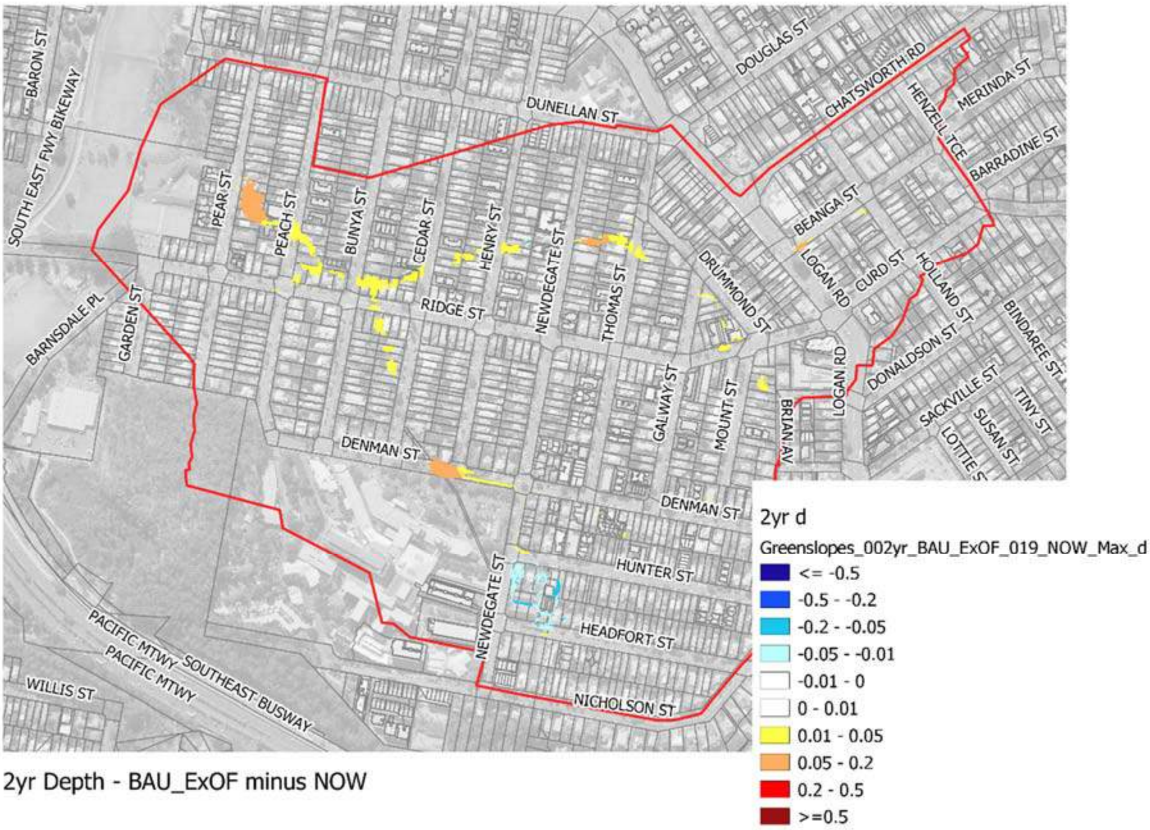
2yr Depth - BAU_ExOF minus WS_ExOF



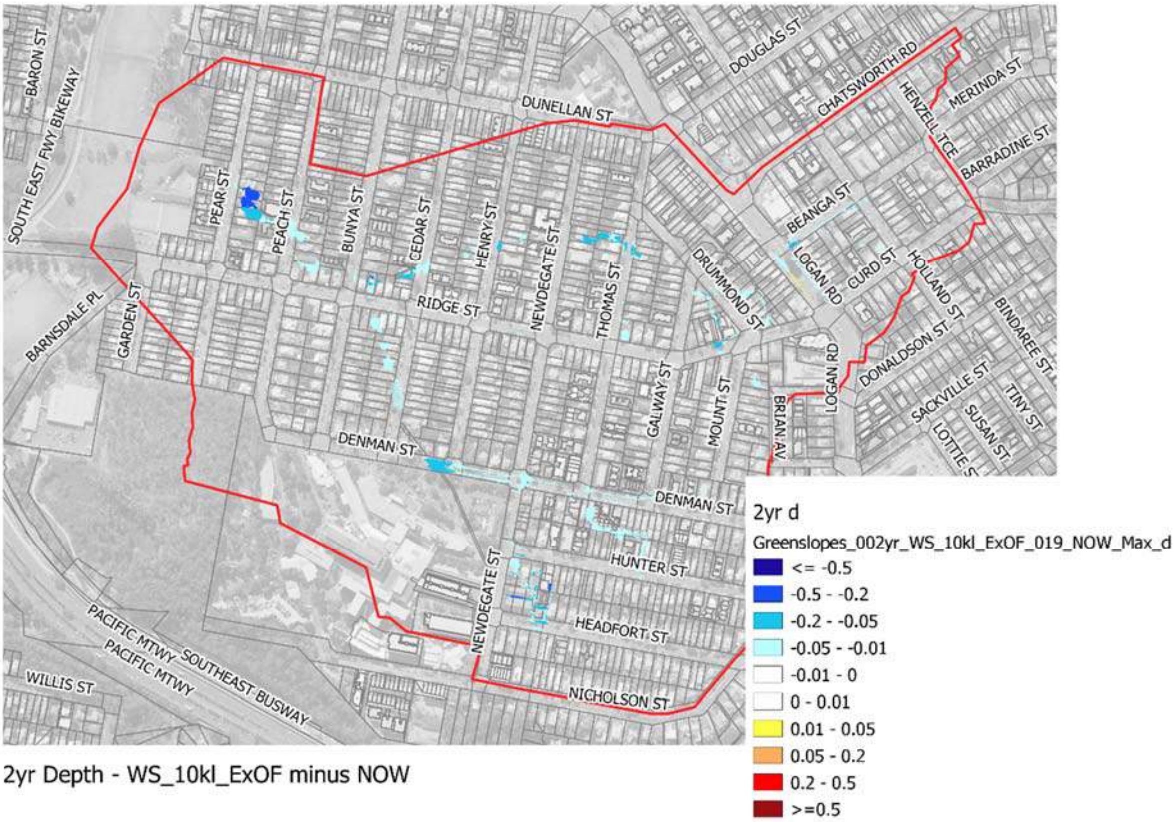
2yr Depth - WS_ExOF minus NOW



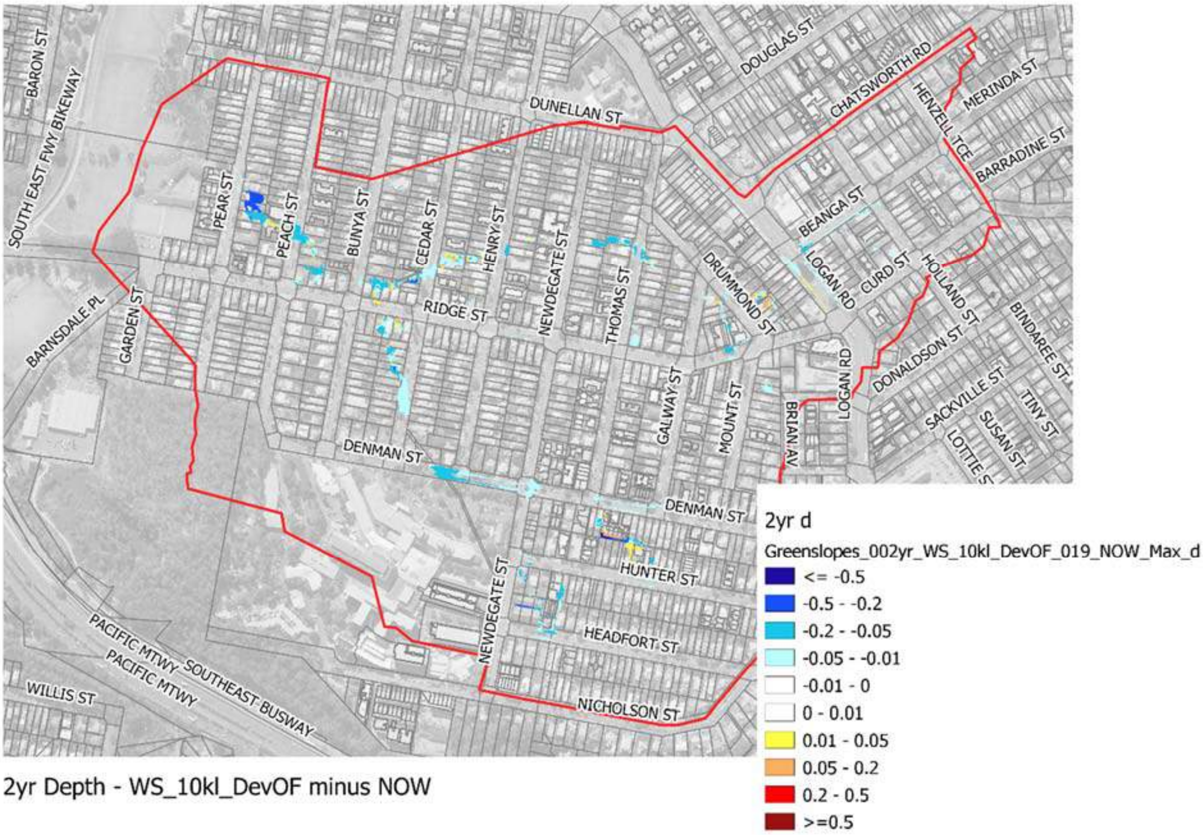
2yr Depth - BAU_BauOF minus NOW



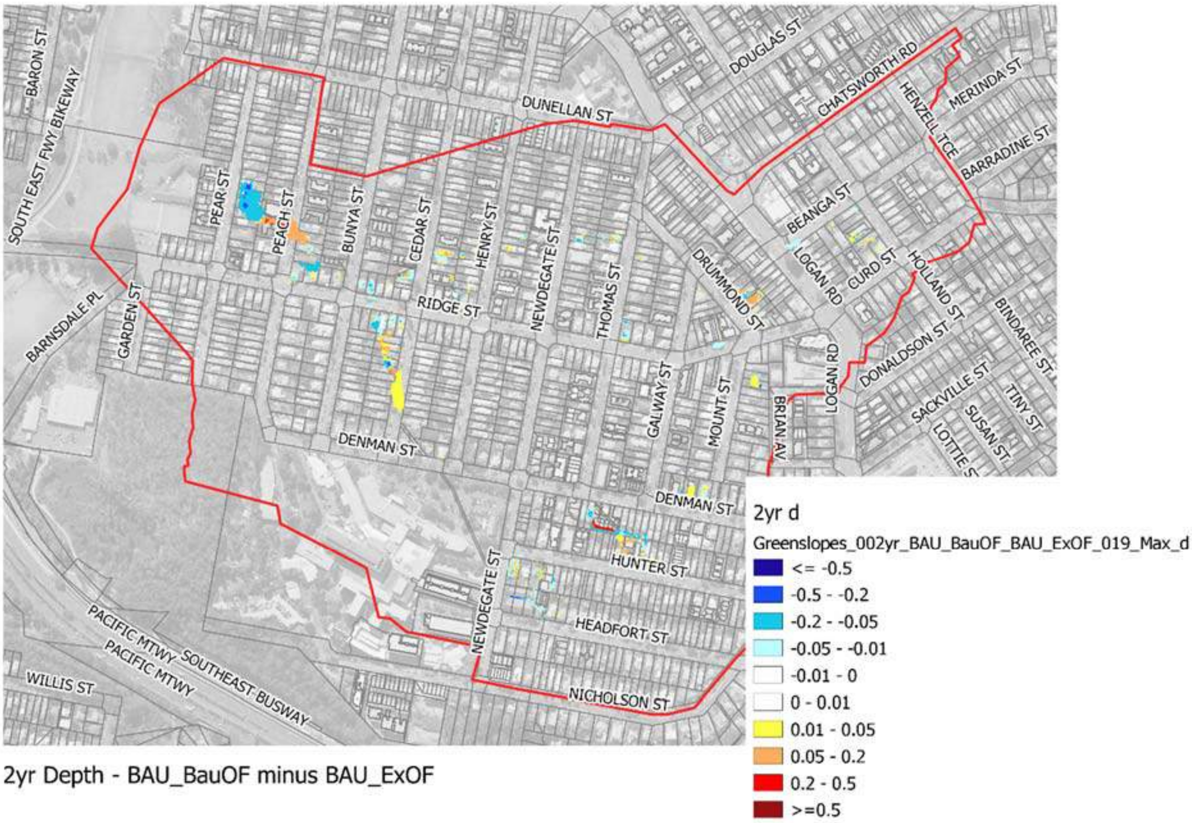
2yr Depth - BAU_ExOF minus NOW



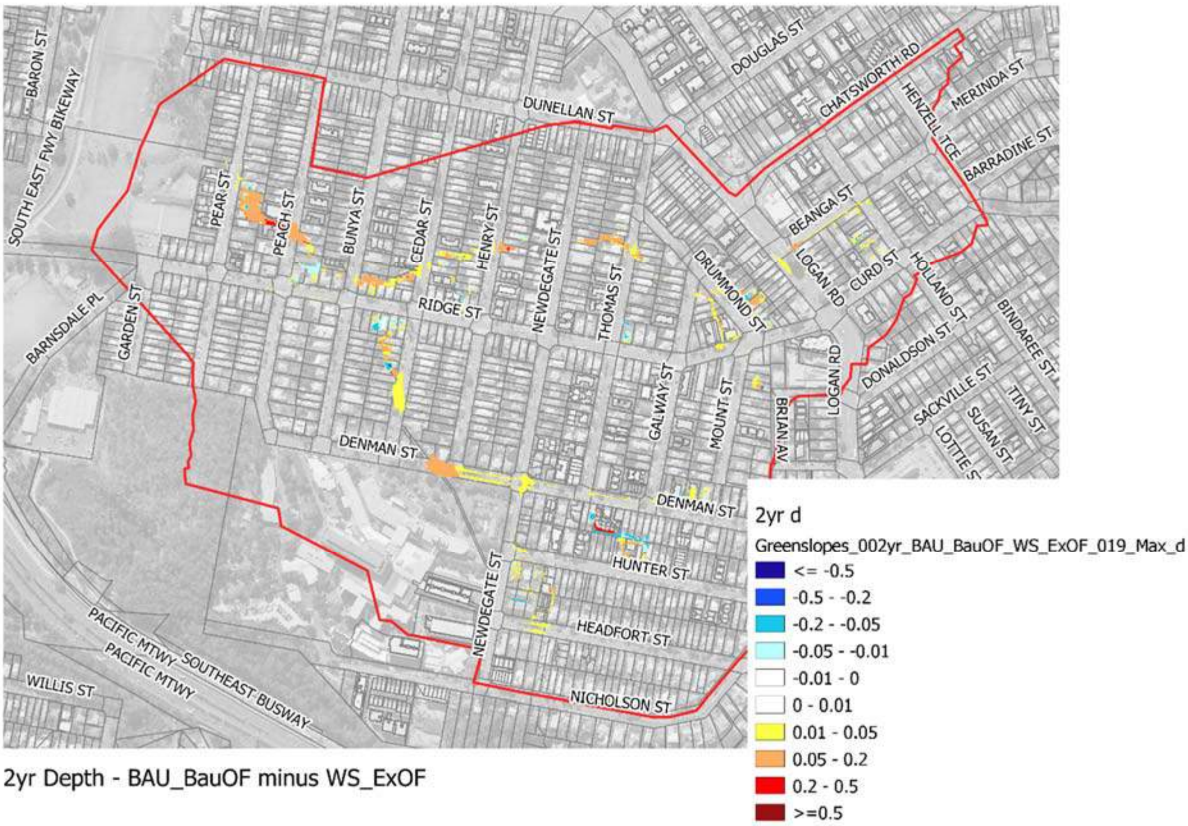
2yr Depth - WS_10kl_ExOF minus NOW



2yr Depth - WS_10kl_DevOF minus NOW

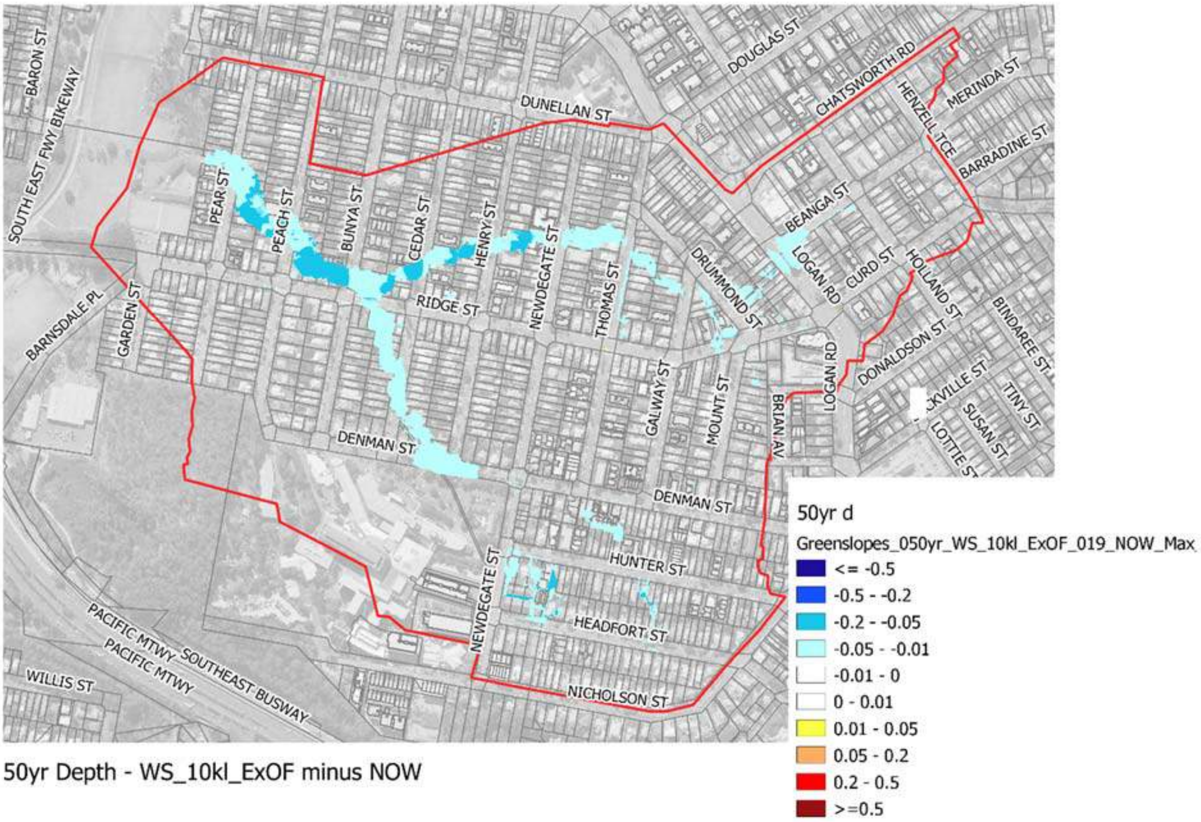


2yr Depth - BAU_BauOF minus BAU_ExOF

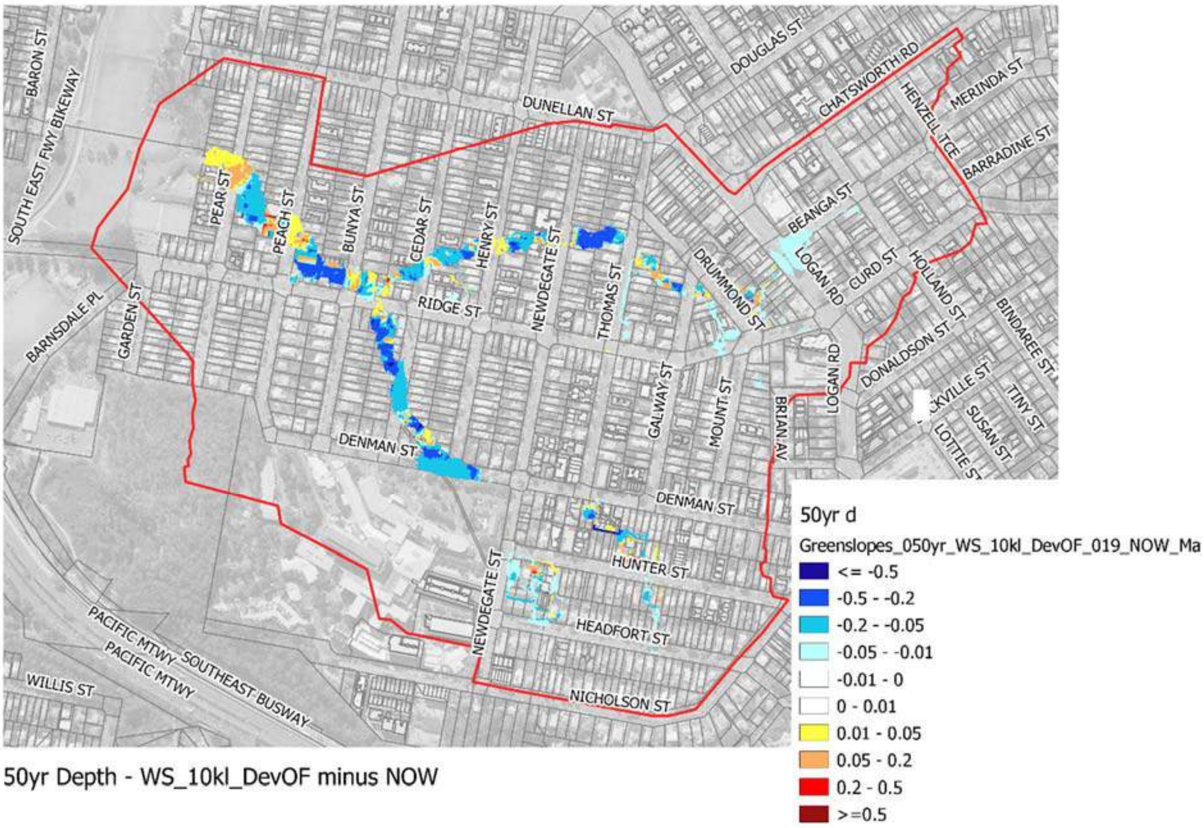


2yr Depth - BAU_BauOF minus WS_ExOF

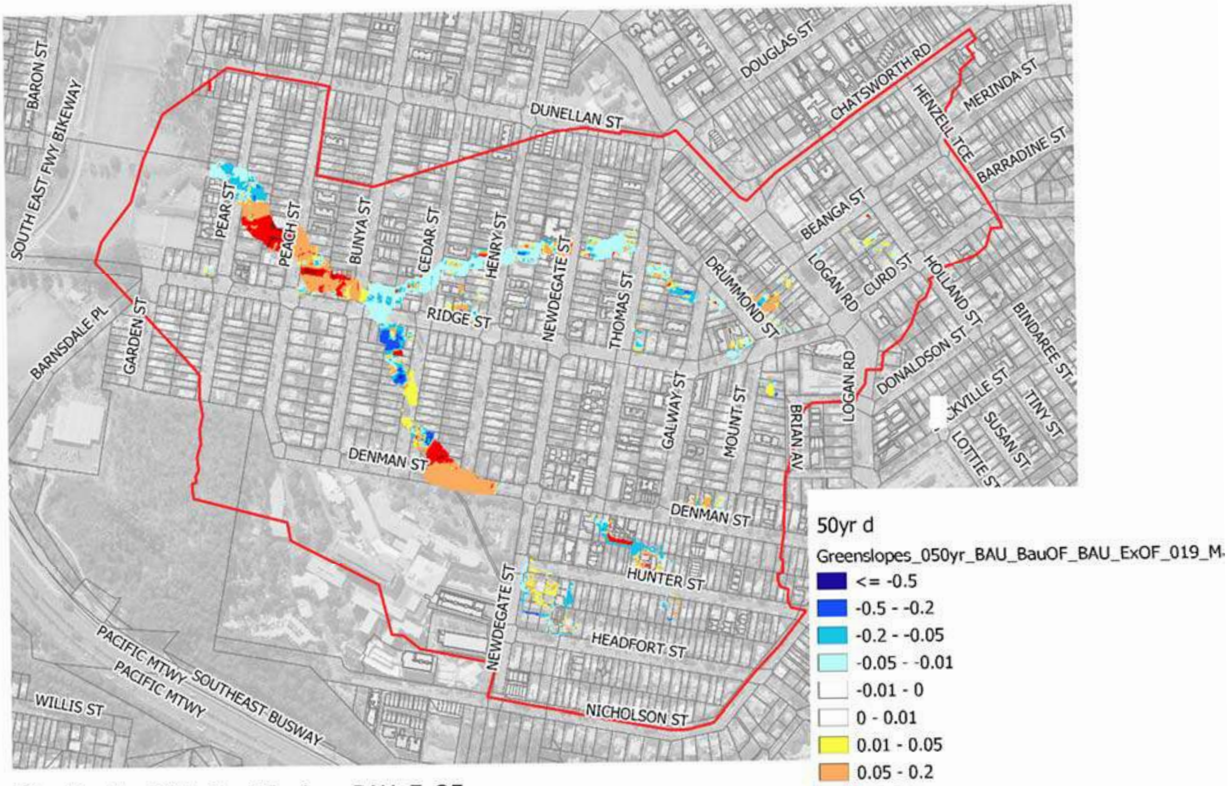
2% AEP - Flood Depth difference mapping (m)



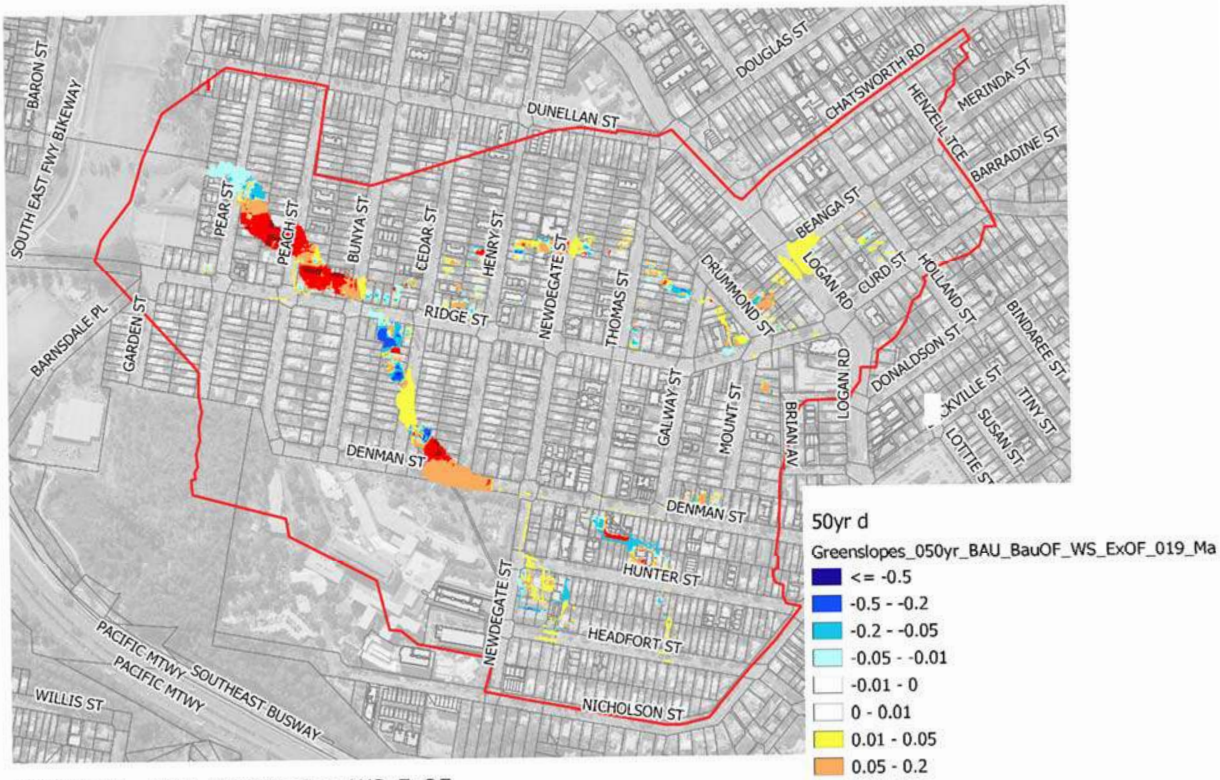
50yr Depth - WS_10kl_ExOF minus NOW



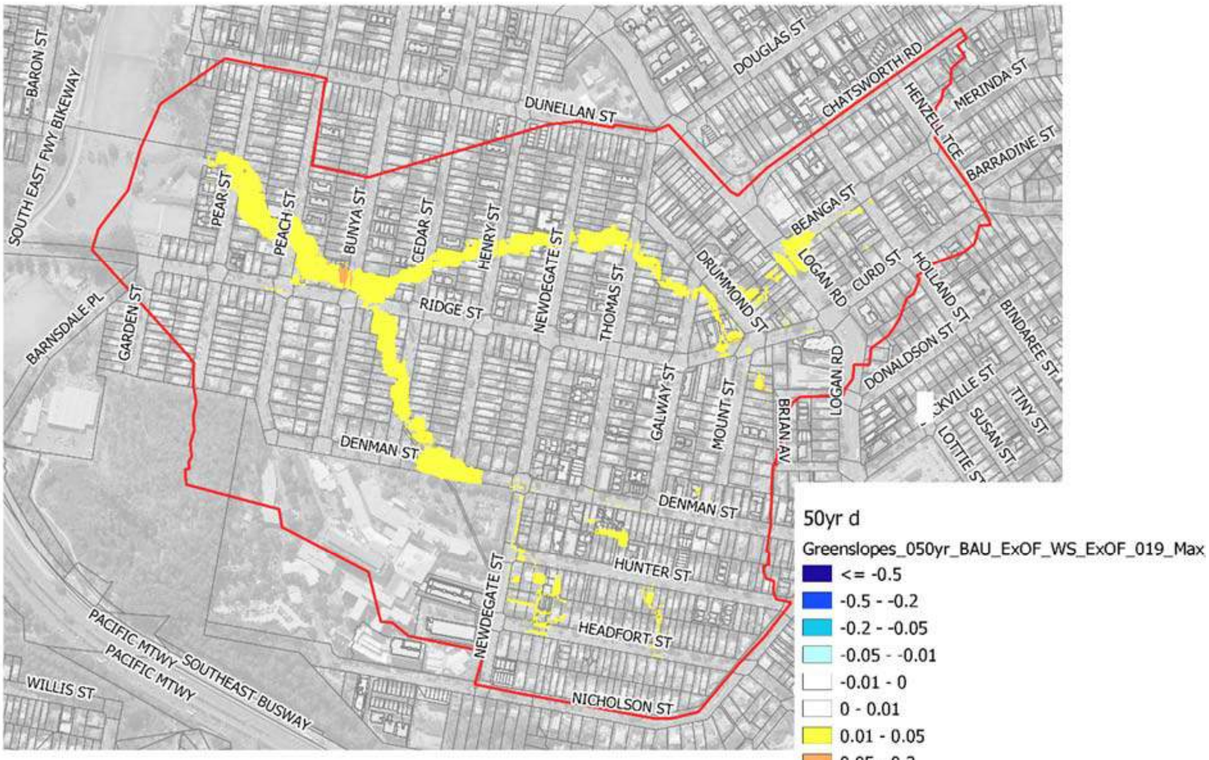
50yr Depth - WS_10kl_DevOF minus NOW



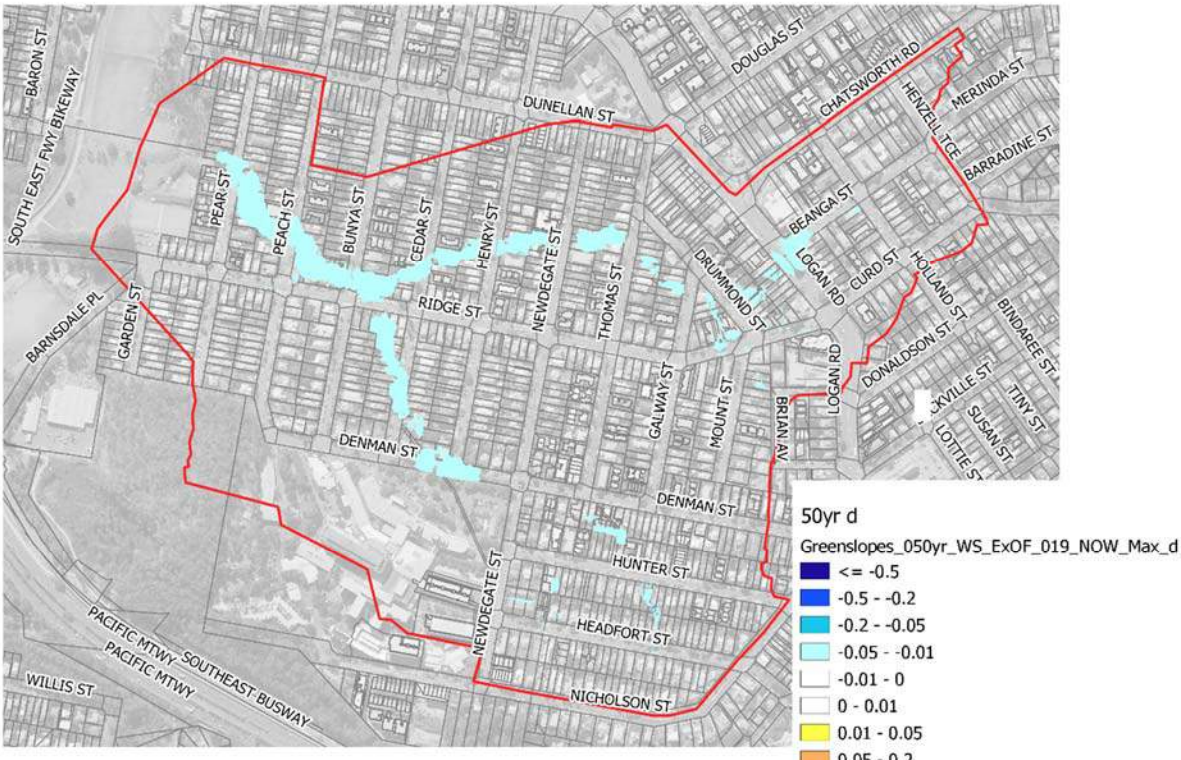
50yr Depth - BAU_BauOF minus BAU_ExOF



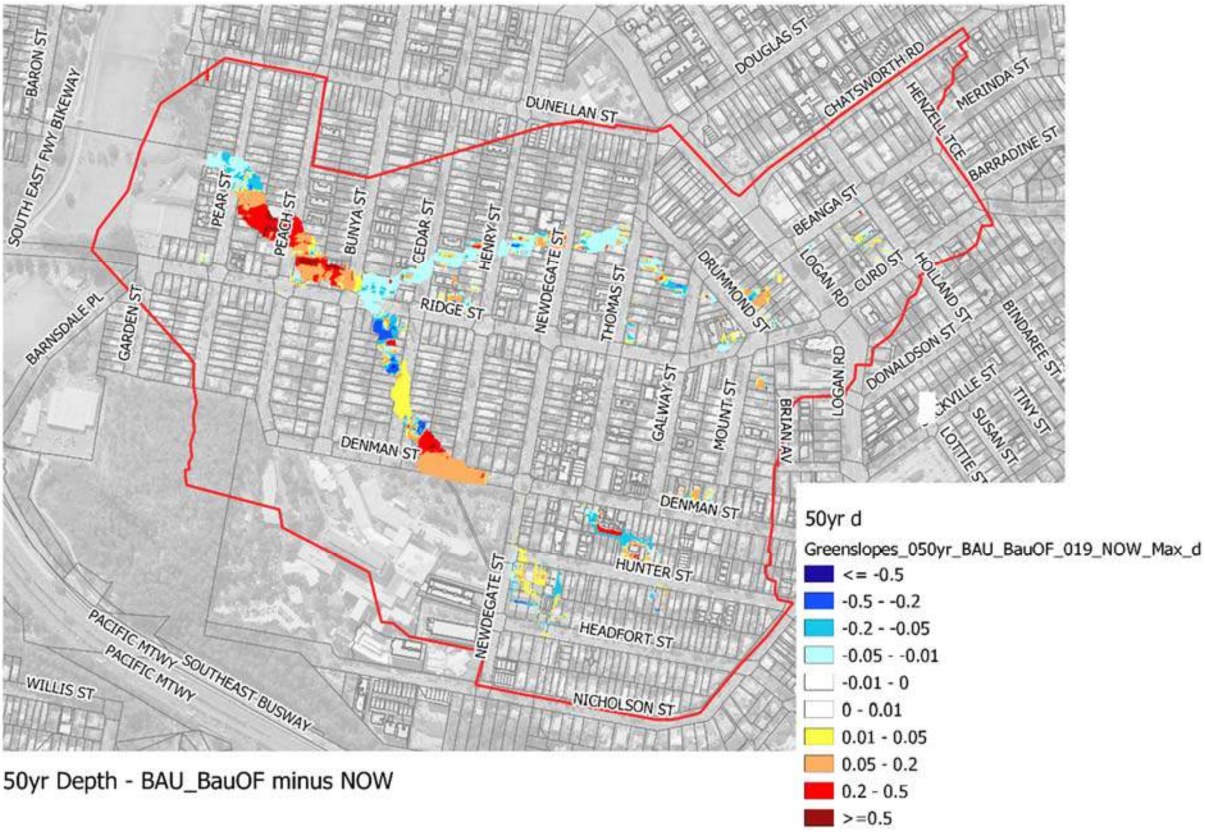
50yr Depth - BAU_BauOF minus WS_ExOF



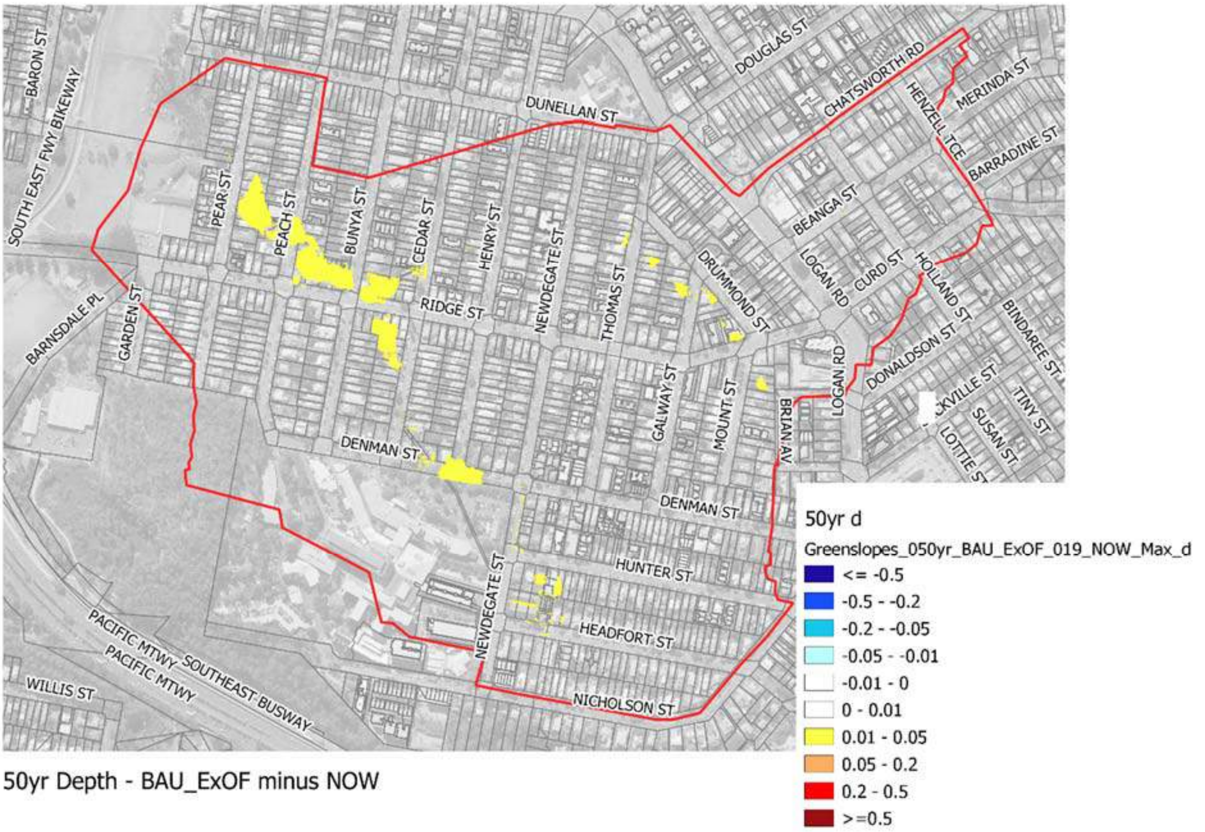
50yr Depth - BAU_ExOF minus WS_ExOF



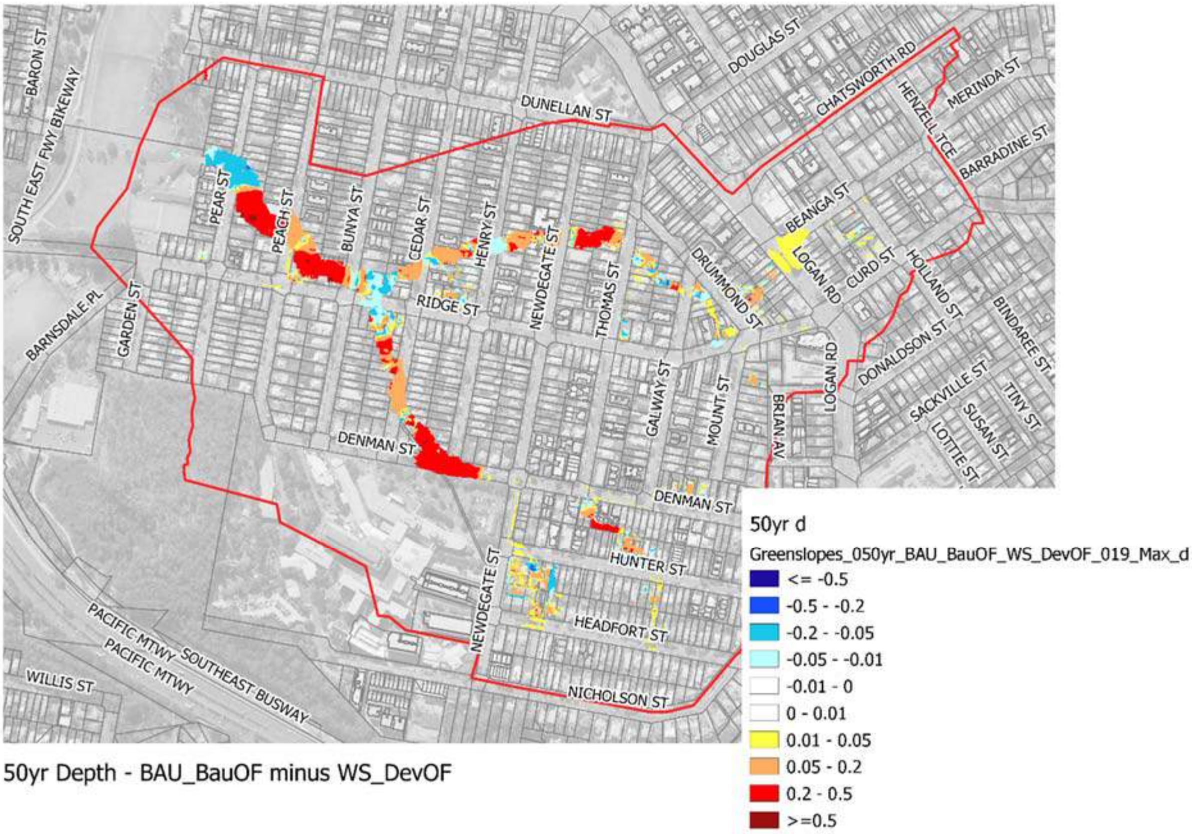
50yr Depth - WS_ExOF minus NOW



50yr Depth - BAU_BauOF minus NOW



50yr Depth - BAU_ExOF minus NOW



50yr Depth - BAU_BauOF minus WS_DevOF

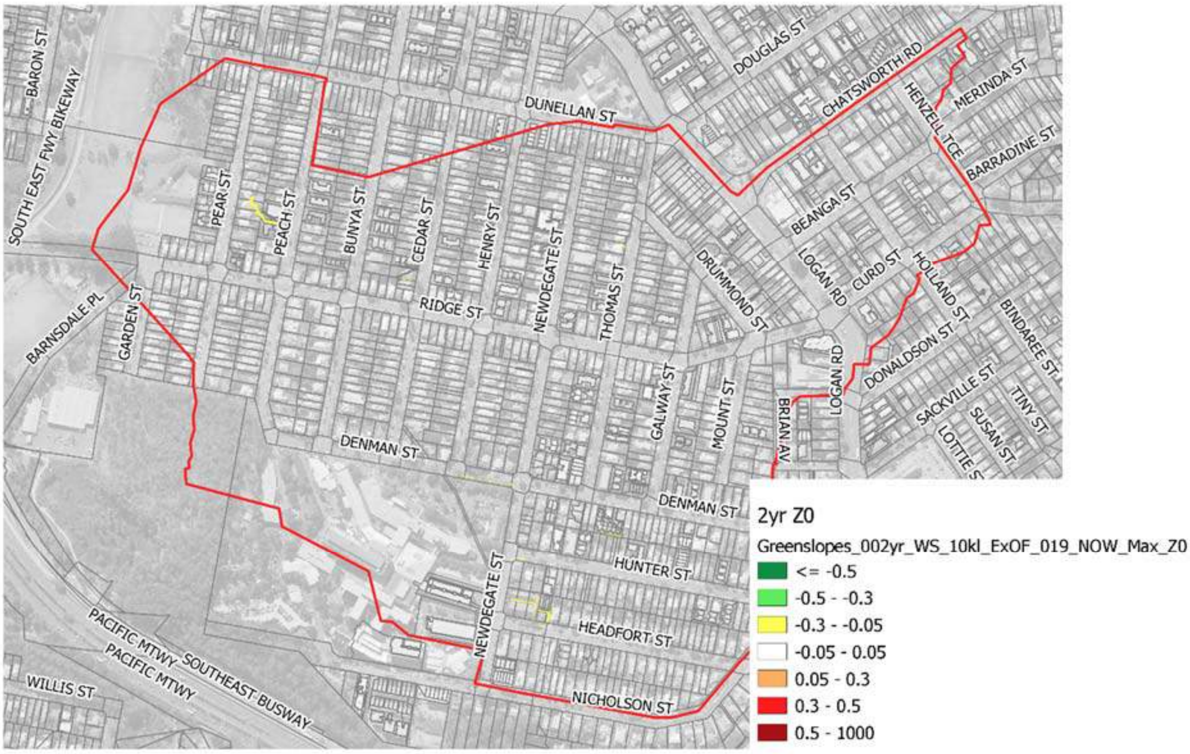
39% AEP - Flood Hazard difference mapping (m/s²)

2yr Hazard - BAU_BauOF minus BAU_ExOF

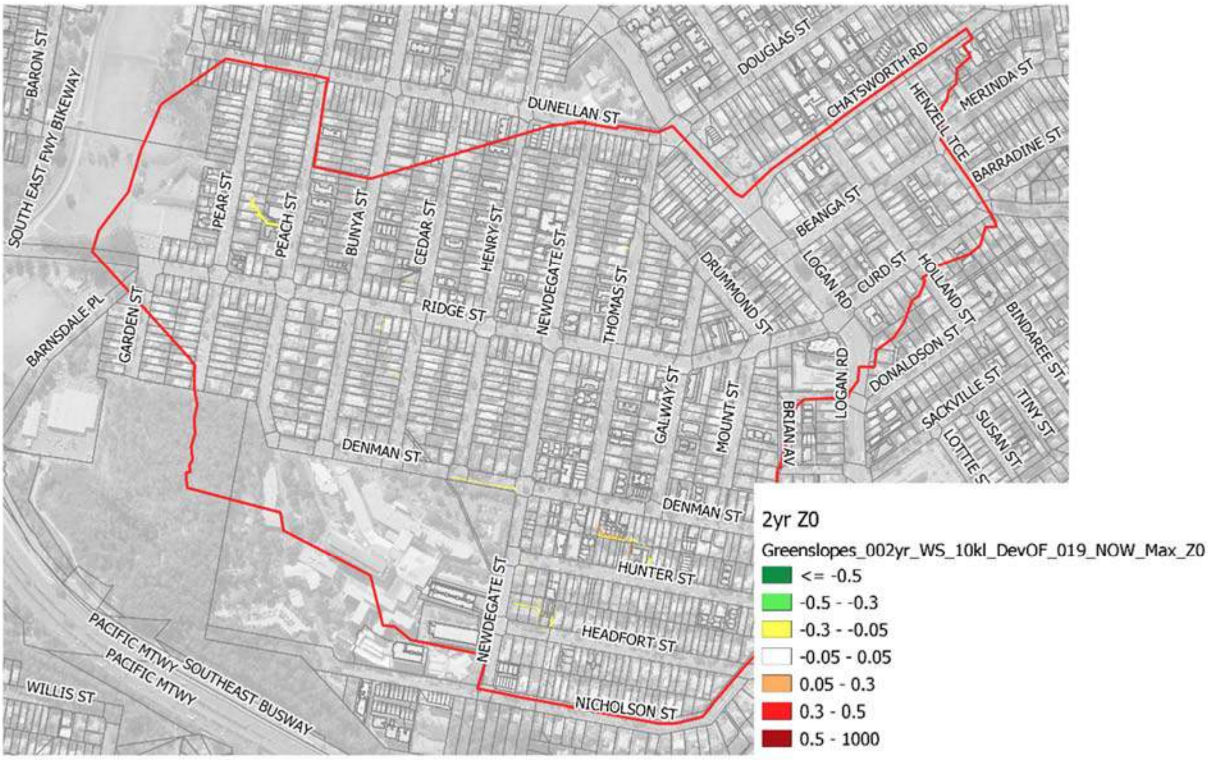
2yr Hazard - BAU_ExOF minus WS_ExOF

2yr Hazard - WS_ExOF minus NOW

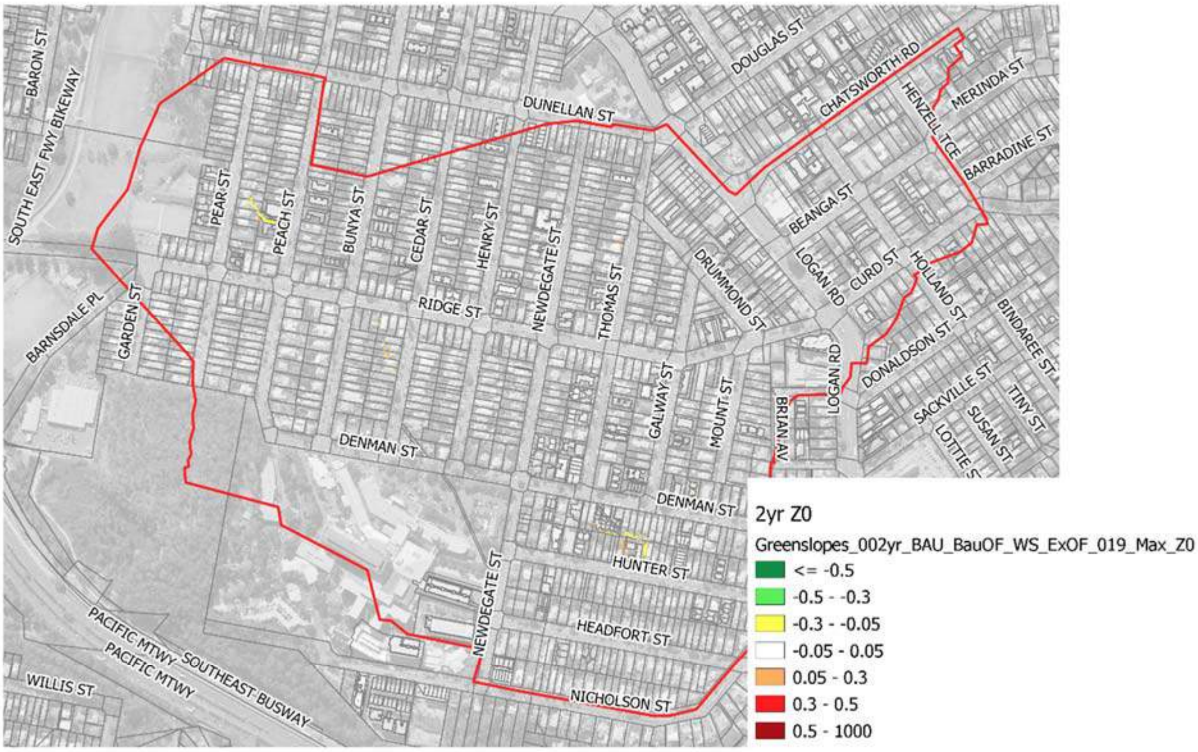
2yr Hazard - BAU_ExOF minus NOW



2yr Hazard - WS_10kl_ExOF minus NOW



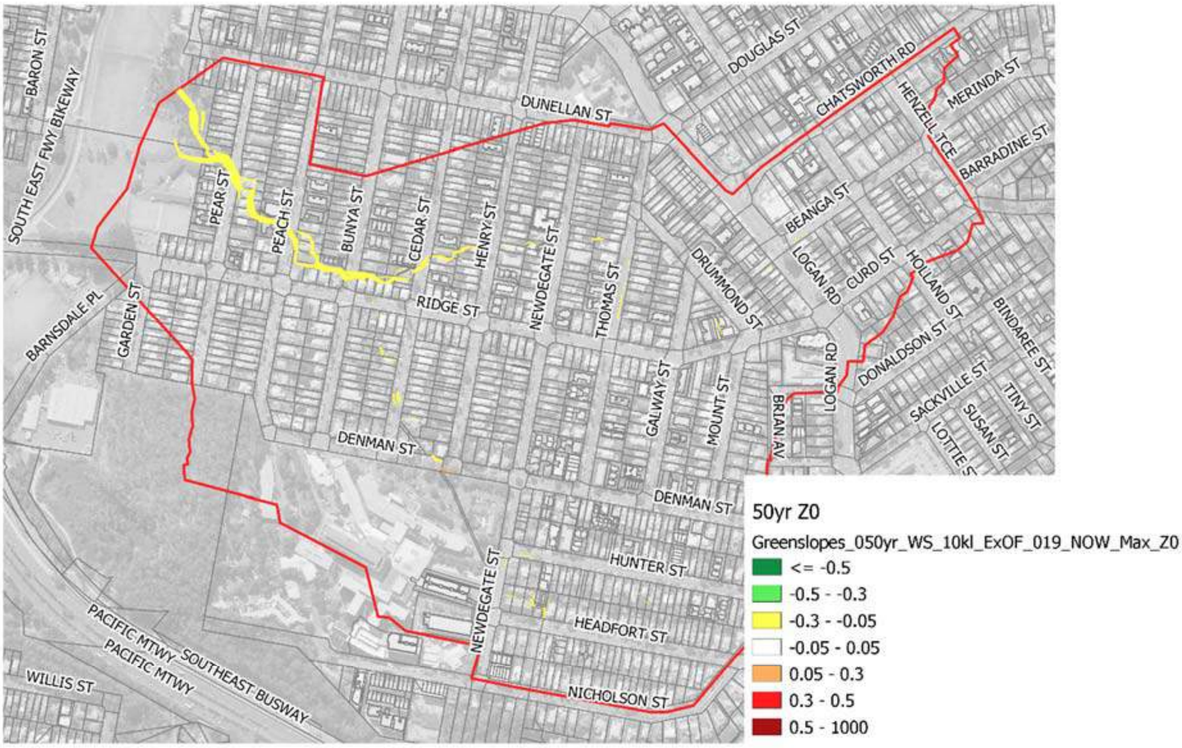
2yr Hazard - WS_10kl_DevOF minus NOW



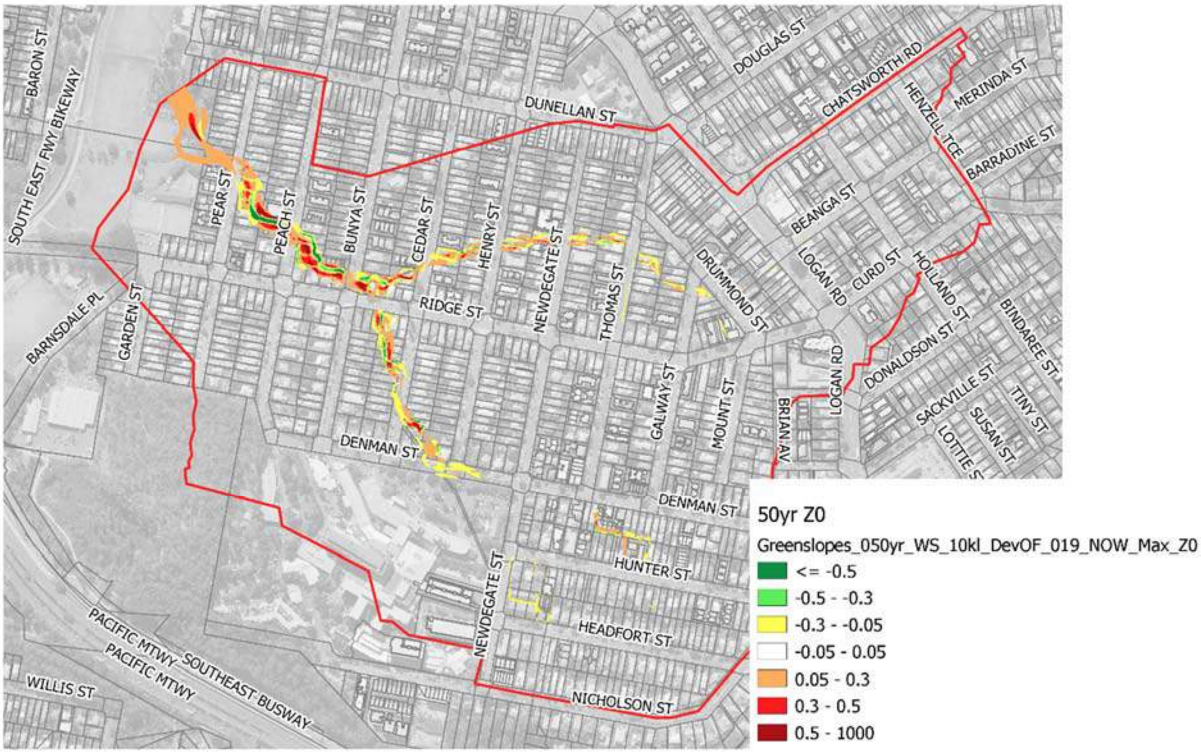
2yr Hazard - BAU_BauOF minus WS_ExOF

2yr Hazard - BAU_BauOF minus NOW

2% AEP - Flood Hazard difference mapping (m/s^2)



50yr Hazard - WS_10kl_ExOF minus NOW



50yr Hazard - WS_10kl_DevOF minus NOW

50yr Hazard - BAU_BauOF minus BAU_ExOF

50yr Hazard - BAU_BauOF minus WS_ExOF

50yr Hazard - BAU_ExOF minus WS_ExOF

50yr Hazard - WS_ExOF minus NOW

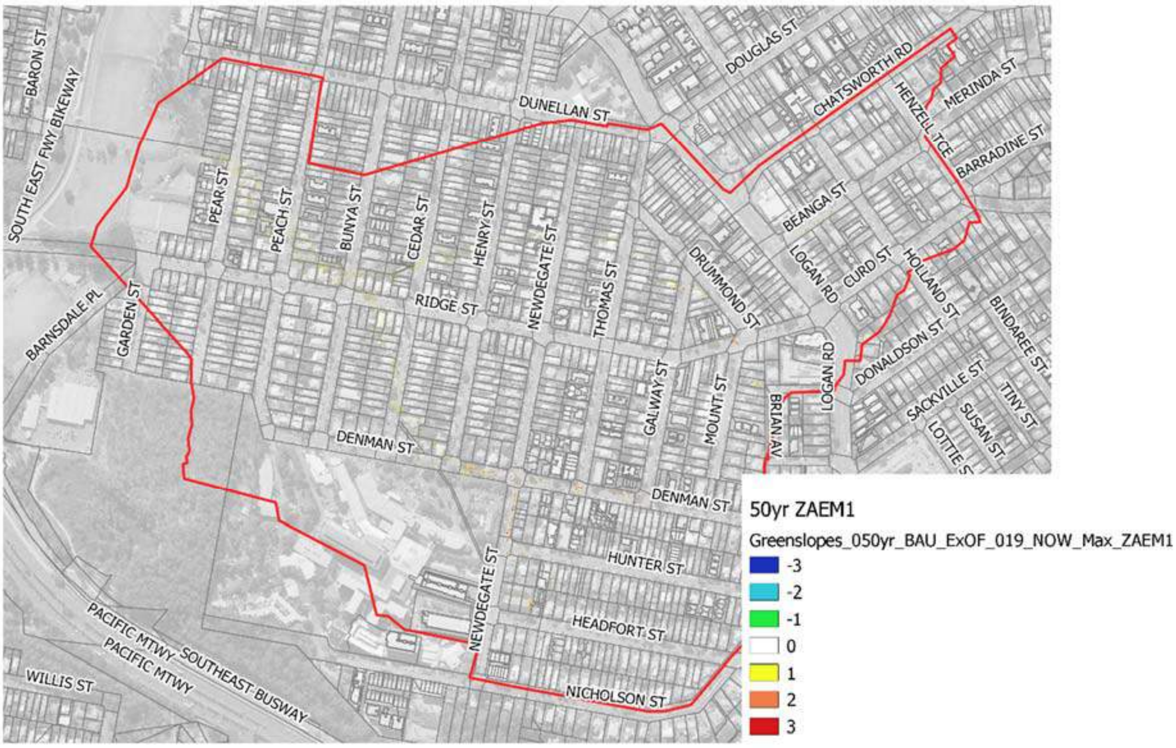
50yr Hazard - BAU_BauOF minus NOW

50yr Hazard - BAU_ExOF minus NOW

50yr Hazard - BAU_BauOF minus WS_DevOF

2% AEP - Flood Hazard Classification (AEMI) difference mapping

50yr Hazard Class - BAU_BauOF minus NOW



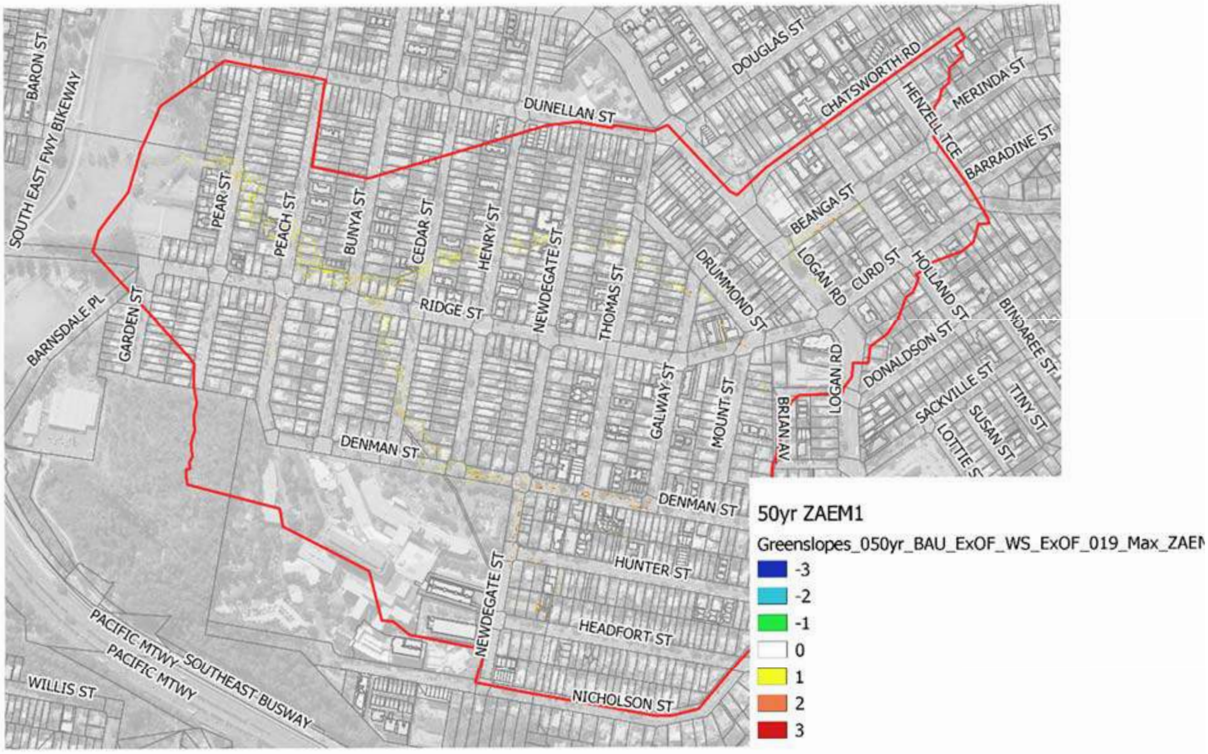
50yr Hazard Class - BAU_ExOF minus NOW

50yr Hazard Class - WS_10kl_ExOF minus NOW

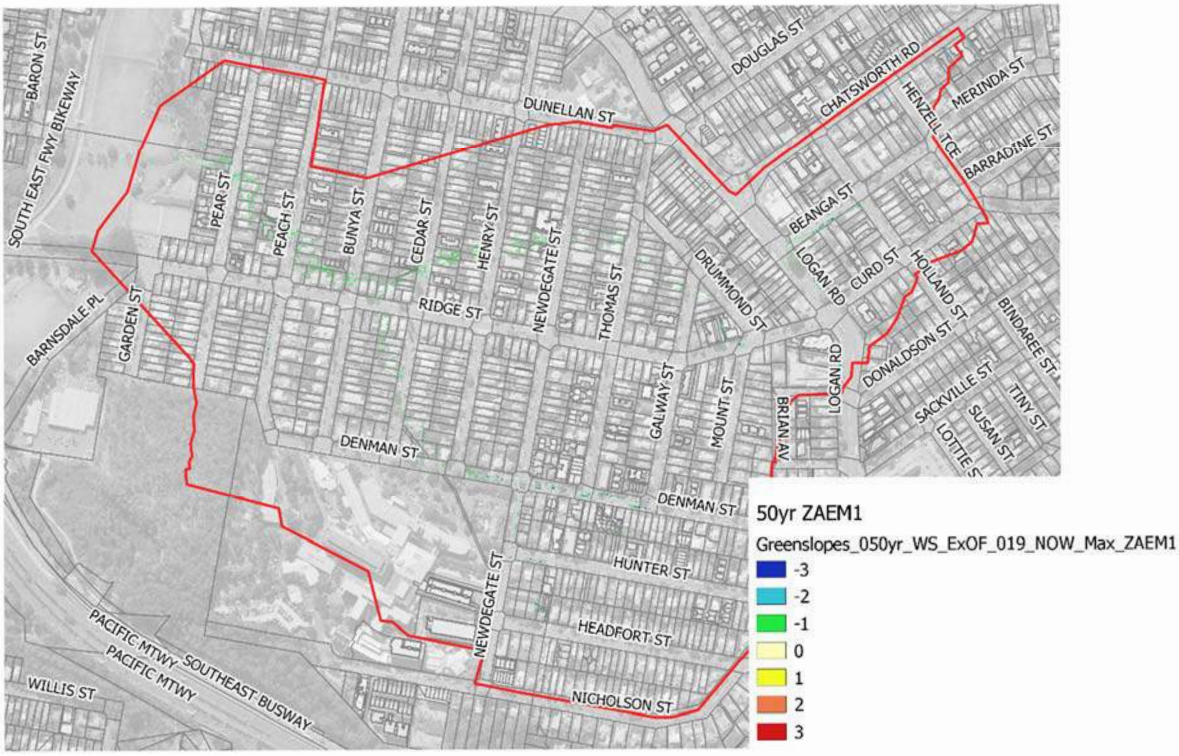
50yr Hazard Class - WS_10kl_DevOF minus NOW

50yr Hazard Class - BAU_BauOF minus BAU_ExOF

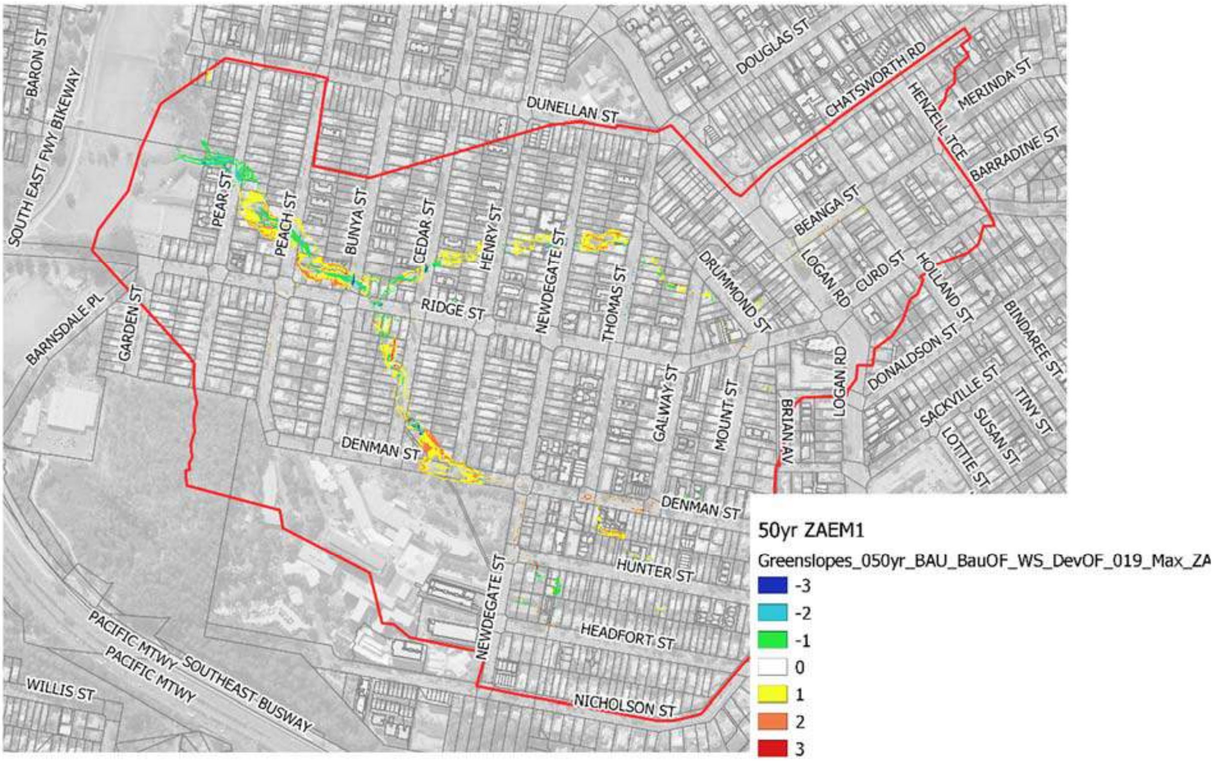
50yr Hazard Class - BAU_BauOF minus WS_ExOF



50yr Hazard Class - BAU_ExOF minus WS_ExOF



50yr Hazard Class - WS_ExOF minus NOW



50yr Hazard Class - BAU_BauOF minus WS_DevOF

Appendix A: Typologies map

Figure 1: BAU Design Topologies Distributions

Figure 2: WS Design Topologies Distributions

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