Stormwater Management Plan

Patyegarang Project, Morgan Road, Belrose

For Metropolitan Local Aboriginal Land Council, **July 2023**

Contents

 This report has been prepared by Craig & Rhodes Pty Ltd and has undergone a quality assurance review. The signatures below confirm review completion.

Issue	Date	Purpose	Author	Approved
A	19-9-22	Issued	Kylee Smith	Andrew Halmarick
B	17-07-23	Re-issue, updated project name	RF	AH

On 9th June 2023, the Department of Planning and Environment issued a Gateway determination for the planning proposal. Following the issue of the Gateway determination, the Metropolitan Aboriginal Land Council resolved to adopt an alternative name for the project to reflect the Aboriginal cultural heritage of the site. This report has accordingly been updated to reference the Patyegarang Project. No other changes have been made to the content of this report.

1. Introduction

1.1 Preamble

The Metropolitan Local Aboriginal Land Council (MLALC) applies to rezone their Morgan Rd, Belrose site in accordance with Chapter 3, State Environmental Planning Policy (Planning Systems) 2021.

The purpose of this report is to describe the likely requirements for stormwater management and how this may be achieved within the proposed subdivision development.

The site is located on Morgan Road, Belrose, has a land area of approximately 70 hectares and is within the Northern Beaches Local Government Area. General development requirements and related background information were sourced from Northern Beaches Council to inform these investigations.

1.2 Background and Context

1.2.1 Site Location

The site is located in the suburb of Belrose, bounded by Forest Way and Morgan Road, shown in Figure 1. The downstream receiving waters are Middle Creek and Narrabeen Lagoon.

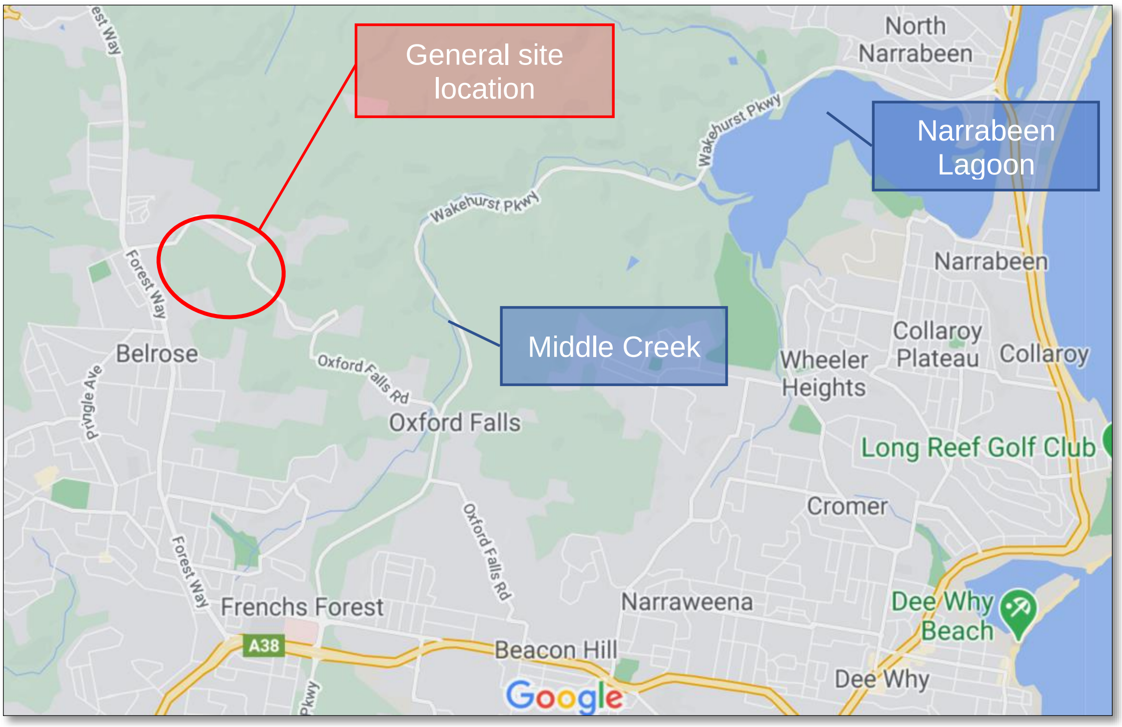


Figure 1 General Site location

A detailed site location is provided in Figure 2, showing the location of Snake Creek and Middle Creek.

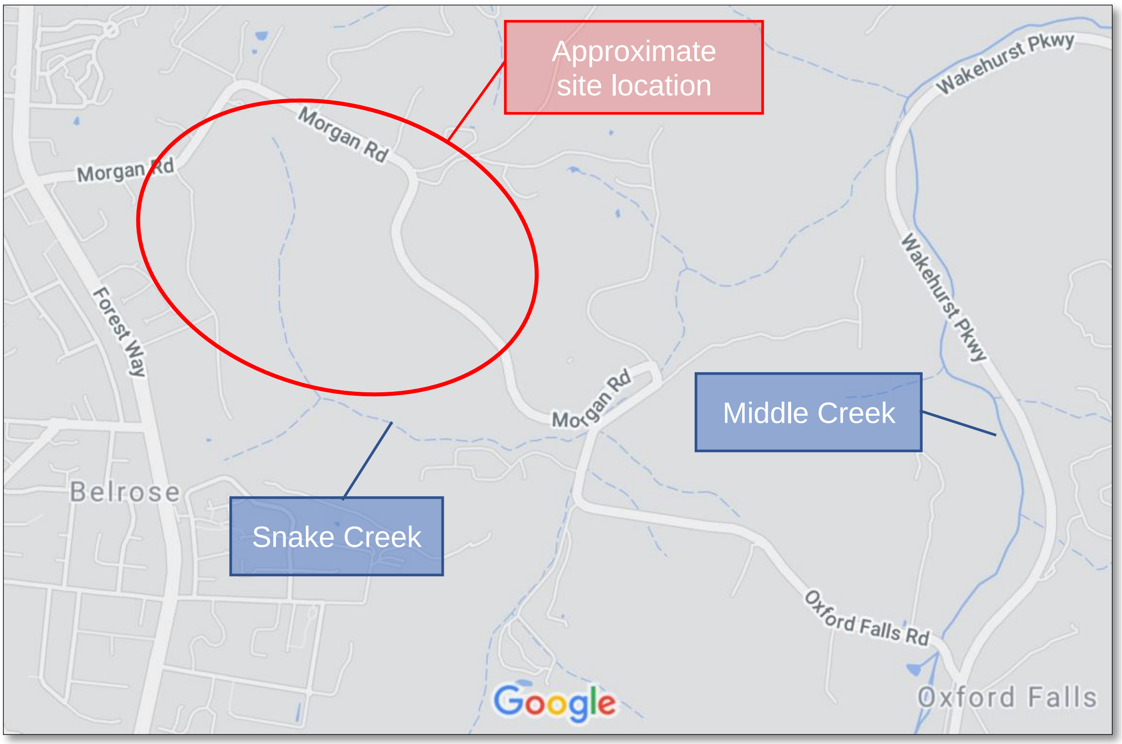


Figure 2 Site location

1.2.2 Proposed Subdivision

The proposed subdivision extents are shown in Figure 3 below in the context of Morgan Rd and Forest Way.

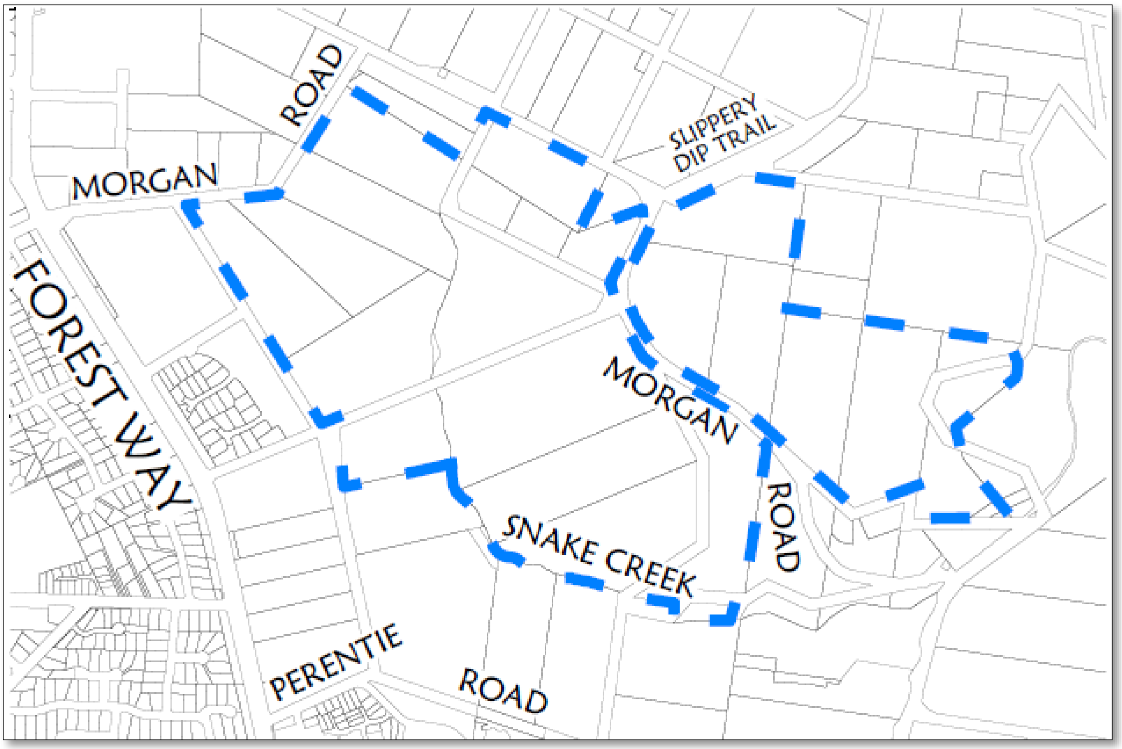


Figure 3 Proposed Subdivision Extent

The draft structure plan of this area is shown in Figure 4. The pink shaded areas denotes potential R2 Residential, and the green shaded area denotes various reserved area for conservation, bushfire management, parklands, riparian corridor and stormwater treatment.

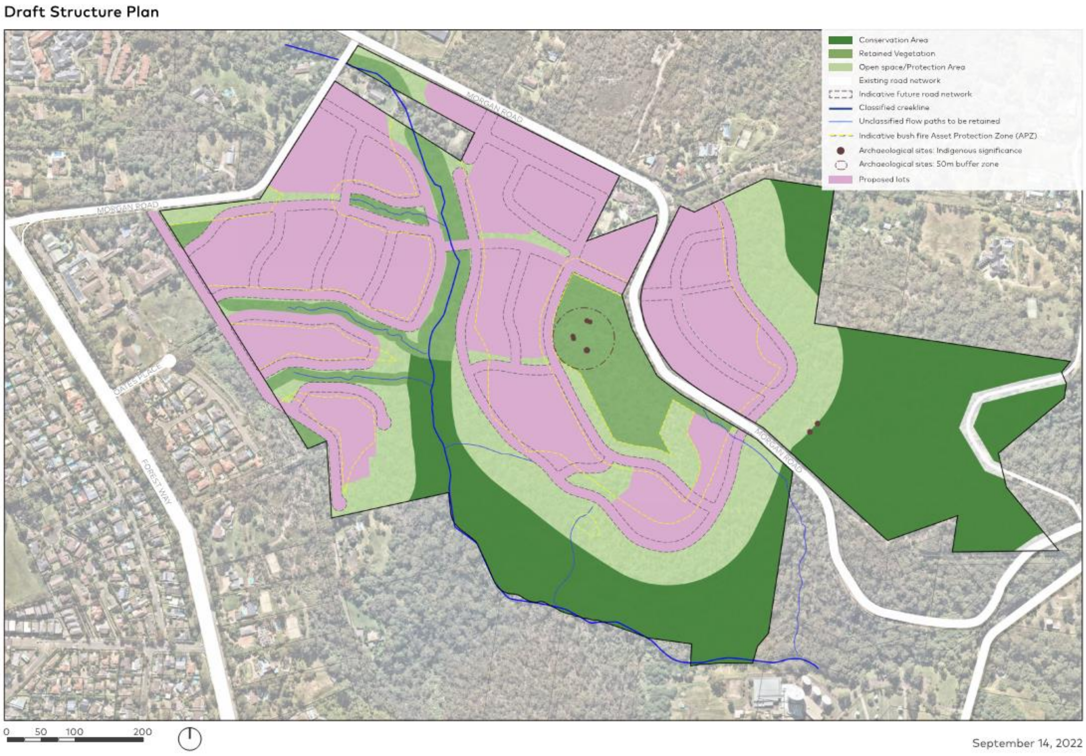


Figure 4 Draft Structure Plan by Cox

1.2.3 Snake Creek

The site encompasses the headwaters of Snake Creek that drains into Middle Creek and Narrabeen Lagoon. There are stormwater culverts under Morgan Rd that direct upstream urban runoff into Snake Creek at the headwaters. The higher reaches of Snake Creek within the proposed development area is deeply incised in a sandstone escarpment as shown in Plates 1 and 2.

Plate 1: General view of Snake Creek

Plate 2: Example of escarpment profile

The creek is characterised as a seasonal stream, with intermittent creek flows throughout the year. The site geology and soil profile is conducive to a stable creek. Baseflow for an extended period of time after a rain event.

The creek bed is very stable, being predominantly bedrock. An example is shown in Plate 3 below.

Plate 3: Exposed bedrock

The Warringah Creek Management Study (2004) classifies Snake Creek and Oxford Creek as Class B acknowledging some degradation in the upper reaches.

Council uses the Strahler System of Stream Order (1957) in their Policy for Protection of Waterways and Riparian Land (PL 740) to classify waterways a riparian corridor widths.

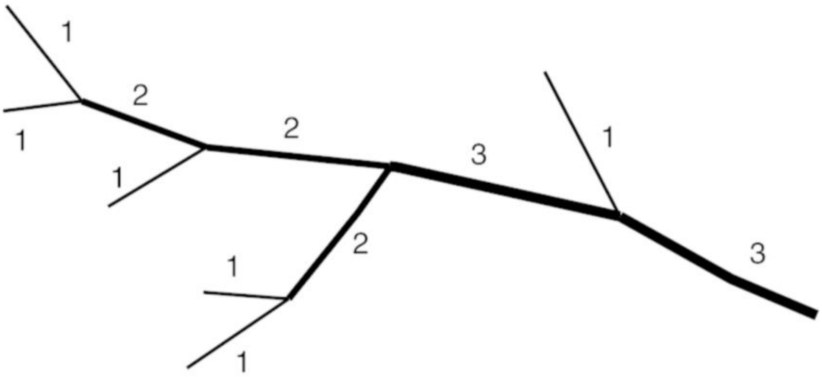


Figure 5 Strahler Stream Order System (extracted from Protection of Waterways and Riparian Land)

Figure 6 shows the extent of 1st order and 2nd order streams within the site extent. Most of the development is adjacent to 1st order with the south-east extremity being 2nd order.

According to Attachment 1 of '*Policy for Protection of Waterways and Riparian Land'* (PL 740), a 10m riparian zone with a 10m buffer is required for 1st order streams. A 2nd order stream of permanently flowing watercourse requires a 20m riparian zone and a 10m buffer.

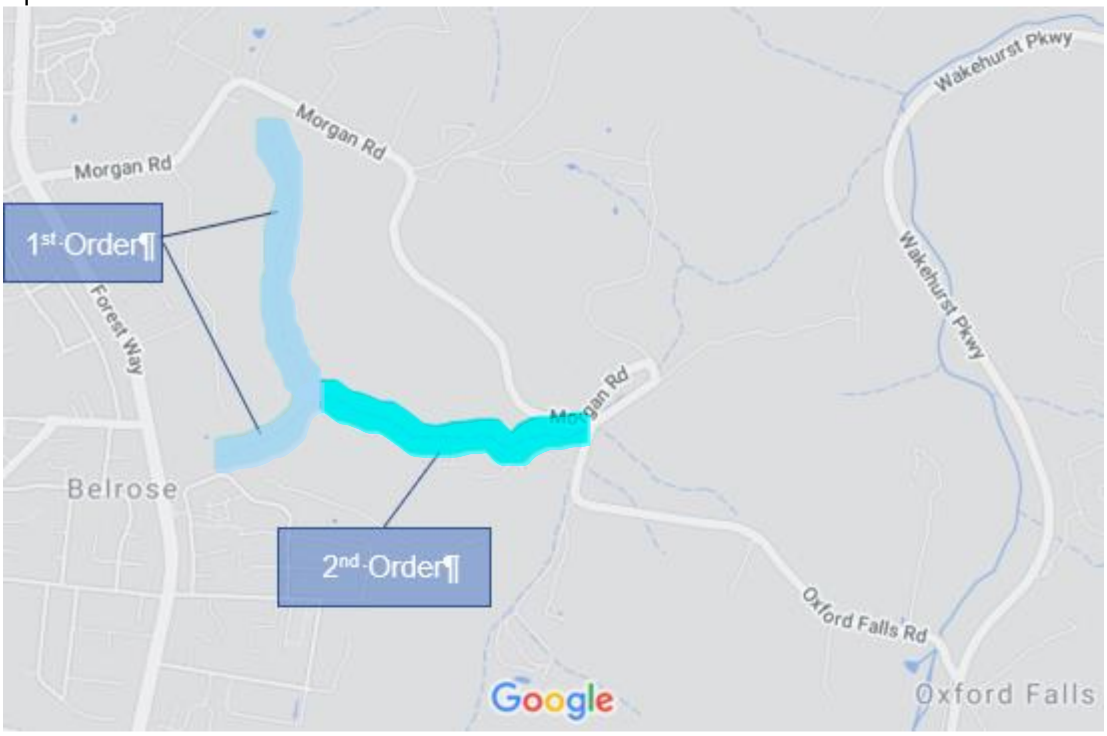


Figure 6 Stream Order definition according to Strahler System

Attachment 2 of '*Policy for Protection of Waterways and Riparian Land'* (PL 740), contains a map that identifies Snake Creek as a waterway. An extract is provided in Figure 7 below.

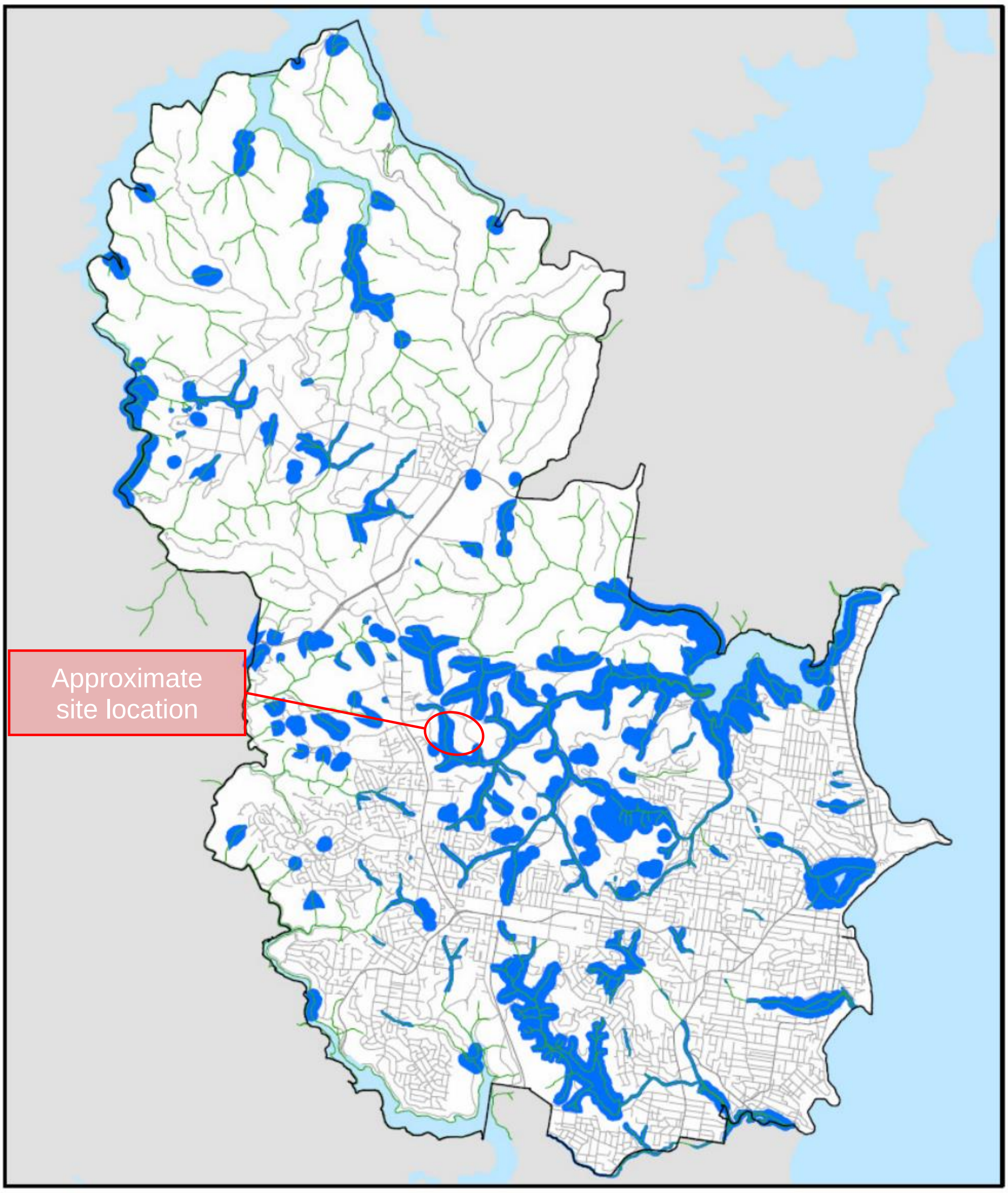


Figure 7 Waterways and riparian land map (extract from Attachment 2 of Protection of Waterways and Riparian Land)

1.2.4 Site Soils

The precinct is mapped by various soil landscapes, including Gymea, Oxford Falls, Hawkesbury and Lambert. The site is underlain by the Hawkesbury Sandstone formation of the Wianamatta group. The Hawkesbury sandstone formation typically comprises of course-grained quartz sandstone with minor shale and laminate lenses. These are overlain by podzolic soils with shallow to moderately deep siliceous sands along drainage lines.

The precinct is considered to have a high susceptibility to erosion due to the characteristics of the colluvial and erosional soil-landscape combine with the high rainfall intensity resulting in soil loss conditions. Soil depths will vary depending on the bedrock, with typical depths of 0.5m. It is expected that gullies will have a greater depth of soil cover up to 2m. It is expected that the hydraulic conductivity of the soil would vary from 60-120 mm/hr due to the variety of soil textures.

1.3 Information Relied Upon

There are several documents that informed the development of this stormwater management plan. These are:

1.3.1 Structure Plan/Masterplan

This plan shows the proposed layout of the development, including roads, superlots, parks/reserves conservation areas. This plan encompasses the recommendations for:

- Bushfire management
- Flora and fauna
- Infrastructure requirements to service the development
- Conservation areas, including the riparian zone

This plan has been relied upon for the development of the stormwater management plan.

1.3.2 Warringah Creek Management Study 2004

This is a relatively old study; however, it is likely to inform the preparation of the LEP and DCP. The critical elements of this document are presented below:

- Classifies Snake/Oxford Cks as Group B - some degradation in the upper catchments, but high ecological value downstream; generally, 10-15% connected impervious area (Snake, Oxford, Duffys, Kierans, Bare)
- Water quality Snake/Oxford Ck was
    - Total Suspended Solid (TSS) 1mg/L
    - Total Nitrogen (TN) 0.3mg/L
    - Nitrate/Nitrites 0.1mg/L
    - Total Phosphorus (TP)<0.01mg/L
- Waterway value
    - moderate ecological value
    - low recreational value
    - moderate landscape value (except for waterfalls)
- Recommendations:
    - Short term: limit catchment development and require WSUD
    - Medium term: prepare a Creek Management Plan, educate residents on plant selection/garden waste management.
    - Long term: riparian vegetation/weeding in long term.

Comment:
1. This report is over 16 years old however it is considered current by the fact it remains on the website. 2. Classification of Group B means that the creek is not considered priority by the Protection of Waterways and Riparian Land Policy 3. The water quality at the time was quite good however may have declined with development in the catchment since 2004

1.3.3 Warringah Local Environmental Plan 2011

The objective of the LEP is to make planning provisions for land in the Warringah area to create and maintain a high level of environmental quality throughout Warringah. In particular relation to environmental quality, the objectives are;

- achieve development outcomes of quality urban design, and
- encourage development that demonstrates efficient and sustainable use of energy and resources, and
- achieve land-use relationships that promote the efficient use of infrastructure, and
- ensure that development does not have an adverse effect on streetscapes and vistas, public places, areas visible from navigable waters or the natural environment, and
- protect, conserve and manage biodiversity and the natural environment, and
- manage environmental constraints to development, including acid sulphate soils, landslip risk, flood and tidal inundation, coastal erosion, and biodiversity,

And in relation to environmental heritage, to recognise, protect and conserve items and areas of natural, indigenous, and built heritage that contribute to the environmental and cultural heritage of Warringah, in relation to community well-being, to:

- ensure good management of public assets and promote opportunities for social, cultural and community activities, and
- ensure that the social and economic effects of development are appropriate.

1.3.4 Warringah Development Control Plan 2011

The overriding objective of the DCP is to create and maintain a high level of environmental quality throughout Warringah. Development should result in an increased level of local amenity and environmental sustainability. The other objectives of this plan are:

- To ensure development responds to the characteristics of the site and the qualities of the surrounding neighbourhood
- To ensure new development is a good neighbour, creates a unified landscape, contributes to the street, reinforces the importance of pedestrian areas and creates an attractive design outcome
- To inspire design innovation for residential, commercial and industrial development
- To provide a high level of access to and within the development.
- To protect environmentally sensitive areas from overdevelopment or visually intrusive development so that scenic qualities, as well as the biological and ecological values of those areas, are maintained
- To achieve environmentally, economically and socially sustainable development for the community of Warringah

Part C4 of this DCP relate to Stormwater. The requirements are that stormwater runoff must not cause downstream flooding and must have minimal environmental impact on any receiving stormwater infrastructure, watercourse, stream, lagoon, lake and waterway or the like. There are specific objectives noted in this chapter of the DCP that have been adopted in the preparation of this report and are noted in the project objectives.

Part E8 of this DCP relates directly to Waterways and Riparian Lands. The objective are similar to that of C4 Stormwater but also have aspirations of improving the waterway condition to achieve Group A classification. It also reinforces the Asset Protection Zones must not extend into riparian zones.

Comment:
1. The specific stormwater management objectives in this DCP are considered to be directly relevant have been adopted for this project.

Warringah Development Control Plan 2011 (C4 Stormwater) objectives are:

1. Improve the quality of water discharged to our natural areas to protect and improve the ecological and recreational condition of our beaches, waterways, riparian areas and bushland;
2. To minimise the risk to public health and safety;
3. To reduce the risk to life and property from any flooding and groundwater damage;
4. Integrate Water Sensitive Urban Design measures in new developments to address stormwater and floodplain management issues, maximise liveability and reduce the impacts of climate change.
5. Mimic natural Stormwater flows by minimising impervious areas, reusing rainwater and Stormwater and providing treatment measures that replicate the natural water cycle
6. Reduce the consumption of potable water by encouraging water efficiency, the reuse of water and use of alternative water sources
7. To protect Council's stormwater drainage assets during development works and to ensure Council's drainage rights are not compromised by development activities.
8. In addition, the project will enhance the water quality of Narrabeen Lagoon by treating upstream storm water catchments together with the implementation of best practice “at source” water sensitive urban design technology.

Comment:
These objectives relating to the site will be considered in the stormwater management approach and more broadly to this project

1.3.5 Protection of Waterways and Riparian Land Policy (PL 740)

Riparian land is defined as all land within 100 metres of a wetland or within 40 metres of a watercourse (taken to start at the highest bank of the watercourse, for ephemeral streams without a defined channel, the start of the riparian land is the creek centre line).

This Policy provides Warringah Council and members of the public with guidance in relation to the Water Management Act 2000 (NSW) ["the Act"] and Warringah Council's own planning instruments.

The Act is based on the concept of "ecologically sustainable development". In summary, the Act provides for:

- the fundamental health of our rivers and groundwater systems and associated wetlands, floodplains, estuaries must be protected
- the management of water must be integrated with other natural resources such as vegetation, soils and land
- to be appropriately effective, water management must be a shared responsibility between government and the community
- water management decisions must involve consideration of environmental, social, economic, cultural and heritage aspects
- social and economic benefits to the State will result from the sustainable and efficient use of water

This Policy gives priority to those creeks that:

- are significant to threatened species,
- are within mapped wildlife corridors (see DCP Map Wildlife Corridors),
- most closely represent natural conditions, or
- are classified as Group A Creeks.

In addition to Council's requirements, development within 40m of a waterway may require relevant approvals under other legislation namely a Controlled Activity Approval pursuant to the Water Management Act 2000.

Comment:

1. Snake Creek is classified as Group B and therefore not considered priority. This is consistent with the value allocated in Warringah Creek Management Study 2004 being low to moderate. However this development is espousing good protection of the waterway as it relates to cultural conservation that the current and traditional owners value.
2. Snake Creek is predominantly a first order stream that requires a 10m riparian zone and a 10m buffer according to Attachment 1 of this policy.
3. The proposed Masterplan indicates that development (roadways) are proposed within 40m of the top of bank. This is likely to trigger other approvals being required including a Waterway Impact Statement for the any encroachments especially the proposed crossing.

1.3.6 Waterway Impact Statement

The technical requirements of a Waterway Impact Statement are provided in Council guidelines for preparation of such a document and the 4 main areas are listed below:

Waterway analysis	Description of waterway condition and values. Description of proposed development including construction activities. Description of stormwater management proposed.
Assessment of Impacts	Water quality, channel stability, ecology, landscape, flooding and vegetation removal.

Assessment of Compliance with DCP	C4 Stormwater C5 Erosion and Sedimentation E2 Prescribed Vegetation E3 Threatened species, populations, ecological communities listed under State or Commonwealth legislation, or High Conservation Habitat E4 Wildlife Corridors E5 Native Vegetation E6 Retaining unique environmental features on site E8 Waterways and Riparian Lands
Provision of Mitigating Measures	Outcome 1: Protection of native species and communities Outcome 2: Prevent loss of natural diversity through protecting waterway and riparian vegetation Outcome 3: Minimise damage to public and private property by waterway processes through maintaining the relative stability of the bed and banks Outcome 4: Preserve natural ecological processes

Comment:

1. An impact statement will likely be required in the approval process to satisfy Northern Beaches Council.
2. The objectives of the development align with Council's intend of these documents. Much of the material in this report could be used to inform a Waterway Impact Statement.

2. Stormwater Strategy

2.1 Introduction

Historically, Stormwater Management has been managed in silos where conveyance, flooding, water quality and volume management have been addressed separately and, in some cases, not at all. The term integrated water management is understood to have firstly been introduced in the context of water supply and wastewater with drainage. More recently the term has been centred around stormwater management, recognising that Stormwater has a direct impact on water supply through roof water harvesting and stormwater harvesting as well as direct passive irrigation. It is also understood that effective management of Stormwater can reduce the volume of wet weather wastewater flows.

Integrated stormwater management provides holistic consideration to stormwater volumes, peak flow management, water quality management and drainage. This approach has been adopted in response to the historical degradation of receiving waters and urban streams as a result of development in our catchments lacking effective stormwater controls and measures. Historically the value of our waterways has been reduced as the mitigation or protection has been marginal and our communities are recognising the benefits of healthy waterways and how that relates to liveability today and for future generations.

The primary impact of development on our local waterways is the increase in stormwater runoff volume. The increase in flow volumes due to development without mitigation is 4 to 5 times the volume of a natural catchment. The flow regime in an unmitigated developed catchment results in the typical channel forming flows that would typically occur once every 1-2 years to now occur multiple times per year. This degrades our waterways physically through geomorphic adjustments by erosion of the banks and beds, which cannot cope with the additional flow volumes.

The secondary impacts are the deterioration of water quality. Development not only efficiently drains pollutants to our waterways during rainfall events but also accommodates activities that introduce pollutants to the catchment such as hydrocarbons, metals, calcium, and litter.

Water Sensitive Urban Design (WSUD) has historically focused our attention on improving stormwater quality; however, volume management has largely been ignored. Volume reduction has been acknowledged in tools such as the Stream Erosion Index and reported in water quality modelling packages such as MUSIC, but it has not been the focus of our attention as we have been largely unaware of the nexus with the deterioration of our waterways. It is recognised that the adoption of WSUD does reduce the volume of runoff and in turn reduces the pollutant loadings to our urban waterways. This includes rainwater tanks which is a Building Sustainability Index (BASIX) requirement by the NSW government.

2.2 Approach

Storm believes that the key objectives of the project are No 5 in the DCP C4 together with industry best practice being:

> "*Mimic natural stormwater flows by minimising impervious areas, reusing rainwater and stormwater and providing treatment measures that replicate the natural water cycle*"

Achieving this objective results in flood afflux being managed as well as water quality. The concept is that Snake Creek experiences no notable change in the hydrological regime, which means there is no prompt for hydrogeological adjustments to the waterway.

The key variable in mimicking pre-development flow regimes is stormwater volume, and that is why we use the concept of Stormwater Footprint. The Stormwater Footprint is a simple way of reporting the likely impacts of a proposed development on the existing waterway, and this is further explained below.

The stormwater footprint strategy is presented at various scales being lot, street and neighbourhood. The benefits of applying WSUD at these scales is provided in Table 1 below.

Table 1 Benefits of applying WSUD to development at the various scales

Scale	Benefits
Lot	Reduces stormwater volumes Better distribution of infiltrated Stormwater into the landscape. (note salinity) Reduces pollutants to the street and receiving waters. Provides potable water reduction through raintanks and passive irrigation. Maintenance undertaken by lot owner / tenant.
Street	Greening the streets through passive watering Reduction of potable water Healthier streetscape environment eg mitigate heat island effect through creation of tree canopy cover, creates amenity Reduction in stormwater volume downstream Reduction in pollutant loads downstream Interest of home-owners / tenants in maintaining streetscape
Precinct	Last line of defence to protect urban waterways Benefit from upstream WSUD Creates amenity. Potential multiple purpose zones Enhances bio-diversity and enhances corridors

The specific measures at each scale are discussed further below in this report.

2.3 The Stormwater Footprint

The Stormwater Footprint is a straightforward measure that directly relates the potential impact of the development on the receiving waterways in terms of degradation through erosion and water quality reduction as well as potential flooding. It is reported in the following way:

The Stormwater Footprint = average annual runoff post-development / average annual runoff from pre-developed catchment

The Stormwater Footprint is calculated with:

- MUSIC modelling
- Over the designated representative period
- The pre-developed condition in a natural state unless Council specifies otherwise
- The post-development condition to include all WSUD elements proposed to mitigate the post-development stormwater impacts.

Table 2 below describes the impacts on downstream waterways from setting your Stormwater Footprint.

Table 2 Stormwater Target Impacts

Stormwater Footprint Target	Impact of Target on Downstream Waterways
1	The downstream waterway will remain unaffected by the proposed development. The geomorphic conditions will remain unchanged. The stormwater quality will be reasonable as a result of managing the runoff from the impervious areas.
< 1	This may be imposed to counter existing unmitigated development in the catchment. There could be significant waterway degradation or flooding downstream that needs to be rectified.
> 1	This may be imposed to catchments that have low-value receiving waters where further waterway erosion is not expected or not of concern nor the impacts of increased flooding. Other specific water quality targets may be imposed irrespective of volume reduction targets.

3. Adopted Targets for Development

3.1 Stormwater Footprint

The development aims to protect and safeguard the waterway ecology. The focus is to preserve the natural frequency and volume of flow events in the waterways. Stormwater footprint addresses flow volume and water quality which supports the natural preservation of the waterway. The targets for the stormwater footprint are detailed below.

Table 3 Stormwater Footprint Targets

Scale	Targets	Benefits
Lot	<1	The downstream waterway will remain unaffected by the proposed lots
Street	>1	The downstream waterway will remain unaffected by the proposed roads were possible. Neighbourhood scale opportunities will be implemented to mitigate excess road flows
Precinct	<1	Neighbourhood scale treatments will be implemented to offset unmitigated street flows

3.2 Stormwater Quality

The aims for water quality modelling were to assess the impacts of the proposed development on the stormwater quality with the proposed WSUD measures from the Stormwater footprint assessment. The critical pollutants modelled are Gross Pollutants, Total Nitrogen, Total Phosphorus and Total Suspended Solids.

Table 4 Pollutant load reduction target

Pollutant	% Reduction Target
Total Suspended Solids (TSS)	85%
Total Phosphorus (TP)	65%
Total Nitrogen (TN)	45%
Gross Pollutants	90%

3.3 Flooding

A peak flow assessment is undertaken to review peak flows for the 50% and 1% AEP. This assessment focuses on the magnitude of certain storm events.

The 50% AEP has been adopted to assess stream forming flows. The 1% AEP has been adopted to assess the flood risk. The target is to match the pre-development hydrograph (volume and peak flow) for these recurrences post-development.

Peak flow management is achieved by reducing stormwater runoff volumes from the proposed development using WSUD measures.

- Pre and post hydrographs of the downstream condition are shown on the same graph at given storm durations with +/- 5% hydrograph volume.
- The developed hydrograph is no more than +/- 10% of pre-development at any location on the graph.

4. Stormwater Footprint Assessment

4.1 Approach

The stormwater footprint is computed with MUSIC modelling over a designated period of years. The post-development condition includes all WSUD elements proposed to mitigate the post-development stormwater impacts. It is compared against the pre-development flow volume.

- At a lot scale, rainwater tanks are implemented with bioretention systems to retain water within the catchment.
- At a street scale, bioretention systems, infiltration systems and storages treat runoff and retain flows.
- At a precinct scale, flows are retained within infiltration systems and bioretention systems to match streamflow as mimic baseflow along riparian corridors.
- Gross pollutants controls will also be implemented at source, where available and at precinct scale.

The target for each is set out in Section 3.1 and 3.2. The initial loss of the site was also reviewed to determine the required volume to be retained within each scale of development such that the post-development hydrograph closely mimics the pre-development hydrograph.

4.2 MUSIC Model Setup

Refer to **Appendix A** for MUSIC modelling parameters. A MUSIC model was set up for the predeveloped and developed scenario at a lot, road, and neighbourhood scale.

4.2.1 Initial Loss Continuing Loss Estimation

A review of the ARR data hub was undertaken to estimate the site losses. Existing initial loss values within the current ARR system have been found to have a significant bias toward default values. Considering this, a hierarchy approach to loss and pre-burst estimation is used. In this case, the least preferred option (option 5) is to be used as more detailed information on losses, and pre-burst was not available.

The probability neutral burst initial loss values established in the WMAWater 2019 study and available through the ARR datahub were reviewed within the area and for sites with similar geomorphic conditions. It was critical to match the initial loss to the site soil conditions to model stormwater volumes accurately. The review estimated the initial loss was approximately 5-7mm/hr and that the continuing loss was 0.1-0.5mm/hr. An initial loss of 7mm/hr and a continuing loss of 0.5mm/hr was adopted for this assessment.

4.3 MUSIC Model at Scale

4.3.1 Lot Scale Treatment

The focus of on-lot WSUD measures, such as rainwater tanks, is to reduce the volume of stormwater runoff. This reduces the runoff frequency and the pollutant loads received by the downstream waterway. On-lot WSUD measures aim to offset the increase in pollutant load and stormwater volumes as a result of the increase in impervious surface.

While the master plan specifies developments ranging in lot sizes and fraction imperviousness, a homogenous 600m^2 lot with 60% effective imperviousness was adopted for the proposed development areas. It has been calculated that at the precinct scale, effective imperviousness for lots is below 60%. As such the adopted 600m2 lot with 60% effective imperviousness in a conservative estimate providing a factor of safety.

Table 5 Developed Catchment Lot Scale

Catchment	Area	Imperviousness %
Roof	300m^2	100%
Untreated impervious	60m^2	100%
Untreated impervious	240m^2	0%

Table 6 Predevelopment Catchment Lot Scale

Catchment	Area	Imperviousness %
Rural Residential	600m^2	0%

The WSUD approach for the 300m^2 roof area is to install two rainwater tanks and a bioretention system. The first 5kL rain tank is for reuse. A reused demand of 500L a day was applied, following Sydney Waters guidelines, 2015.
The second 5kL tank leaks to a 10m^2 bioretention system. Bioretention parameters can be found in **Appendix A.** The leak rate has been modelled by adopting an initial loss equal to the impervious area*7mm. This mimics the initial loss infiltration. This lot treatment train can be scaled to match the imperviousness and lot areas.

The MUSIC model set up for the lot scale is provided below in Figure 8.

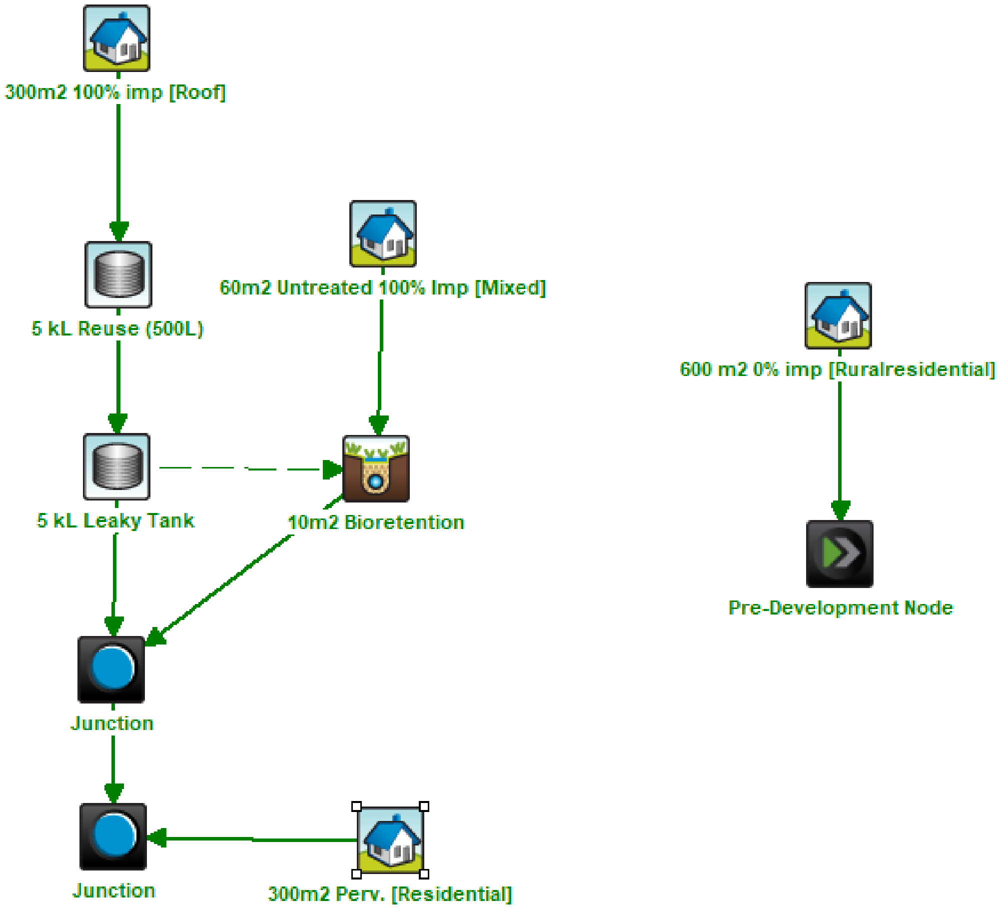


Figure 8 Lot Scale MUSIC model layout

Table 7 Stormwater Footprint Results Lot Scale

Parameter	Outflow ML/year
Annual Runoff Predeveloped	0.253
Annual Runoff Developed	0.217
Stormwater footprint	0.85

The lot scale treatment has a stormwater footprint of less than 1, meaning the downstream waterway will be unaffected by the development.

4.3.2 Street Scale Treatment

The focus of WSUD at a street scale is to reduce the volume of stormwater runoff. In turn, this reduces the frequency of runoff and the water quality pollutant loads. There are two street scale strategies to manage stormwater runoff.

Cross street roads will be treated by bioretention systems and subsurface storages. The proposed system treats the runoff and retains the 7mm initial loss within the catchment. The 7mm initial loss will be released over a period of 1 day to precinct scale biofiltration and infiltration systems.

Roads adjacent to riparian zones will be treated by Infiltration systems, which mimic baseflow by infiltrating Stormwater along the creek corridors.

It has also been identified that, particularly due to the terrain, that there will be street areas that are unsuitable for treatment. Excess flows will be treated at a precinct scale. 1000m^2 impervious areas were adopted for the street scale modelling.

Table 8 Developed Catchment Street Scale

Catchment	Area	Imperviousness %
Road	1000m^2	100%

Table 9 Predevelopment Catchment Road Scale

Catchment	Area	Imperviousness %
Rural Residential	1000m^2	0%

Cross Street Road Model

The WSUD approach for the cross street road area is for runoff to be treated by a 60m^2 bioretention system. The bioretention overflows to a 14kL storage tank which has a leak rate of the impervious area*7mm initial loss per day. This mimics the initial loss of the storm infiltrating into the subsurface. This volume will be treated at a precinct scale along the creek corridors mimicking baseflow.

The MUSIC model set up for the cross-street road scale is provided below in Figure 9.

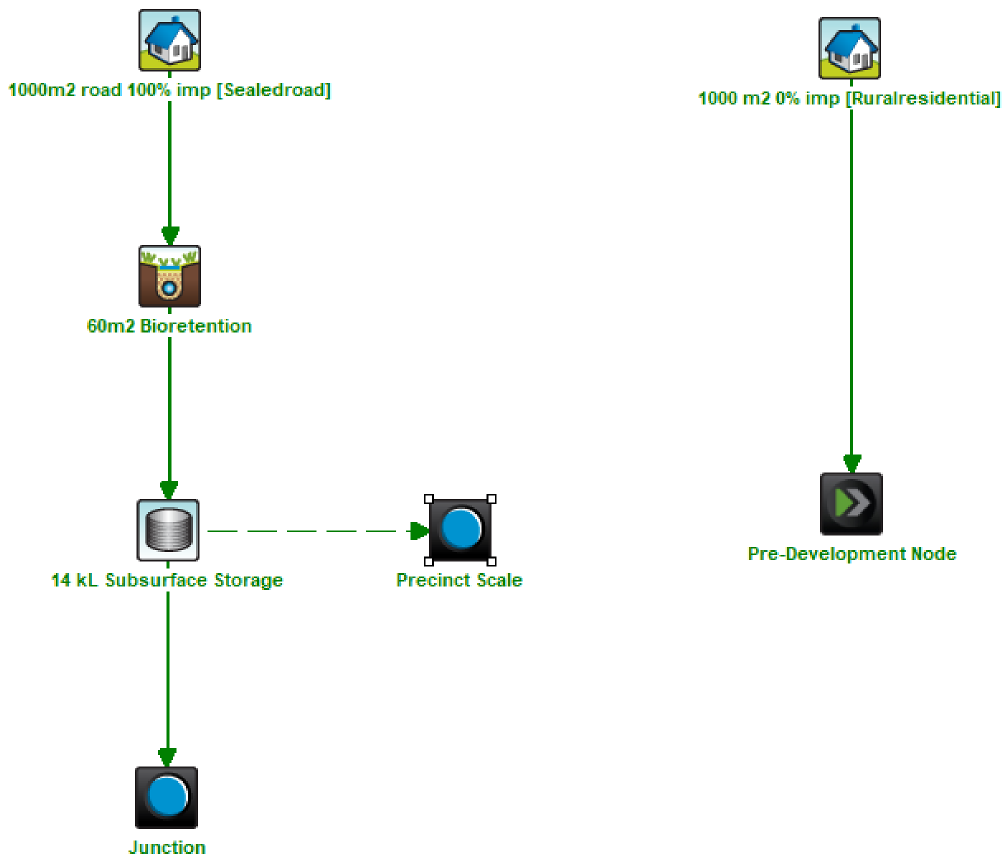


Figure 9 Street Scale (cross street) MUSIC model layout

Table 10 Stormwater Footprint Results Street Scale (Cross Street)

Parameter		Outflow ML/year
Annual Runoff Predeveloped		0.423
Annual Runoff Developed		0.888
Stormwater footprint		2.1

The street (cross street) scale treatment has a stormwater footprint of greater than 1, meaning that further stormwater management is required for this catchment. This will be achieved through precinct scale measures.

Riparian Zone Street Infiltration Model

The WSUD approach for road areas adjacent to riparian zones is for runoff to be treated by infiltration. This mimics the catchments baseflow to the receiving waterways. Infiltration parameters can be found in **Appendix A**.

The MUSIC model set up for the lot scale is provided below in Figure 10.

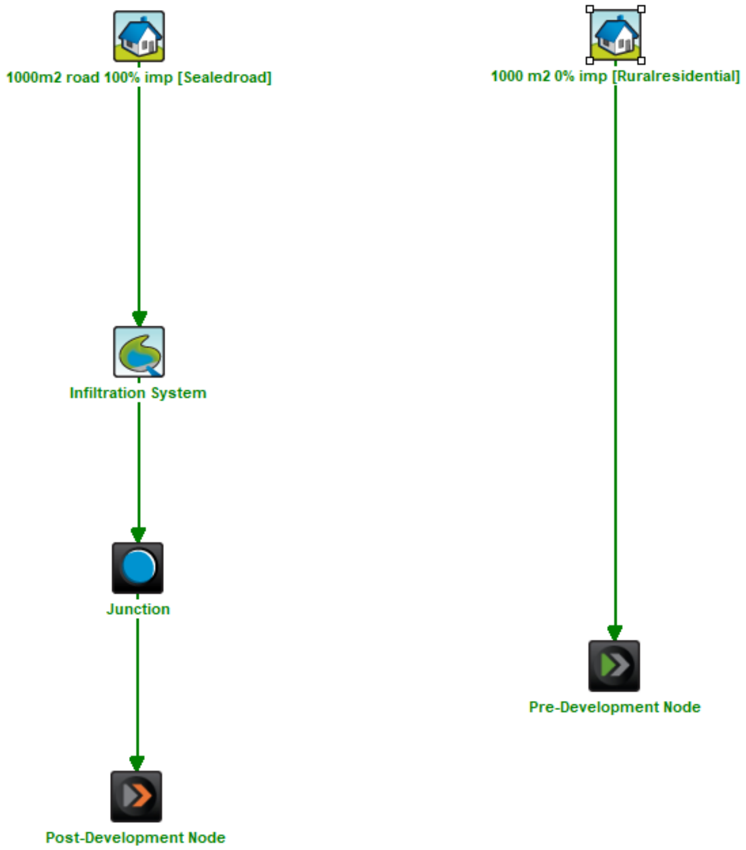


Figure 10 Street Scale (Infiltration) MUSIC model layout

Table 11 Stormwater Footprint Results Street Scale (Infiltration)

Parameter		Outflow ML/year
Annual Runoff Predeveloped		0.423
Annual Runoff Developed		0.286
Stormwater footprint		0.68

The street (infiltration) scale treatment has a stormwater footprint of less than 1, meaning the downstream waterway will be unaffected by the development. The infiltration system also mimics natural baseflow back to the waterway.

4.3.3 Precinct Scale Treatment

The objectives of precinct scale WSUD measures are to reduce the volume of stormwater runoff and to infiltrate stormwater to mimic the catchment baseflow. Due to the steep terrain, meeting stormwater footprint as a street scale may not be feasible or desirable. Precinct scale WSUD measures will be implemented to manage untreated road areas.

- Stormwater harvesting
- Bioretention systems
- Infiltration systems
- Passive irrigation

Precinct options can be varied depending on each sub-catchment characteristics. An example of a bioretention system with infiltration is shown below. The system was sized to treat and infiltrate the excess runoff from the cross-street system.

The MUSIC model set up for the lot scale is provided below in Figure 11.

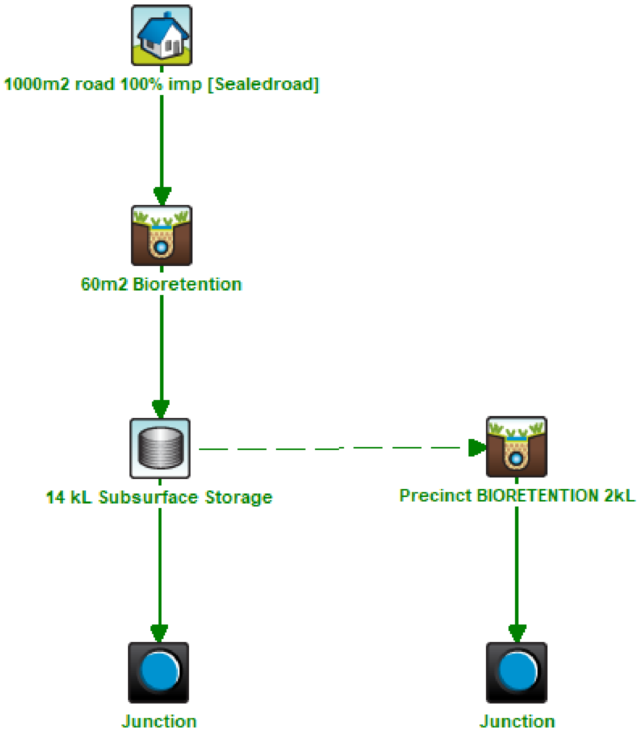


Figure 11 Precinct Scale MUSIC model layout

Table 12 Stormwater Footprint Results Precinct Scale

Parameter		Outflow ML/year
Annual Runoff Predeveloped		0.465
Annual Runoff Developed		0
Stormwater footprint*		0

The precinct scale treatment at this scale has a stormwater footprint of 0. In the next stage of design, specific precinct scale treatments will be sized to mitigate excess flow volumes in each sub-catchment. The site was reviewed, and available space for precinct scale systems was confirmed. Precinct scale stormwater harvesting and passive irrigation could also be implemented to manage stormwater volumes.

5. Water Quality Management

5.1 Approach

Water quality is managed by the "treatment trains" set out within the stormwater footprint approach. It is expected that standard industry water quality targets will primarily be achieved by reducing the stormwater runoff volume back to the catchment in a natural state. The Stormwater Footprint measure is adopted in this instance as it focuses on the measures for retention of stormwater where pollution reduction is a beneficial consequence as well as critically waterway protection.

Regardless of the above, there has been a precedence set for water quality targets that specify pollution retention for key parameters of stormwater runoff. The industry standard targets, set out in section 3, have been adopted in this case to provide consistency to the water quality approach.

The catchment pollutant retention is calculated with MUSIC modelling over a designated period of years. The post-development condition includes all WSUD elements proposed to mitigate the post-development stormwater impacts. It is compared against the unmitigated scenario.

5.2 MUSIC Model Setup

Refer to **Appendix A** for MUSIC modelling parameters. A MUSIC model was set up for the developed and mitigated developed scenario. The MUSIC model mitigated model is provided below in Figure 12.

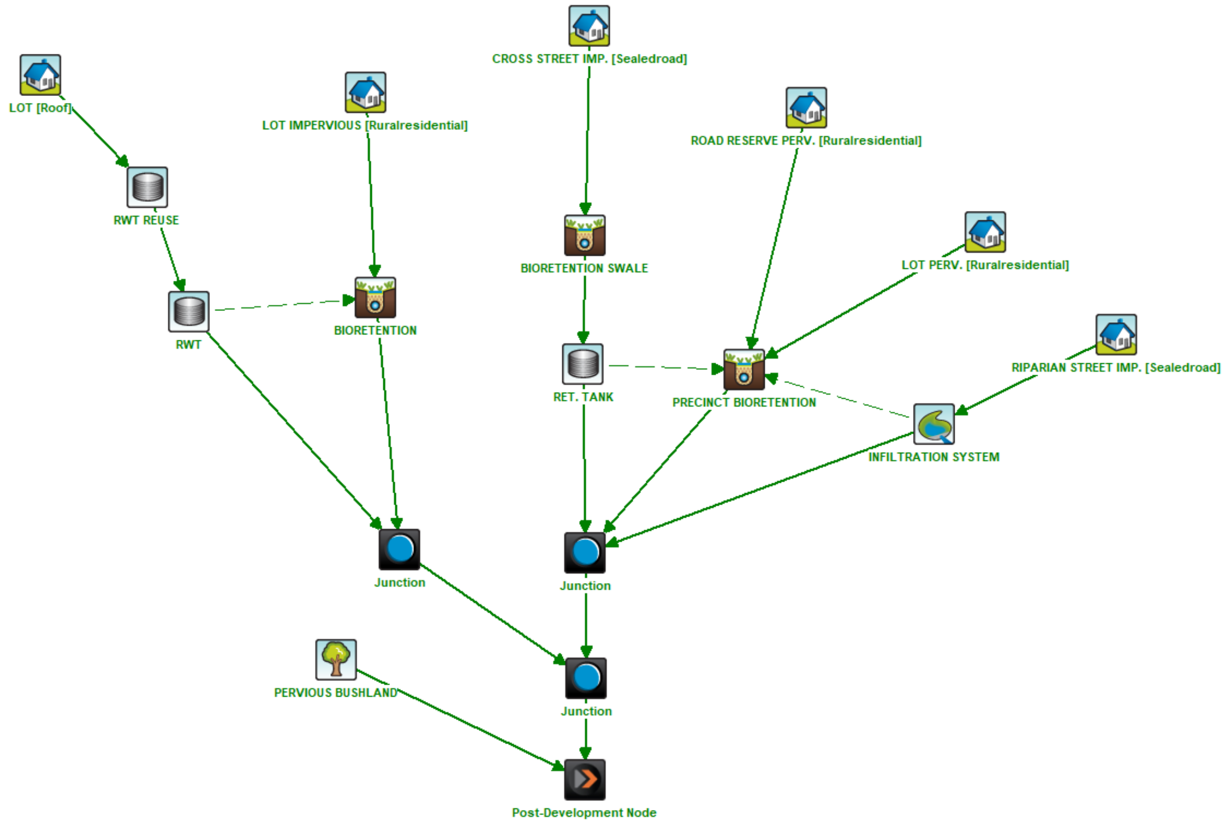


Figure 12 Mitigated case MUSIC model

5.3 MUSIC Model Quality Results

The mitigated scenario model was developed incorporating the treatment train described in the stormwater footprint approach, with the results compared against the unmitigated developed scenario. The results outlined in Table 13 indicate that the water quality improvement objectives set out in this stormwater strategy are achieved for the precinct.

Table 13 MUSIC Model Water Quality Results

Pollutants	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	Gross Pollutants (kg/yr)
Source Load	36200	77.9	583	5670
Output	4690	13.3	148	0.2
Reduction	86%	82%	75%	99%
Target	85%	65%	45%	90%

6. Flood Modelling

6.1 Approach

Council stormwater policies generally focus on stormwater peak flow management only. Peak flows area certainly a key factor in calculating hydraulic stormwater controls for conveyance purposes. The table below describes key considerations for peak flows at the various recurrence intervals.

Table 14 AEP recurrence

ID	Event Recurrence	Comment	Target
1	50% AEP	This is the typical recurrence interval for stream forming flows. Maintaining the natural hydrograph (volume and peak flow) for this recurrence post development ensure the existing structural integrity of our waterways.	Reduce stormwater runoff volumes from proposed development up to this recurrence interval using WSUD. This will likely meet water quality targets. Report Stormwater Footprint.
2	20% AEP	Design capacity of the minor drainage system for residential development. Design capacity of restored waterways.	Conveyance without nuisance flooding in residential areas and within banks or restored waterways.
3	10% AEP	Design capacity of minor drainage system for commercial and industrial areas.	Conveyance without nuisance flooding.
4	5% AEP	Design capacity of minor drainage system for sub-arterial roads.	Conveyance without nuisance flooding.
5	1% AEP	Design overland flowpaths to convey flood flows safely with adequate freeboard. Define appropriate riparian corridor widths to convey these flood flows with adequate freeboard.	Convey flood floods safely with adequate freeboard to floor levels. Arterial roads are flood free.
6	PMF	To define flood-prone lands and flood evacuation procedures.	Place critical and sensitive infrastructure above the PMF level.

A peak flow assessment is undertaken to review peak flows for the 50% and 1% AEP. This assessment focuses on the magnitude of certain storm events.

The 50% AEP is assessed as it is the accepted recurrence for stream forming flows. The target is to match the natural hydrograph (volume and peak flow) for this recurrence post-development to ensure the existing structural integrity of our waterways. This is achieved by reducing stormwater runoff volumes from the proposed development up to this recurrence interval using WSUD.

The 1% AEP is assessed as it is the accepted recurrence for peak flow conveyance. The target is to match the natural hydrograph (volume and peak flow) for this recurrence post-development. This is achieved also achieved by reducing stormwater runoff volumes from the proposed development up to this recurrence interval using WSUD.
Hydrologic modelling of the precinct was undertaken using XP-RAFTS modelling software. This model is widely accepted by the industry for hydrological modelling to predict stormwater discharge for pre and post-development conditions. Modelling was undertaken with data extracted from the ARR Data Hub, in accordance with Australian Rainfall and Runoff 2019 (ARR2019).

6.2 Study Area

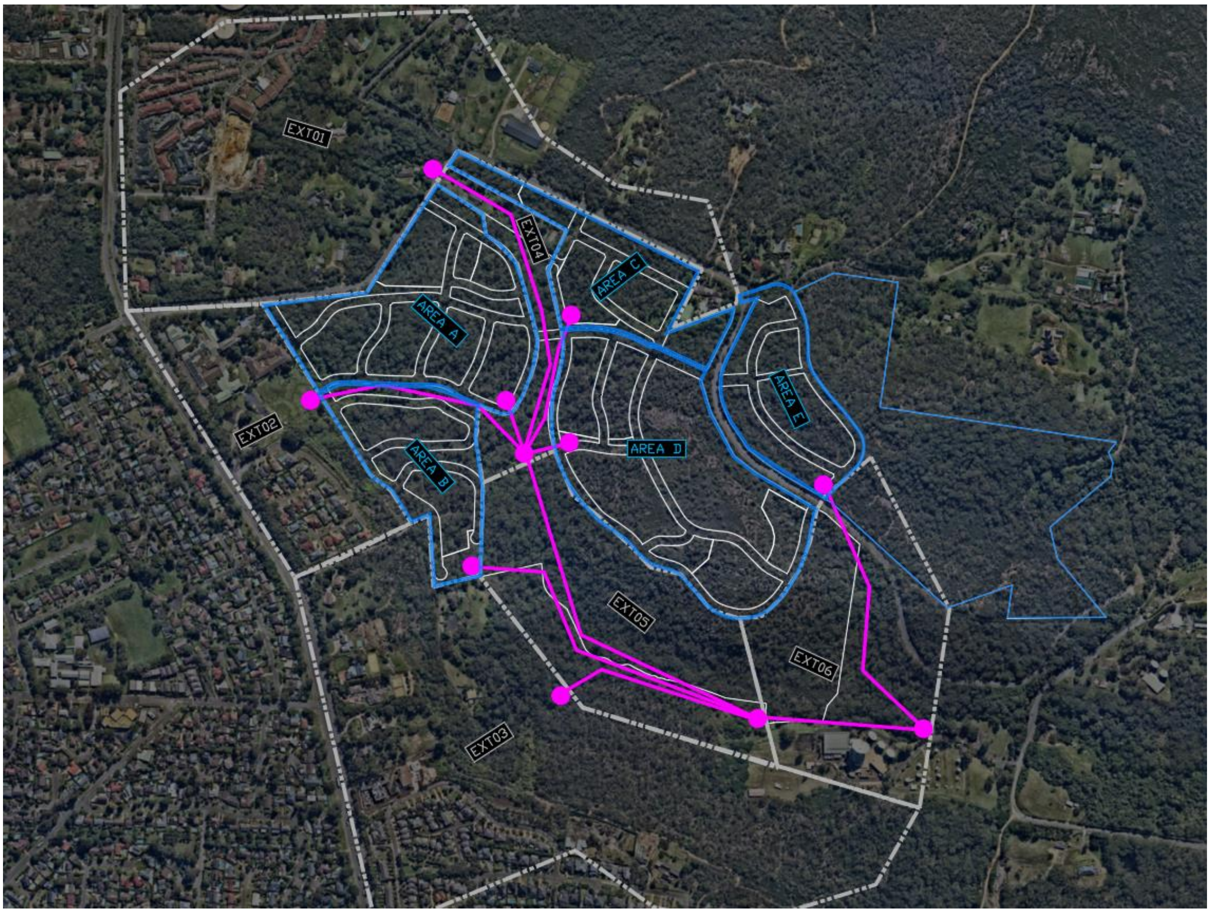


Figure 13 Catchment study area

6.3 Existing Conditions Model

The XP-RAFTS model was developed for the existing conditions to generate catchment hydrographs. The catchment was divided into six existing sub-catchments based on topographical features, representative overland flow paths with existing catchment parameters applied. (refer to **Appendix A**)

A review of existing high-level catchment XP-RAFTS models was considered in the selection of catchment parameters. Initial loss of 7mm/hr and a continuing loss of 0.5mm/hr was adopted for the pervious services. The XP-RAFTS sub-catchment layout for the existing scenario is shown below in Figure 14.

Figure 14 Existing Conditions XP_RAFTS Model

6.4 Developed Conditions Model

The XP-RAFTS model was for the proposed scenario to generate catchment hydrographs. The catchment was divided into six existing sub-catchments and five proposed sub-catchments, based on topographical features, representative overland flow paths and the input requirement. Stormwater volume retention was modelled by increasing the initial loss of the developed areas. Further information on the developed catchment parameters is located in **Appendix B.**

Figure 15 Developed Conditions XP_RAFTS Model

6.5 Results

6.5.1 Developed Sub-catchment results

The critical storm peak flows for the downstream boundaries of each sub-catchment were obtained from the modelled hydrographs for the existing and developed conditions. The peak flows are provided below in Table 14.

Table 15 Critical duration Peak flow results :

Sub Catchment	1% AEP peak Flow (cms)		1% AEP flow Percentage	50% AEP peak Flow (cms)		50% AEP flow Percentage
	Existing (crit)	Developed		Existing (crit)	Developed	
Area A	5.52 (25m#5)	5.52	0%	1.76 (25m#6)	1.56	-10%
Area B	3.20 (25m#1)	3.36	5%	1.04 (25m#5)	1.00	-4%
Area C	3.10 (25m#1)	3.27	5%	1.01 (25m#5)	0.95	-6%
Area D	7.12 (25m#1)	7.56	6%	2.24 (25m#6)	1.94	-13%

Area E	3.16 (25m#1)	3.40	8%	1.03 (25m#5)	0.98	-5%

The results show that the stormwater footprint methodology can manage the peak flows to within a reasonable level of the pre-development condition. Mild variations in the shorter critical durations were found, but critically the stormwater volumes of each hydrograph were comparable.

6.5.2 Downstream Developed Condition Catchment Results

The 15min, 25min, 1hour and 2hour storm durations were modelled for the downstream boundary for the existing and developed conditions. The peak flows and hydrographs for each duration are provided below.

Table 16 Critical duration Peak flow results- Downstream Condition

Sub Catchment	1% AEP peak Flow		1% AEP Percentage	50% AEP peak Flow		50% AEP Percentage
	Existing	Developed		Existing	Developed	
D/S Boundary	57.06 (15m#10)	59.49	4%	14.71 (15m#4)	14.48	-1%
	61.20 (25m#3)	61.07	0%	18.72 (25m#6)	17.43	-7%
	52.27 (1h#6)	52.30	0%	17.38 (1h#5)	17.58	2%
	44.49 (2h#2)	44.26	0%	16.45 (2h#10)	16.59	1%

Overall, the results indicate that that the stormwater management system proposed is effective in attenuating flow peaks and volumes to pre-development levels. Mild variations in the shorter critical durations were found, but critically the stormwater volumes of each hydrograph were comparable. Hydrographs are located in **Appendix B** for volume comparison.

7. Implementation

The implementation of the storm water management system have been designed to be fully integrated with urban outcomes for the project and they are a core objective for the site.

In this regard Storm / Craig & Rhodes have worked with Cox the Urban Planners for the rezoning application to ensure suitable locations and setbacks have been provided to riparian corridors, creeks and perimeter roads for the provision of water quality systems and networks.

This process ensures that planning outcomes are focussed on delivering sustainable & viable environmental measures that are designed to manage, enhance and improve the ecology and water quality of Snake Creek & Narrabeen Lagoon.

8. Discussion

This development aims to protect and safeguard the waterway ecology within and downstream of the site. The focus is to preserve the natural frequency and volume of flow events in waterways. It is well established that increased flows generated from impervious urban surfaces, paired with conventional drainage designs, consistently result in erosion and waterways' ecological degradation.

The “Stormwater Footprint” provides an alternative stormwater management methodology, focusing on volume reduction. Volume reduction has been acknowledged in tools such as the Stream Erosion Index and reported in modelling such as MUSIC, but it has not been the focus of our attention as we have been largely unaware of the nexus with the deterioration of our waterways. However, it is recognised that the adoption of WSUD does reduce the volume of runoff and, in turn, reduces the pollutant loadings to our urban waterways.

As presented in the report, the stormwater footprint strategy is an effective stormwater management system, which mimics flow volumes to the waterway. The report, in turn, addresses the industry conforming water quality and peak flow assessments. Critically the stormwater footprint methodology focuses on maintaining the natural frequency and volume of flow events in waterways, further supporting waterway health.

9. Concept Design Drawings

The concept design drawing set is provided in **Appendix C** and includes the following plans:

Table 17 Design Drawing Set

DRAWING NO.	DRAWING TITLE	REVISION
096-16-SK-001	PRELIMINARY STORMWATER LAYOUT PLAN	B
096-16-SK-002	TYPICAL SECTIONS SHEET 1	C
096-16-SK-002	TYPICAL SECTIONS SHEET 2	C

Appendix A
Water Quality

Climate Data

Rainfall Data

The pluvio rainfall data adopted is the data recommended by the Northern Beaches LGA, as shown in Table 18. Stormwater footprint modelling was undertaken at a 6 min time step.

Table 18 Rainfall Details

Purpose	Time Step	Rainfall Station	Modelling Period
Water quality	6 minutes	066062 Sydney Observatory	1981-1985

Monthly Evapotranspiration Data

Average Sydney potential evapotranspiration (PET) data is suitable for use in modelling water quality and hydrology. The monthly PET values for the Northern Beaches area were adopted and are shown in Table 19.

Table 19 Average Daily Evapotranspiration by Month (mm)

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
PET	180	135	128	85	58	43	43	58	88	127	152	163

Pollutant Generation

In MUSIC, stormwater quality is characterised by mean event concentrations (EMC) for stormflow and baseflow conditions. In this strategy, the default EMC from MUSIC was adopted.

Modelling Parameters Existing Scenario

Catchment

The catchment was modelled based on the current land use. As the portion of the catchment to be developed is currently bushland, the bushland node was used for the existing scenario. Land use impervious percentages were assigned based on the current condition of the catchment. The characteristics are summarised in Table 20.

Table 20 Catchment Conditions Existing Scenario

Land-use type	Area (ha)	Impervious Percentage
Bushland	41.5	0%

Rainfall-Runoff Parameters

The adopted rainfall-runoff parameters for the existing scenario are provided in Table 21.

Table 21 Adopted MUSIC Parameters- Existing Scenario

Parameter	Bushland
Impervious Area Properties	
Rainfall Threshold (mm/day)	1
Pervious Area Properties	
Soil Storage Capacity (mm)	108
Soil Initial Storage (% of Capacity)	30
Field Capacity (mm)	73
Infiltration Capacity coefficient-a	250
Infiltration Capacity coefficient-b	1.3
Groundwater Properties	
Initial Depth	10
Daily Recharge Rate (%)	60%
Daily Baseflow Rate (%)	45%
Daily Deep Seepage Rate (%)	0%

Modelling Parameters Stormwater Footprint

Catchment

The catchment was modelled based on the proposed land use. Land use impervious percentages were assigned based on the proposed imperviousness of the catchment. The characteristics are summarised in Table 22.

Table 22 Catchment Conditions Developed Scenario

Land use type	Area (m^2)	Impervious Percentage
LOT		
Roof	300	100%
Mixed	60	100%
Residential	240	0%
Rural Residential	600	0%
STREET		
Sealed Road	1000	100%
Rural Residential	1000	0%
PRECINCT		
Sealed Road	8.14	100%

Rainfall-Runoff Parameters

The adopted rainfall-runoff parameters for the stormwater footprint scenario are provided in Table 23.

Table 23 Adopted MUSIC Parameters- Stormwater Footprint

Parameter	All Catchments areas
Impervious Area Properties	
Rainfall Threshold (mm/day)	1
Pervious Area Properties	
Soil Storage Capacity (mm)	108
Soil Initial Storage (% of Capacity)	30
Field Capacity (mm)	73
Infiltration Capacity coefficient-a	250
Infiltration Capacity coefficient-b	1.3
Groundwater Properties	

Initial Depth	10
Daily Recharge Rate (%)	60%
Daily Baseflow Rate (%)	45%
Daily Deep Seepage Rate (%)	0%

Proposed Stormwater Footprint Treatment

The water quality treatment proposed for the site consist of;

- Rainwater harvesting and reuse in rainwater tanks
- Stormwater retention in Tanks
- Bioretention basins
- Infiltration systems

Lot Rainwater Harvesting

Rainwater tanks were modelled for the lots based on the following assumptions.

- It is assumed that 100% of the roof area is connected to the rainwater tanks.
- Rainwater tank size of 5kL was adopted, which can be scaled depending on the lot roof size.
- The average reuse adopted for a single dwelling was 500L per day. This was derived from Sydney Water data and assumes water is used for Toilets, washing machine and outdoor uses.

These assumptions have been based on NSW DRAFT MUSIC Modelling guidelines.

Lot Bioretention Basins

The design parameters for the lot bioretention systems is shown in Table 24. Lot basins receive runoff from the leaky tank and surface impervious areas.

Table 24 Lot Bioretention Parameters

Parameters	Value
Area (m^2)	10
Saturated Conductivity (mm/hr)	300
Filter Depth (m)	0.5
Extended Detention (m)	0.1
TN Content (mg/kg)	600
Orthophosphate Content (mg/kg)	30
Exfiltration Rate	50
Base Lined	No

Street Bioretention Basins

The design parameters for the street bioretention systems is shown in Table 25. Street basins receive runoff from the road impervious areas.

Table 25 Street Bioretention Parameters

Parameters	Value
Area (m^2)	60
Saturated Conductivity (mm/hr)	300
Filter Depth (m)	0.5
Extended Detention (m)	0.1
TN Content (mg/kg)	600
Orthophosphate Content (mg/kg)	30
Exfiltration Rate	0
Base Lined	YES

Street Infiltration Systems

The design parameters for the street infiltration systems is shown in Table 26. Street infiltration systems receive runoff from the road impervious areas.

Table 26 Street Infiltration Parameters

Parameters	Value
Surface Area (m^2)	9
Filter Area (m^2)	9
Extended Detention (m)	0.2
Unlined Filter Media Perimeter (m)	20
Filter Depth (m)	0.8
Exfiltration Rate	50

Precinct Bioretention Basins

The design parameters for the precinct bioretention systems is shown in Table 27. Precinct basins receive runoff from various catchments and are a catch-all to manage flow volumes.

Table 27 Precinct Bioretention Parameters

Parameters	Value
Area (m^2)	Varies
Saturated Conductivity (mm/hr)	300
Filter Depth (m)	0.5
Extended Detention (m)	0.3
TN Content (mg/kg)	600
Orthophosphate Content (mg/kg)	30
Exfiltration Rate	50
Base Lined	No

Modelling Parameters Developed Scenario

Catchment

The catchment was modelled based on the proposed land use. As the portion of the catchment to be developed is currently bushland, the bushland node was used for the existing scenario. Land use impervious percentages were assigned based on the current condition of the catchment. The characteristics are summarised in Table 28.

Table 28 Catchment Conditions Developed Scenario

Land use type	Area (ha)	Impervious Percentage
Bushland	8.037	0%
LOT Roof	10.175	100%
LOT IMPERIOUS Rural Residential	2.035	100%
LOT PERVIOUS Rural Residential	8.14	0%
CROSS STREET IMPERVIOUS Sealed Road	4.6	100%
PERVIOUS ROAD RESERVE Rural Residential	3.9	0%
RIPARIAN STREET IMPERIOUS	4.6	100%

Rainfall-Runoff Parameters

The adopted rainfall-runoff parameters for the developed scenario are provided in Table 29.

Table 29 Adopted MUSIC Parameters- Existing Scenario

Parameter	Bushland
Impervious Area Properties	
Rainfall Threshold (mm/day)	1
Pervious Area Properties	
Soil Storage Capacity (mm)	108

Soil Initial Storage (% of Capacity)	30
Field Capacity (mm)	73
Infiltration Capacity coefficient-a	250
Infiltration Capacity coefficient-b	1.3
Groundwater Properties	
Initial Depth	10
Daily Recharge Rate (%)	60%
Daily Baseflow Rate (%)	45%
Daily Deep Seepage Rate (%)	0%

Developed Scenario Treatment

Proposed stormwater footprint treatment systems were scaled to a precinct scale. Precinct catchment areas are presented in the concept stormwater layout plan in **Appendix C.**

Developed Scenario Results

Results from the MUSIC analysis are presented in Table 30. The adopted stormwater footprint measures have helped achieve the proposed water quality targets.

Table 30 MUSIC Model Water Quality Results

Pollutants	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	Gross Pollutants (kg/yr)
Source Load	36200	77.9	583	5670
Output	4690	13.3	148	0.2
Reduction	86%	82%	75%	99%
Target	85%	65%	45%	90%

Hydrology

A number of parameters are required for a RAFTS model. The critical parameters including initial and continuing loss rate and manning's roughness. The parameters adopted are listed below.

Table 31 Adopted Parameters XP-RAFTS model

Land Type	%Impervious	Pervious IL (mm)	Pervious CL (mm/hr)	Pervious 'n'	Impervious IL (mm)	Impervious CL (mm/hr)	Impervious 'n'
Existing	10	7	0.5	0.03	1	0	0.013
Lot – Roof	100	-	-	-	**17.7**	0	0.013
Lot – Driveway	100	-	-	-	1	0	0.013
Lot – Pervious	0	7	0.5	0.03	-	-	-
Public road	70	7	0.5	0.03	**7**	0	0.013
Open Space	10	7	0.5	0.03	1	0	0.013
External Catchment	Varies	7	0.5	0.03	1	0	0.013

These parameters are consistent with the stormwater footprint methodology, ARR recommendations and studies undertaken in the area. IL loss was varied to mimic stormwater retention within the catchment.

Modelling approach

Design storms

Design rainfalls have been obtained from 2016 BOM IFD at the site location. Temporal patterns have been obtained from ARR Datahub. The design rainfall and temporal hydrologic data have been used in the RAFTS modelling for both the existing and developed scenarios.

Catchment delineation

Internal catchments have been delineated based on the site Draft Structure Plan, 29th April 2021 by Cox Architecture. External catchments have been delineated based on site topography using lidar data.

Vector Average slope

The catchment average slope has been calculated using lidar levels and representative flowpath for each catchment.

Hydraulic routing

Existing and developed catchments has been routed based on existing site topography. Catchment lag times have been calculated based on the uniform flow velocity of 2m/s and measured flowpath lengths between nodes.

Subcatchment properties

Catchment % impervious, IL/CL values and Manning's 'n' values are summarised in Table in Section 2.1

EXISTING MODEL CATCHMENT PROPERTIES

Node ID	Total Area [ha]	%Imp	Vectored Slope [%]
A_lot dvwy	0.5201	10%	15
A_lot perv	2.0804	10%	15
A_lot roof	2.6005	10%	15
A_OpSpace	0.9047	10%	15
A_road	4.4373	10%	15
B_lot dvwy	0.228	10%	15
B_lot perv	0.912	10%	15
B_lot roof	1.14	10%	15
B_OpSpace	1.612	10%	15
B_road	1.918	10%	15
C_lot dvwy	0.3684	10%	15
C_lot perv	1.4736	10%	15
C_lot roof	1.842	10%	15
C_OpSpace	0.6876	10%	15
C_road	1.2384	10%	15
D_lot dvwy	0.543	10%	15
D_lot perv	2.172	10%	15
D_lot roof	2.715	10%	15
D_OpSpace	4.7853	10%	15
D_road	3.5388	10%	15
E_lot dvwy	0.376	10%	15
E_lot perv	1.504	10%	15
E_lot roof	1.88	10%	15
E_OpSpace	0.048	10%	15
E_road	2.002	10%	15
Ext01	32.338	10%	12.5
Ext02	10.78	10%	12
Ext03	37.801	10%	21
Ext04	4.14	10%	7

Ext05	14.142	10%	3
Ext06	14.098	10%	15

DEVELOPED MODEL CATCHMENT PROPERTIES

Node ID	Total area [ha]	%Imp	Vectored Slope [%]
A_lot dvwy	0.5201	100	15
A_lot perv	2.0804	0	15
A_lot roof	2.6005	100	15
A_OpSpace	0.9047	10	15
A_road	4.4373	70	15
B_lot dvwy	0.228	100	15
B_lot perv	0.912	0	15
B_lot roof	1.14	100	15
B_OpSpace	1.612	10	15
B_road	1.918	70	15
C_lot dvwy	0.3684	100	15
C_lot perv	1.4736	0	15
C_lot roof	1.842	100	15
C_OpSpace	0.6876	10	15
C_road	1.2384	70	15
D_lot dvwy	0.543	100	15
D_lot perv	2.172	0	15
D_lot roof	2.715	100	15
D_OpSpace	4.7853	10	15
D_road	3.5388	70	15
E_lot dvwy	0.376	100	15
E_lot perv	1.504	0	15
E_lot roof	1.88	100	15
E_OpSpace	0.048	10	15
E_road	2.002	70	15
Ext01	32.338	26	12.5
Ext02	10.78	57	12
Ext03	37.801	35	21
Ext04	4.14	10	7

Ext05	14.142	10	3
Ext06	14.098	15	15

D/S Hydrograph assessment

The study undertook a hydraulic assessment for the 15min, 25 min, 1 hour and 2 hour event for the 50% and 1% AEP event for the developed conditions. The estimated peak flows and hydrographs are summarised below. Overall, the results indicate that the proposed strategy is adequate in attenuating flow peaks and volumes to pre-development levels.

Table 32 Critical duration Peak flow results- Downstream Condition

Sub Catchment	1% AEP peak Flow		1% AEP Percentage	50% AEP peak Flow		50% AEP Percentage
	Existing	Developed		Existing	Developed	
D/S Boundary	57.06 (15m#10)	59.49	4%	14.71 (15m#4)	14.48	-1%
	61.20 (25m#3)	61.07	0%	18.72 (25m#6)	17.43	-7%
	52.27 (1h#6)	52.30	0%	17.38 (1h#5)	17.58	2%
	44.49 (2h#2)	44.26	0%	16.45 (2h#10)	16.59	1%

Chart 1 Hydrograph Comparison at D/S Boundary Line 50% 2hr

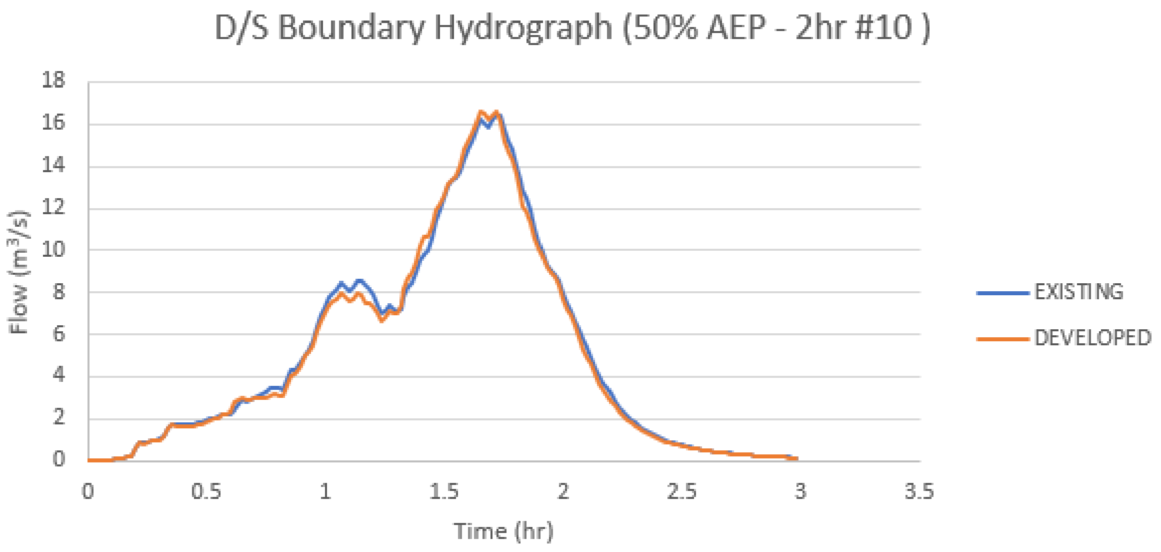


Chart 2 Hydrograph Comparison at D/S Boundary Line 1% 2hr

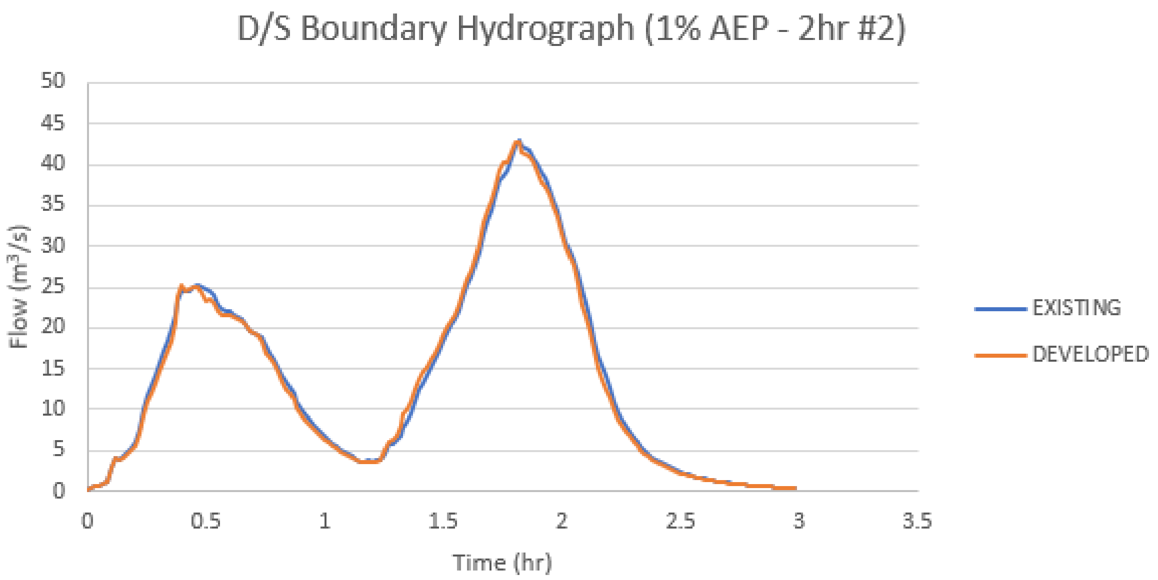


Chart 3 Hydrograph Comparison at D/S Boundary Line 50% 1hr

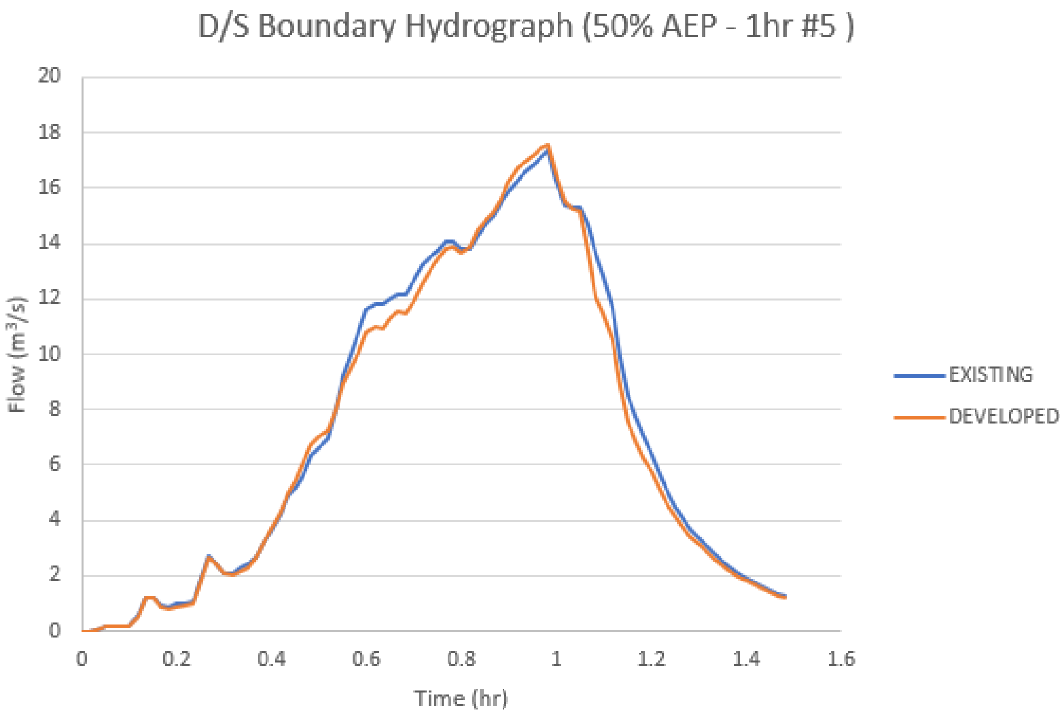


Chart 4 Hydrograph Comparison at D/S Boundary Line1% 1hr

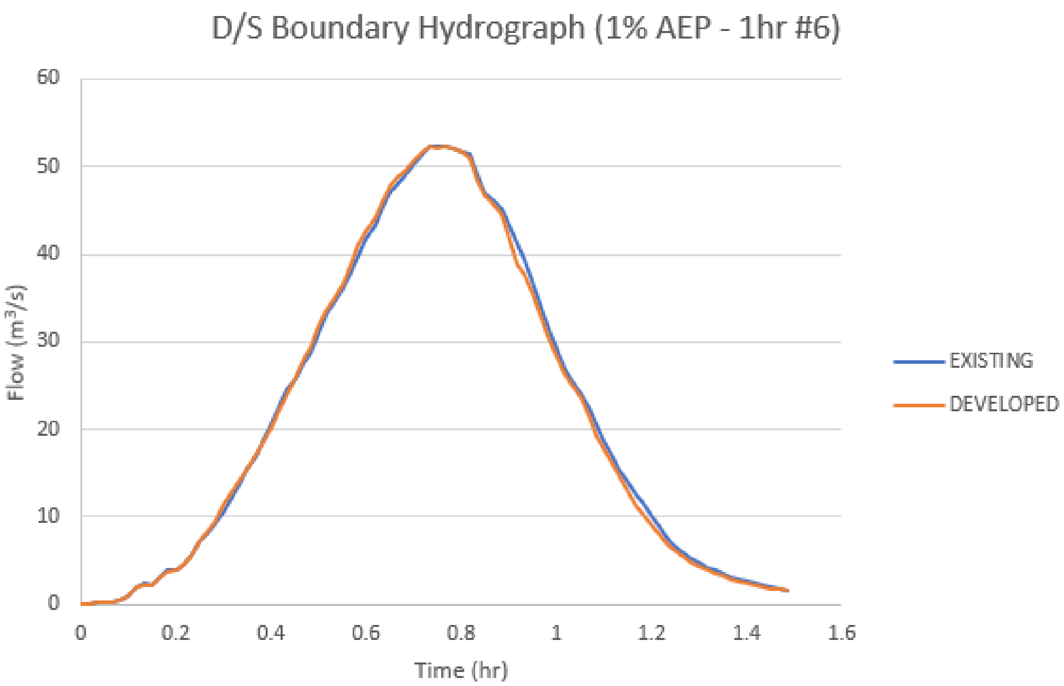


Chart 5 Hydrograph Comparison at D/S Boundary Line 50% 25min

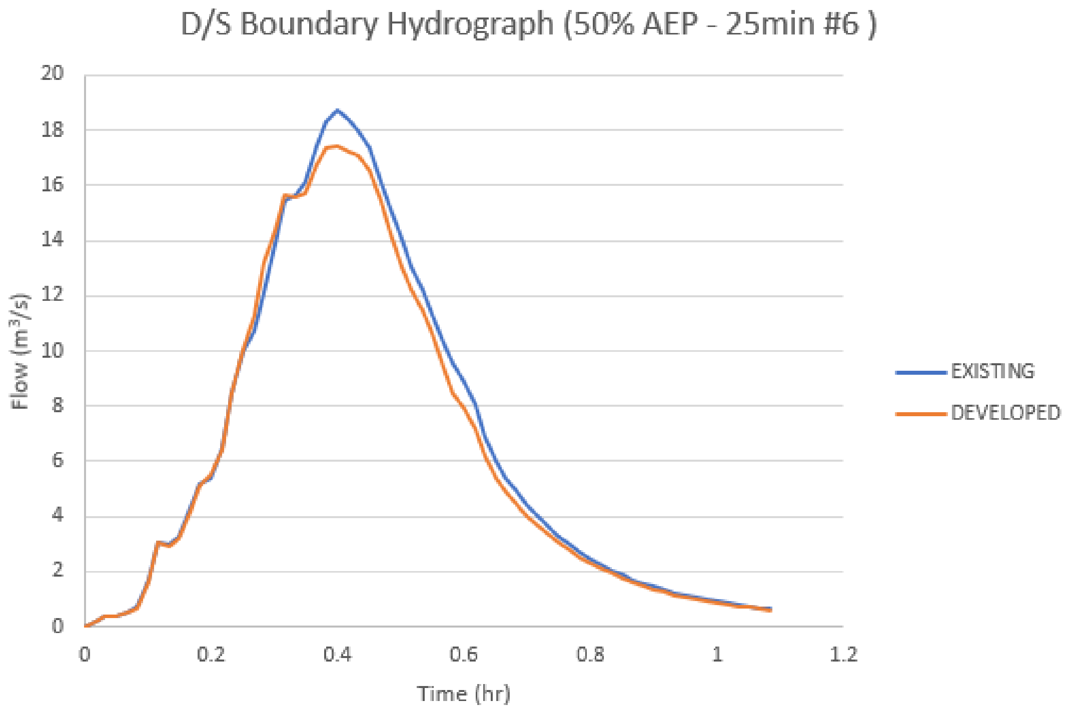


Chart 6 Hydrograph Comparison at D/S Boundary Line1% 25min

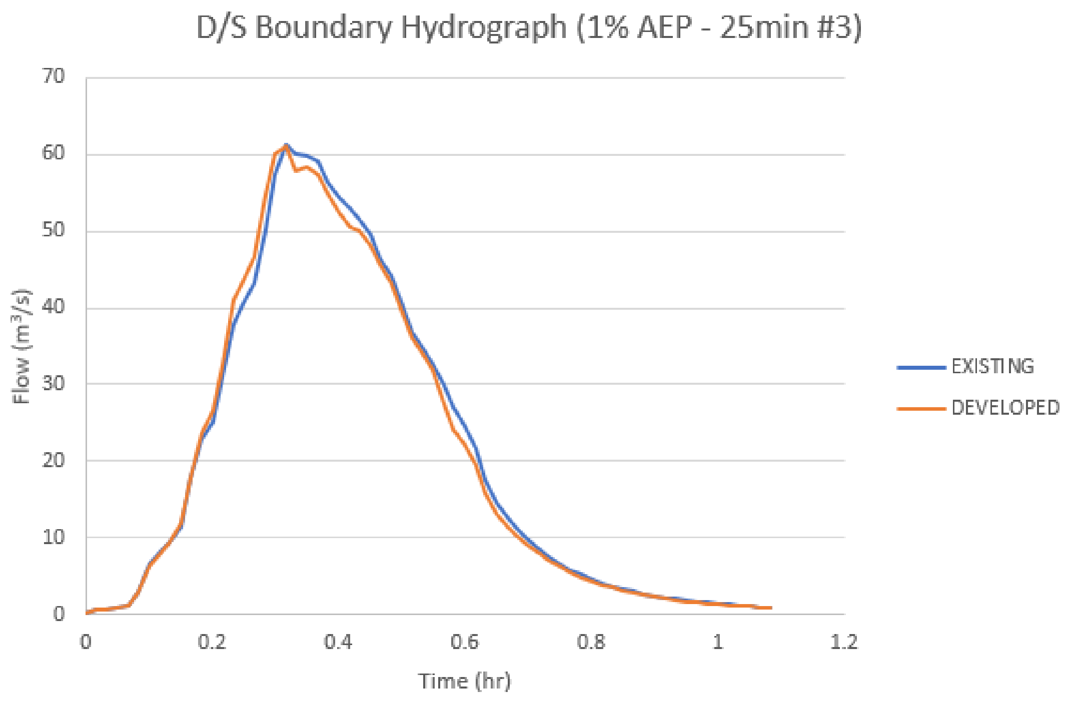


Chart 7 Hydrograph Comparison at D/S Boundary Line 50% 15min

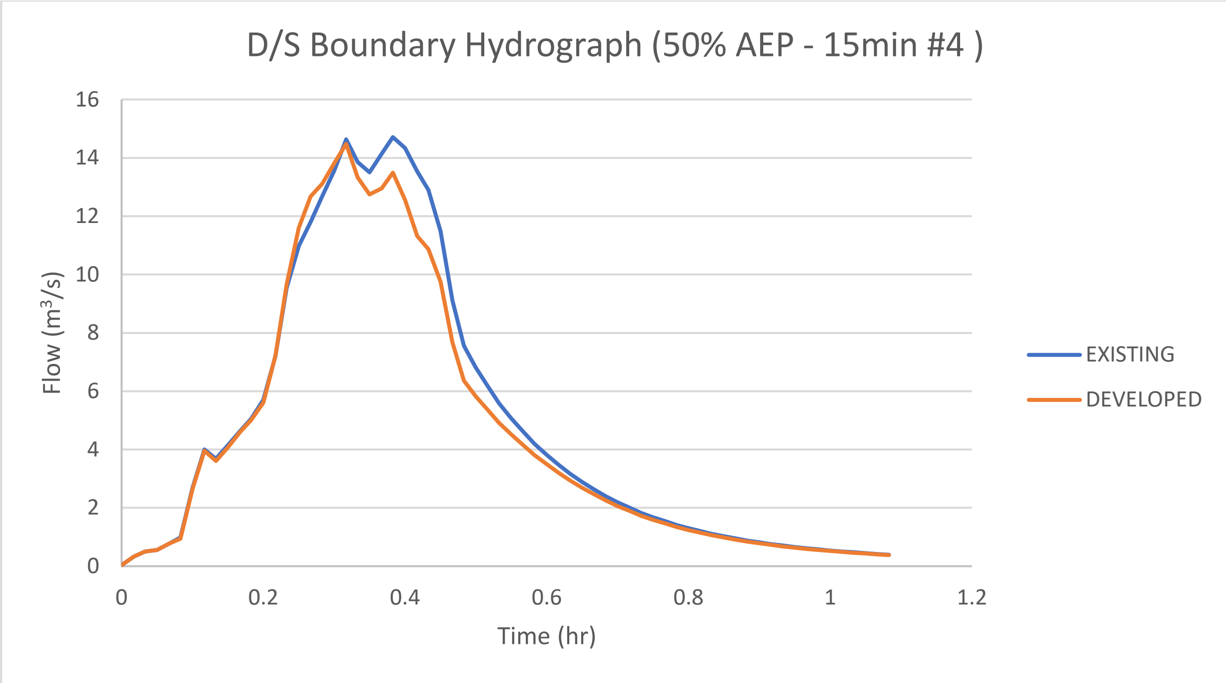
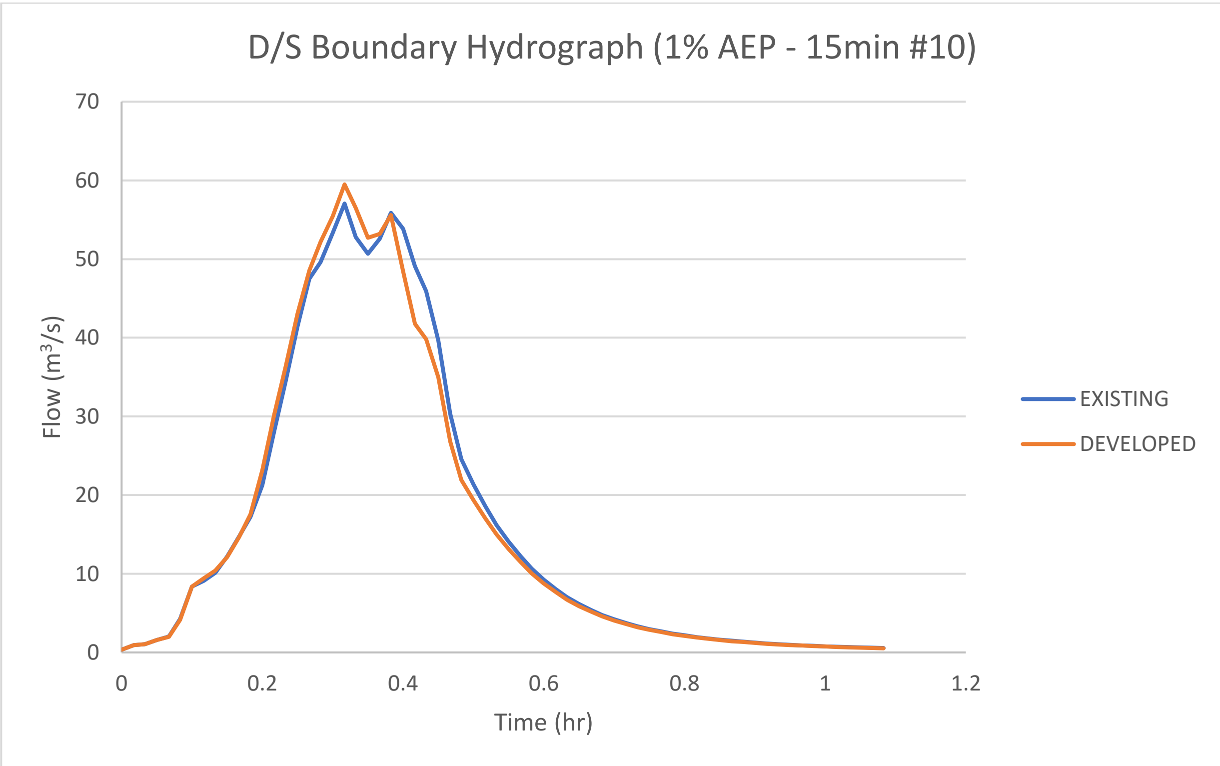


Chart 8 Hydrograph Comparison at D/S Boundary Line 1% 15min



Appendix C
Concept Design Drawings

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