Final Draft Report

Ingleside Precinct Water Cycle Management and Flooding Assessment

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Executive Summary

Introduction

NSW Department of Planning & Environment (DP&E) is proposing to re-zone the Ingleside Release Area (Ingleside Precinct) for residential purposes. The area identified for rezoning is approximately 700 hectares and currently has a non-urban zoning. Cardno has been commissioned by DP&E to prepare a Water Cycle Management and Flooding Assessment Strategy for this Precinct. The Strategy will form part of the Precinct Planning Process to confirm development potential and to establish planning controls to enable development consistent with that potential.

Objective

The objective of this study is to prepare a strategic level Water Cycle Management Strategy for incorporation into the Ingleside Draft Plan through documentation of the following:

- Identification of water management targets (water quality, water quantity and social/ecological requirements) for the future urban development in the precinct.
- Ensuring no adverse impact to flows and flood behaviour in downstream areas.
- Preparation of a water cycle assessment/water balance modelling.
- Consideration of ecological impacts including sustainable environmental flows to Warriewood Wetlands.
- Preparation of a water quality monitoring plan as a determinant of pre and post development impacts.
- Assessment of site constraints and opportunities including:
  - Potentially feasible water management strategies;
  - Management of environmental flows in creeks;
  - Stormwater re-use options;
  - Source control measures; and
  - WSUD options.
- Consolidation of stormwater quality and quantity controls in order to control construction costs and reduce allocation of valuable land for water management purposes.
- Development of feasible options through consideration of:
  - Compliance with management objectives;
  - Reliability;
  - Operation and Maintenance;
  - Land Take; and
  - Stakeholder Acceptance.

The water management targets set for the Ingleside Precinct in consultation with Council and DP&E are provided below. These targets have been established with the aim to reduce impacts from the Ingleside Precinct development on the surrounding environment and neighbouring properties.

ELEMENT	TARGET	REFERENCE
Potable Water	Household use – 192 L/day/dwelling (2.5 Pax)	BASIX (40% reduction target of 320L/dwelling)
Non-potable Water	Irrigation – 125 L/day/dwelling Supply with non-potable water supply from rainwater/wastewater re-use.	EDAW 2008

ELEMENT	TARGET	REFERENCE
Water Quantity (Design Storm Hydrograph)	For the 2 and 100 year ARI events and the 2hr durations: a) Peak flow is +/-5% of predevelopment condition. b) Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration. c) The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs.	Warriewood Water Management Specification
Water Quality	90% capture of gross pollutants 85% reduction of TSS 65% reduction of TP 45% reduction of TN	Sydney Catchment Management Authority (now Local Land Services)
	Limit impacts on water quality during construction using soil and water management plans and water quality monitoring.	Pittwater DCP
Environmental Flows	Flow volume of the post development conditions is to be within +/-5% of pre-development based on a daily water balance (MUSIC) with 31yr simulation period.	Warriewood Water Management Specification
Groundwater	Maintain baseflows so that there are no more than +/-10% of pre-development daily volumes represented in a daily water balance model (MUSIC) with 31yr simulation period.	Groundwater Dependent Ecosystems (Ecological 2014)

Methodology

Flooding Assessment

A computer-based RAFTS model has been used to determine the existing, pre-development stormwater discharges for the site and for the proposed development. In this way, it is possible to assess the potential impacts of the proposed development on the flows. As expected, the modelling showed that the proposed development generally increased the intensity of stormwater flows within and from the site. This is due to the changes in land use, with the transition from green space and bushland that slowly absorb stormwater to a higher proportion of hard surfaces.

Flood detention basins have been proposed for incorporation into the Draft Plan to attenuate the peak stormwater flows to existing levels in the Precinct. Both on-line (i.e. on the existing watercourse) and off-line (located away from watercourses) basins are proposed to provide peak stormwater flow control and ensure there are no adverse impacts on stormwater flows and flood behaviour within and downstream of the developed Precinct.

Various possible locations were identified and evaluated for the basins. On-line basins are more efficient in terms of land-take and consolidate maintenance within the natural drainage corridor. The off-line basins were located based on site topography, location of conservation significant vegetation and modelled design flood extents.

A SOBEK model has been established to assess the impact of urban development options to existing flood behaviour. Flood mapping for existing conditions and proposed development have been undertaken to demonstrate that the water management targets for flooding are achieved.

Water Cycle Management

The computer-based Model for Urban Stormwater Improvement Conceptualization (MUSIC) was used for the analysis of the stormwater management requirements for the Precinct. A stormwater ‘treatment train’ approach incorporating different types of Water Sensitive Urban Design systems was evaluated. Based on the outcomes of this analysis, the following treatment train approach has been proposed to achieve the water quality and water quantity targets:

- Rainwater harvesting and re-use of residential, mixed use, community centre and school roof runoff by utilising rainwater tanks;
- Gross Pollutant Traps (GPT) to pre-treat runoff prior to discharge into basins;
- Bioretention basins which will receive flows from the GPTs;
- Detention basins as water retention ponds; and
- Stormwater harvesting for re-use in irrigation of sports field.

Conclusion

This Water Cycle Management Strategy has been prepared to inform the Precinct Planning process and support the rezoning process for the Ingleside Precinct. It presents guiding principles for WCM across the precinct and preliminary management measures. This includes conceptual sizes and locations for elements of the stormwater management network, including detention and water quality treatment infrastructure, and maintenance requirements in determining the best water cycle management option. Indicative layouts of detention basins and bioretention systems have been provided. This will be subject to more detailed assessment during the design phase based on detailed site survey, detailed geotechnical and soil investigations, and also when the final development plan for the sub-catchments is finalised.

In May 2016 Pittwater Council was merged into a new body, the Northern Beaches Council. As this report was prepared prior to these changes, it makes reference to the former council. The plans and strategies of the former council continue to apply to the former local government area until the new council prepares its own plans and strategies.

List of Abbreviations

AEP	Annual Exceedance Probability
ALS	Aerial Laser Survey
ANZECC	Australia and New Zealand Environment and Conservation Council
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runff
BOM	Bureau of Meteorology
DTM	Digital Terrain Model
LGA	Local Government
MHL	Manly Hydraulic Laboratory
OSD	On-site Detention
PMF	Probably Maximum Flood
WSUD	Water Sensitive Urban Design

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1 Introduction

Cardno has been commissioned by the NSW Department of Planning & Environment (DP&E) to prepare a Water Cycle Management and Flooding Assessment (WCM) for the Ingleside Precinct. The WCM will form part of the Precinct Planning Process to confirm development potential and to establish planning controls to enable development consistent with that potential.

This Report summarises the following:

> **Section 2 – Background:** Provides background on the Study Area, the previous water related studies conducted in the area, and the various development controls and policies that are relevant to the study area;

> **Section 3 – Objectives:** Based on the development controls and policies relevant to the study area, sets specific flooding and water quality and quantity design objectives for the Precinct WCM Strategy that satisfy all relevant controls and take into account the water cycle management issues relevant to the study area;

> **Section 4 – Flooding Assessment:** Summarises the modelling methodology and demonstrates how the flooding objectives for the Precinct have been met;

> **Section 5 – Flood Emergency Response:** Assesses the flood emergency response implications of development of the Ingleside Precinct;

> **Section 6 – Water Cycle Management Strategy:** Summarises the modelling methodology and identifies the management approaches required to meet the water quality and quantity objectives for the Precinct;

> **Section 7 – Riparian Corridor Assessment:** Based on the assessment of the riparian lands within the Ingleside Precinct that has been undertaken by Eco Logical Australia, provides concept design for basins (detention and bioretention) to be located within the riparian corridors; and

> **Section 8 – Water Quality Monitoring Program:** Establishes the general framework for water quality monitoring within and downstream of the Ingleside Precinct for the purpose of managing any impacts associated with the proposed land development.

2 Background

2.1 Study Area

2.1.1 Location

Ingleside is a suburb of Sydney's northern beaches area, approximately 30km north of the CBD, and is located along the ridge line 2km to the west of North Narrabeen and Warriewood Beaches. The precinct area is approximately 700 hectares as shown in **Figure 2-1**. The Precinct is delineated by major roads, conservation areas and crown lands. Mona Vale Road bisects the Precinct and also forms part of its south-western boundary. Ku-ring-gai Chase National Park is located to the north of the precinct, Garigal National Park to the south, Katandra Bushland Sanctuary and Warriewood Wetlands to the east.

2.1.2 Climate

The Ingleside climate is related to the recorded information for Sydney where average temperatures range from 13.8 to 21.7 ^{0}C and an average annual rainfall of 1,213mm is recorded (www.bom.gov.au). Summer months generally experience the highest quantity of rainfall and evaporation. In 2013 temperatures were recorded approximately 2^{0}C higher than the average maximum and a considerably higher quantity of rainfall occurring in autumn and winter months. Conversely the years of 2010, 2011 and 2012 all featured lower than average temperatures, particularly in the first half of the years with higher than normal amounts of rainfall. This is generally attributed to a La Nina pattern. Current predictions indicate that an El Nino pattern would be experienced in 2014, generally involving drier weather and warmer temperatures for the latter part of 2014.

2.1.3 Topography

Ingleside includes a range of topography due to its location on the Warriewood Escarpment. Above the escarpment the land gently undulates from the ridge line of Mona Vale Road into a number of waterways. These elevated areas then begin to increase in slope before reaching the escarpment. In general the escarpment delineates the boundary of the precinct; conservation areas and urban development exist thereafter. The urban settlements of Warriewood, Elanora and North Narrabeen are located to the east of the precinct over a steep transition of the escarpment to the foothills before continuing at a lower grade to Warriewood Wetlands and Narrabeen Lagoon. To the north, the urban areas of Church Point and McCarrs Creek are located along the transition from the escarpment to the foreshore. To the west the land slopes down to Wirreandra Creek, then winds its way to the north meeting McCarrs Creeks and ultimately Pittwater. To the south, the escarpment is located beyond the precinct boundary within Garrigal National Park and slopes away to Elanora Heights and eventually to Narrabeen Lagoon.

2.1.4 Land Use

Historically Ingleside has been used as a rural residential area with large homes accommodating large lots. It is not uncommon to encounter grazing and equine uses on a small scale in Ingleside. In addition, light industrial uses are evident along with market gardens and nurseries.

The land use immediately surrounding the precinct boundary is mostly National Parks and Conservation Lands, with the exception of urban areas of Bayview and Monash Country Club and Elanora country club golf courses.

2.1.5 Waterways

The Ingleside Precinct waterways are shown in **Figure 2-2**. The northern and western portions of the Precinct flow into McCarrs Creek, which discharges into Pittwater. McCarrs Creek is a natural waterway and has a catchment dominated by National Park and recreational grounds. Tributaries to McCarrs Creek located within the Precinct include Crystal Creek, which flows in a westerly direction by the northern boundary before joining Wirreandra Creek, and Cicada Glen Creek flowing through the centre of the Precinct in a northerly direction until it discharges into McCarrs Creek. Wirreandra Creek located on the western part of the Precinct flows north through Ku-ring-gai Chase National Park and further downstream into McCarrs Creek.

A number of tributaries of Mullet and Narrabeen Creeks are located on the eastern side of the Precinct. The eastern and southern portions of the Precinct flow into these waterways, which then flow into the environmentally sensitive and regionally significant Warriewood Wetlands, and ultimately into Narrabeen Lagoon.

2.1.6 Soils

As per the Preliminary Land Capability, Salinity and Contamination Assessment report (SMEC, 2014), the Precinct is mapped by a variety of soil landscapes including Gymea, Oxford Falls, Hawkesbury, Somersby and Lambert. The site is entirely underlain by the Hawkesbury Sandstone formation of the Wianamatta Group from Triassic Period. The Hawkesbury Sandstone formation typically comprises medium to coarse-grained quartz sandstone with very minor shale and laminate lenses.

The Precinct is considered to have a higher susceptibility to erosion due to the characteristics of a colluvial and erosional soil landscape combined with high rainfall intensity resulting in high soil loss conditions.

As per advice from SMEC, the hydraulic conductivity of the soil could vary from 60mm/hr to 120mm/hr due to the variation in soil textures. Soil depths are generally less than 0.5m before encountering bedrock. Exposed bedrock is present on site and gullies could have 2.0m soil over bedrock.

2.1.7 Groundwater

According to the SMEC 2014 report, local groundwater occurs at depths ranging from 10 to 20 metres below ground level (mbgl) and regional groundwater are likely to be deeper at 100 to 200 mbgl (SMEC, 2013). As per the report, groundwater is of reasonable quality with non-saline characteristics.

Figure 2-1: Ingleside Precinct Study Area

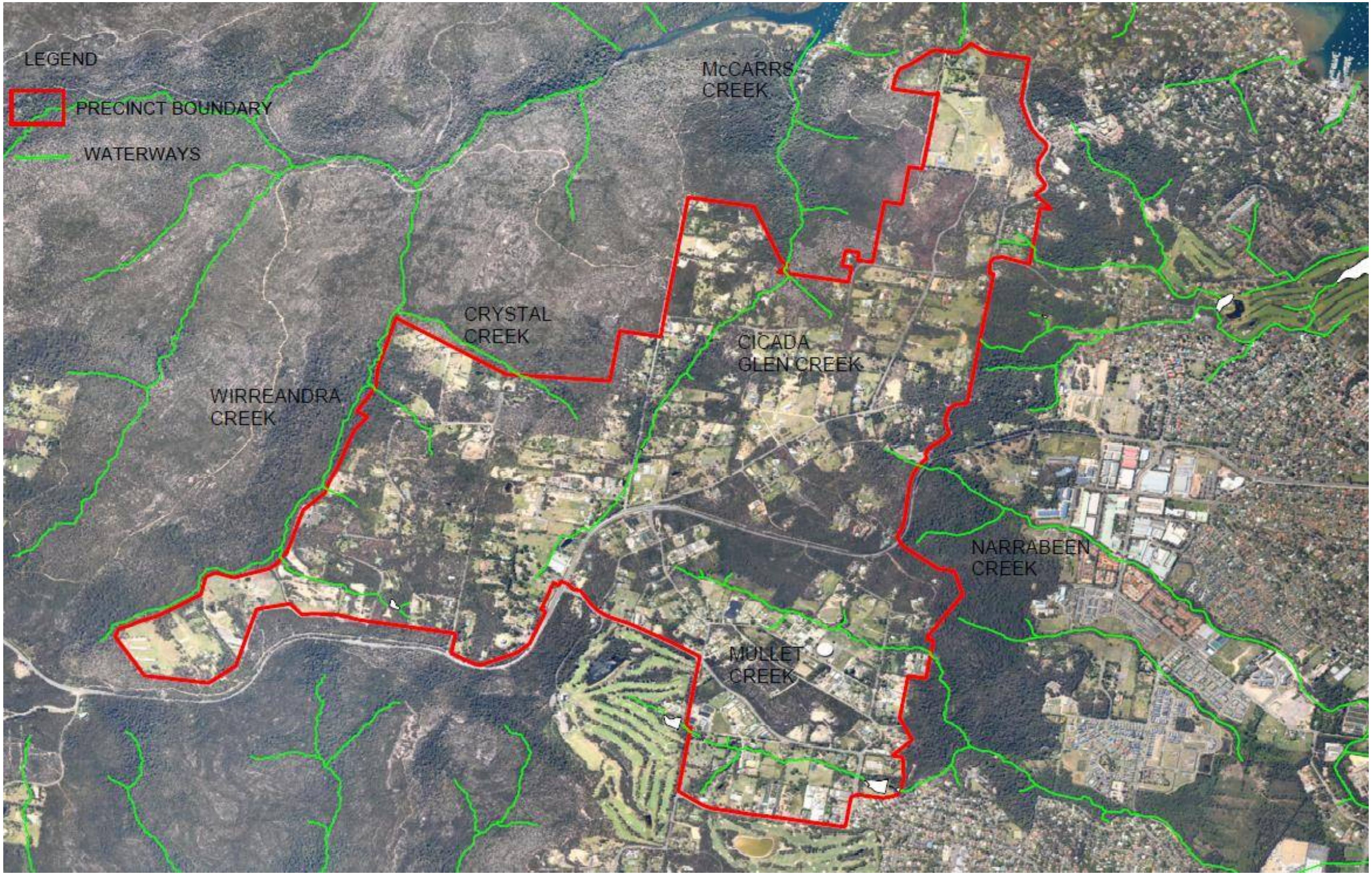

Figure 2-2: Ingleside Precinct Waterways

2.2 Previous studies

2.2.1 Effects of urbanisation on water quality in creeks draining Hawkesbury Sandstone (Laxton, 2001)

Water quality data and macroinvertebrate counts were collected and compared for the Cowan and McCarrs Creek catchments containing the Hawkesbury soil landscape. The locations of sampling focused on a sub-catchment and receiving environment scale to formulate an analysis of urban development impact. The land use in the sub-catchments ranges between natural bushland, partially urbanised catchments and rural residential. A number of the McCarrs Creek sub-catchments included in the study are part of the Ingleside precinct. It was found that urban development, even for a small portion of a sub-catchment, can modify the water quality in the receiving environment. Within McCarrs Creek it was shown that pH, TSS and TN parameters were modified when comparing the natural bushland sub-catchments with those containing urban/rural uses. Typically pH increased from approximately 5 in natural areas up to around 7 in the urban areas. This indicates that the naturally acidic water quality, originating from dispersive sandstone runoff, becomes neutralised once land is cleared and materials such as concrete are introduced. Furthermore TSS increases from around 1mg/l in natural areas to around 6mg/l in the urban areas.

The findings indicate that the modification in land use directly affects water quality in receiving waters of McCarrs Creek. The impacts on aquatic ecology also demonstrate how the urban development modifies its receiving environment. In natural catchments species such as Mayfly Larvae, Stonefly Larvae, Shrimps and Crayfish were recorded. In urban catchments the above species were less prominent and the Gastropod species were predominant. This can be indicative of water quality that is more turbid and less acidic where the conditions suffocate the species of natural catchments and allow proliferation of Gastropods which thrive on turbid conditions and are reported to feed on algae. These findings were found in McCarrs Creek, where little urban development exists, and supported with water quality analysis from Cowan Creek where more dense urban development can be found.

2.2.2 Warriewood Valley Water Management Specification (Lawson & Treloar, 2001)

2.2.2.1 Summary

Warriewood Valley had urban development planned for rural land areas surrounding the sensitive Warriewood Wetlands. Pittwater Council moved to develop an Integrated Water Cycle Management (IWCM) strategy in 1995 that set out management objectives and treatment targets to mitigate the impacts of the planned development. The Warriewood Valley Water Management Specification (WMS) was prepared to supplement the IWCM strategy and provide development controls to protect existing water quality and aimed to prevent degradation to existing ecosystem conditions. The sensitivity of the receiving environment led to the planning controls requiring nil impact on water quality and quantity for urban development. A staged approach to the consideration of the water cycle assessments was presented relative to common steps in the planning process (rezoning, development application, construction certificate, construction and hand-over).

The steps of the planning process prior to construction certificate rely on preparation of a Water Management Report at each stage of the process. Thereafter, an Environmental Management Plan & Erosion and Sediment Control Plan would outline requirements for construction followed by quarterly water quality reports during the maintenance liability period.

The various aspects of the water cycle that require assessment and reporting on include:

1. Water cycle assessment – overview of the total water cycle at the site and a daily water balance model that addresses overland flow, baseflow and changes in sub-surface water levels on an annual basis. A comparison of the existing and developed case scenarios is to be made demonstrating how nominated management measures provide no adverse impact to the existing scenario.
2. Water quality assessment – A water quality monitoring plan is to be developed both with baseline data and additional sampling for water quality in the nearest riparian watercourse. Sampling is to be undertaken upstream and downstream of the development input to the water course along with sampling from the development itself. Reporting of the testing results is to be included throughout all stages of the planning process.

3. Water quality management – Pre and post development condition pollutant estimations are to be made using a proven method using established pollutant load concentrations provided in the specification. The objective is set for no worsening of pre development runoff quality (expressed in terms of pollutant loads) in addition to seeking to meet ANZECC ecosystem protection criteria for in-stream measured water quality (ANZECC, 2000). It is suggested that the daily flow output from the water balance model could be coupled with the pollutant concentrations to establish export load values for Total Suspended Solids, Total Phosphorous and Total Nitrogen.
4. Watercourse and Creekline Corridor preservation/restoration – Riparian corridors are to be established/retained along creek lines to observe WSUD principles. A number of technical requirements are outlined for the estimation of environmental flows, riparian corridor width, channel characteristics and buffer widths. A number of design requirements are outlined to guide the preparation of channel/riparian corridor design. An erosion and sedimentation control plan is required for construction management.
5. Flood protection – Planning controls for flood planning levels and requirements of the flood modelling are outlined for inclusion in the Water Management Report at each stage of the development process. Aspects of the flood protection section require information on flood modelling methodology, plans showing flood levels, interim flood protection works and a flood evacuation plan. Consideration of design storm events include the 50%, 20%, 5%, 1% AEPs together with the PMF.
6. Stormwater quantity management – On-site detention parameters are outlined for the various sectors of development in the valley in order for flows from development sites to be retarded so they do not exceed pre development conditions for the full range of durations and frequencies up to the 1% AEP. Replication of the base case hydrograph is required. This is to be achieved through both detention and retention of stormwater and a number of options to achieve this are identified (basins, ponds, OSD systems, seepage and re-use). Specific requirements for the hydrograph replication are noted as per below:
    a. Peak flow is +/-5% of pre-development condition;
    b. Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration; and
    c. The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs.
7. Stormwater drainage concept plan – Design of the water management measures and findings of the various assessments are to be documented on a concept plan in support of the Water Management Report.
8. Wastewater Infrastructure Considerations – Generally refers to the requirements of Sydney Water.

Collection of field data for parameters such as stream flow, rainfall, infiltration, soil type and water quality is required to inform the various assessments listed above. It is noted that whilst this information may not easily be obtained for some of the locations within the land release area there is common data collection locations located within the vicinity such as the flow gauges on Fern and Mullet Creeks operated by Manly Hydraulics Laboratory on behalf of Council and partially grant funded by the Office of Environment and Heritage.

2.2.2.2 Application to Ingleside

It is noted that the Warriewood Valley Water Management Specification (2001) outlines stringent objectives aiming to limit the impact of urban development across all aspects of the water cycle and sought to implement a zero net change approach to impact (a pre-cursor to the Neutral or Beneficial Effect concept used for water quality controls on development in the Sydney Catchment Authority catchment area). The Ingleside Precinct is the neighbouring land release area to Warriewood Valley and a portion of the precinct drains to the same creeks as Warriewood Valley (and ultimately Narrabeen Lagoon). The majority of the area to the east of Mona Vale Road has similar land uses and physical characteristics to Warriewood Valley, whilst the area located to the western side of Mona Vale Road has a lower density of urban land use and drains to McCarrs Creek (and ultimately the estuary of Pittwater).

It can be expected that similar overall water management objectives could apply to the Ingleside precinct considering that the receiving environments on both sides contain valuable ecosystems. However, it should be noted that the ecosystems in and around McCarrs Creek and Pittwater estuary are different to those of Narrabeen Lagoon and its tributaries and both have been impacted by existing development to differing levels.

Common overall water management objectives are considered applicable to the precinct because of shared geography and expectations of stakeholders. Therefore it is prudent to consider the foundations of the Warriewood Valley Water Management Specification (2001) and how it may be modified to maintain the water management objectives and improve upon the experiences of recent urban development in the valley.

2.2.2.3 Lessons Learned

Ongoing urban development in Warriewood Valley has been undertaken with reference to the Water Management Specification (2001).

The WMS (2001) was applied to all rezoning and development applications received for the various sectors in the Warriewood Valley. Key learnings from the review of applications by Cardno over the period from 1999 to 2009 were:

- Only the absolute minimum water quality data required was collected and mostly consent had to be withheld until such time as the data was collected and submitted to Council. Water quality data collected during construction and post construction phases were often supplied to Council months after an impact was shown and no action was taken at the time of the incident, nor was it able to be taken long after the incident had occurred. An improved system of construction and post-construction phase monitoring that ensures that action is taken or penalties are applied would be appropriate to achieve the environmental outcomes necessary for the receiving systems.
- A review of potential water quality issues for the locality was better conducted with consideration of Phase 1 and (where available) Phase 2 contaminated land investigations.
- It was difficult to demonstrate compliance with flow and flood requirements of the WMS (2001) without considered incorporation of these concepts in the initial rezoning application. Council eventually set some limits on acceptable flood impacts where zero impact could not be reasonably demonstrated using flood modelling, especially for sector developments in large complex systems. The use of regional flood models established by Council ended up being a more effective means of assessing regional flood impacts of a development, rather than requiring individual developments establish their own flood models for each locality.
- Having set local (sector-specific) requirements for on-site detention (site storage requirements and permissible site discharges) meant that applications could be more easily assessed against these pre-set requirements.
- Requirements for zero net change in pollutant loads were challenging but could be addressed with innovative solutions and ensuring that sufficient space for these solutions was set aside early (such as in the rezoning application).
- The use of infiltration as a mechanism for achieving a water balance was not always possible with local geology (rock close to the surface) and proper testing using double ring infiltrometer testing at rezoning stage allowed for early identification of these constraints. Alternatives, such as larger rainwater tanks or more extensive irrigation or in-house/on-lot reuse (e.g. for laundry as well as toilet flushing and garden irrigation) could be flagged earlier, which contributed to lot sizing requirements.
- The then Part 3A process (repealed in 2011) for some developments within the land release area largely circumvented some of the detailed requirements laid out in the WMS (2001) and often these requirements were relaxed or reduced and did not allow for proper integration of the overall regional strategy.
- Legacy issues for former agricultural sites were present and not always able to be addressed effectively with respect to the protection of receiving environments. For example, groundwater in some areas showed very high nutrient concentrations and controlling the mobilisation of these nutrients associated with large scale earthworks and stormwater infiltration systems incorporated into developments was beyond the scope of the requirements of the WMS (2001).

- Where a creekline corridor was shared and the creek was to be rehabilitated, constructing one half of the creekline as part of the development on that side of the creek was achievable but presented challenges in the interim period prior to the other half being constructed. Flood impact assessments also had to demonstrate that a half-creek construction did not result in short term flood impacts upstream or downstream from a site.
- Integration of wastewater infrastructure in the creekline corridor designs (often outside of the scope of an individual development and managed by Sydney Water) would be more effective at an early planning stage rather than after a creekline corridor was constructed.
- In addition to on-lot controls for dwellings across all developed areas (e.g. on-lot rainwater tanks and associated in-dwelling or irrigation re-use, on-lot on-site detention facilities, on-lot infiltration facilities),a number of gross pollutant traps, proprietary stormwater treatment systems, ponds, detention basins/systems, infiltration facilities, swales, bioretention systems and constructed wetlands exist within the public domain space (i.e. in the private buffer areas of the riparian corridors and beyond) managing flows from cluster developments. The water management controls in public domain areas have largely been handed over to Council, but some have been retained in private ownership (e.g. those in the Shearwater Estate, also known as Sector 12) with the inherent maintenance responsibility. Often the maintenance requirements have not been fully implemented for those facilities in private ownership by the residents and the water quality treatment performance is compromised as a result. Some facilities, such as dry detention basins can perform their water quantity management function with a limited amount of maintenance (such as lawn mowing of batters).

2.2.3 Mullet Creek Rehabilitation Plan (Hyder, 2008)

The rehabilitation plan aimed to conserve Mullet Creek and its receiving environment through providing a strategic framework for rehabilitation. The plan identified a number of social and ecological values of the waterway that are of high value and outlined actions for conservation. Objectives were listed that aimed to improve the understanding of the Mullet Creek hydrology, geomorphology, water quality and aquatic ecology in order to inform a set of creek management recommendations. Investigations into the key indicators for creek health were undertaken through site inspection, community consultation and review of previous studies. The key indicators were then listed in a matrix with corresponding condition, issues and causes. In general it was found that the creek was degraded as a result of land clearing, rural residential uses, increased nutrient loading, water extraction and modified hydrology.

Identification of issues for various reaches of the creek were tabulated with corresponding management actions. The actions were then prioritised based on a qualitative assessment of a range of criteria including cost, stakeholder acceptance, severity of the issues and effectiveness of the management measure. The measures were both preventative and responsive. The consultant undertaking the study and Council then rationalised the management actions to a refined list before going to public exhibition. Following the collation of comments the list was finalised and funding was to be sought for further action. The preparation of the Ingleside Water Cycle Management (WCM) Strategy was identified as management action number 3. The WCM should integrate the various riparian, geomorphology, flooding and water quality principles to sustain the creek health during and following urban development. Management actions were also identified that lead to the development of the studies have been reviewed in **Sections 2.2.4 and 2.2.5**.

2.2.4 Mullet Creek Environment Flow Assessment (SKM, 2010)

Pittwater Council implemented a Rehabilitation Plan for Mullet Creek in 2008, as discussed in Section 2.2.3. As an outcome of the rehabilitation plan, an environmental flow assessment was prepared to determine the impact of urban development to flow regimes in Mullet Creek and the projected impacts of further irrigation were also investigated. The assessment identified the time series flows in Mullet Creek through WaterCAST modelling of hydrology. Since the catchment involves a range of land uses particular attention was made to the significant water users such as the Monash Country Club and Elanora Golf Course. Urban development occupies approximately 10% of the catchment and rural residential uses occupy approximately 40%. The remainder of the catchment is bushland.

The study uses rainfall data from a MHL operated station in Narrabeen Creek, evaporation data from the BOM station at Sydney Airport and water level data from the MHL gauge at Garden Street. The model was built to represent 11 sub-catchments using a DTM created from Council's ALS. Validation of the model was undertaken by comparing flows of the catchment model to those of a rating table developed for the water level recorded by the MHL gauge in the Garden Street culvert. It was found that the rating table estimations of flow volume were abnormally high and disregarded. Alternatively, a volumetric runoff coefficient of 0.3 was used to adjust the catchment parameters to suit. A number of dams and irrigation demands of those were also included.

The study found that the natural hydrology of Mullet Creek, prior to European settlement, had a similar regime to that of existing conditions with the irrigation demands included. Analysis of the existing condition without the irrigation proved that there were increases in the amount of flow at the Garden Street culvert. It was concluded that the impact of the relatively low urbanisation of the catchment decreased the low flows received by Warriewood Wetland and increased the high flows. This was a more significant impact than the harvesting of flows for irrigation of the golf courses. It is noted that the golf courses were not using their full water license allowances and if they were to increase, then impact on the high and medium flows in Mullet Creek could be experienced.

2.2.5 Mullet Creek Water Quality Monitoring Program and Design (Bio-Analysis, 2010)

The monitoring program report was commissioned to investigate the aquatic ecology of Mullet Creek and to outline methods for testing response of the creek to planned development. It was anticipated by Council that the Ingleside precinct would be rezoned for urban development and this program is one of the management actions coming out of the Mullet Creek Rehabilitation Plan. The report notes that creek rehabilitation works are likely to improve water quality in the short term, however, there remains concerns over the impact of future development. The program is informed by previous water quality assessments undertaken by Council and its consultants.

Aquatic habitat was inspected visually and reported to inform the design of the program. A review of available information regarding water quality is summarised below:

- Low dissolved oxygen levels;
- Elevated nutrients;
- Blooms of phytoplankton;
- Faecal contamination;
- Nuisance macro algae and aquatic plant growth;
- Obstruction of flows by dams and culverts;
- Elevated levels of suspended solids;
- Sedimentation; and
- Concentration of heavy metal was below upper limit of ANZECC guideline.

A short description of the aquatic habitat was reported to contain three distinct reaches being:

1. A wetland upstream of Jackson’s Road – wetland similar to those found in Warriewood Wetland.
2. From the wetland limit at around Garden Street to the first waterfall in Epsom Park – Shallow sandy channel with shallow pools having dense riparian vegetation and many weeds. Water quality appeared poor due to turbidity.
3. Upstream of the confluence of the two arms of the Creek that drain either side of Powderworks Road – The south-western arm is relatively undisturbed with several land developments, Monash golf course and dams located adjacent to the creek. The north-western arms is disturbed as a result of land clearing, rural development and road crossings.

An assessment of water quality and related studies identifies that the aquatic habitat is under stress as a result of high nutrient and sediment levels. In addition aquatic biota is predicted to suffer as a result of urban development adjustments to water quality parameters such as conductivity, dissolved oxygen, pH and temperature. Traditionally water quality sampling concentrates on nutrients and suspended solids when monitoring the impact of urban development. It is recommended that sampling of macro-invertebrates is coupled with the water quality testing. Macro-invertebrates are a key indicator of the aquatic biota present in a waterway.

It is proposed in the report that the program should test water quality at a number of locations along the waterway over a given time period to accurately monitor water quality changes. If the water quality and macro-invertebrate levels increase above the average baseline data then it would be determined that impacts have become incurred. Reference to ongoing monitoring in related catchments in the Hornsby and Warringah LGAs could be used for analysis to outline common response of undeveloped catchments to climatic conditions. This would be supportive data to allow a clear identification of urban development impact independent of other variables. Further discussion of the program and how it would be applied for the Ingleside precinct is included in Section 7.

2.2.6 Ingleside Water Management Option (EDAW, 2008)

The Ingleside Water Management Option report was commissioned by Landcom (now UrbanGrowth NSW) to investigate opportunities for water management in the Ingleside land release area. Potable water, wastewater and stormwater management infrastructure options were investigated. It is noted that potable water is most likely to be supplied by a new centralised piped network considering the lack of existing infrastructure. Recommendations are made to reduce potable water demands through rainwater tanks to supply hot water demands and recycled wastewater for non-potable uses.

Wastewater services have been investigated by Worley Parsons and would involve expansion of the Warriewood STP reticulation network. This would be cost effective in servicing locations in the precinct on the eastern side of Mona Vale Road.

Stormwater management is generally recommended to include WSUD, retention of post development flows for events up to the 1.5 year ARI and retard stormwater flows to mimic pre development hydrology. It is noted that there are a wide range of options to meet these stormwater management objectives and could be either located in public domain or within private property. In general land take requirements for stormwater management are reported to be between 1-3% of the development area. Considering the sensitivity of the receiving environments discussion is focussed on the capture, treatment and harvesting of stormwater to reduce the predicted modification of hydrology in Ingleside.

2.2.7 Narrabeen Lagoon Flood Study (BMT-WBM, 2013)

This study was commissioned by Council with the support of the Office of Environment and Heritage and describes the flood behaviour in the Narrabeen Lagoon catchment. Mullet and Fern Creeks are tributaries to the Lagoon. Further discussion of this study in included in **Appendix A**.

2.2.8 Pittwater Overland Flow Flood Study (Cardno, 2013)

This study was commissioned by Council with the support of the Office of Environment and Heritage and aims to increase awareness of Overland Flow in the Pittwater LGA. Various models were prepared that include the entire Ingleside Precinct. Further discussion of this study in included in **Appendix A**.

2.2.9 Mona Vale – Bayview Flood Study (DHI, 2002)

A small part of the Ingleside precinct drains to the north through the Mona Vale – Bayview catchment where flood behaviour was estimated by this Flood Study using a Mike 11 model. Further discussion of this study in included in **Appendix A**.

2.2.10 Warriewood Valley Flood Study (Cardno Lawson Treloar, 2005)

This study was commissioned by Council to investigate the flood behaviour of Warriewood Valley where ongoing urban development was in progress. It has now been superseded by the Narrabeen Lagoon Flood Study (BMT WBM, 2013) and the Pittwater Overland Flow Flood Study (Cardno, 2013). Further discussion of this study in included in **Appendix A**.

2.3 Relevant Development Controls and Policies

2.3.1 Pittwater Local Environmental Plan (LEP)

The Pittwater LEP was gazetted in May 2014 and came into effect in June 2014. It defines the Flood Planning Level in *Section 7.3 Flood Planning, under Item (5):*

> Flood planning level means the level of a 1:100 ARI (Average Recurrence Interval) flood event plus 0.5m freeboard, or other freeboard determined by an adopted floodplain risk management plan.

Section 7.4 Floodplain Risk Management of LEP 2014 outlines safe occupation and evacuation requirements and applies to land as defined under Item (2):

"This clause applies to land between the flood planning level and the level of the probably maximum flood, but does not apply to land subject to the discharge of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard, or other freeboard determined by an adopted floodplain risk management plan. "

2.3.2 Pittwater Development Control Plan (DCP)

The Pittwater 21 DCP was first adopted in 2003 and has since been amended seventeen (17) times and most recently came into force on 14th November 2015. It currently applies planning controls to land uses mapped in the Pittwater LEP 2014 with specific requirements for land release areas such as Warriewood Valley. In regard to water cycle management the DCP includes specific hazard controls for flooding that relate to associated flood hazard maps. The controls recommend a range of flood risk management considerations in the planning and design of urban development. The flooding controls are similar to what has been documented throughout NSW under the Floodplain Risk Management process as defined by the NSW Floodplain Development Manual (NSW Government, 2005). It is noted that specific controls are included for minor and major overland flow paths that are particularly relevant to flood behaviour in Ingleside.

Section C6.1 outlines the controls for integrated water cycle management within the Warriewood Valley locality and a summary of this is included below:

1. Water Management Report – This report is to be prepared by a qualified professional and is to be in accordance with Council's Warriewood Valley Urban Land Release Water Management Specification (2001) and relevant legislation taking into account the Narrabeen Lagoon Flood Study (2013) and the Pittwater Overland Flow Flood Study (2013).
2. Flooding – Flood levels are to be determined as part of the Water Management Report along with assessment of the likely flood impacts from the development.
3. Creekline Corridor – Any creek that passes through/aligns/abuts a sector, buffer area or development site, is required to comprise a total width of 100m. This comprises of a 50m wide Inner Creekline Corridor which would be under Council ownership and contain the 1% AEP flow plus climate change; and an Outer Creekline Corridor 25m wide on each side of the Inner Creekline Corridor. This would be in private ownership and perform the function of part water quality and park fauna/flora corridor.
4. Stormwater Drainage Management – Design of piped stormwater drainage system network with 5% AEP capacity including climate change impacts is required. All development stages are to meet or exceed the water quality criteria within the Warriewood Valley Urban Land Release Water Management Specification (2001).
5. Groundwater – If groundwater is required to be manages as a result of excavation/basement/stormwater or flood mitigation measures then groundwater management measures are to be assessed.
6. Greywater Reuse – if greywater reuse is proposes then on-site treatment, disposal and/or reuse must demonstrate feasibility, compliance with relevant State and Federal regulatory requirements, and achieve current NSW Heath Accreditation.

Section B.25 of the DCP outlines the flood emergency response planning control for areas impacted by flash flooding or overland flow or lagoon flooding or a combination of flooding to ensure that development is undertaken in a way that is reflective of the flood risk.

3 Objectives

The objectives of the WCM strategy are to prepare a strategic level WCM strategy for incorporation into the Ingleside Draft Plan through documentation of the following:

- Identification of water management targets (water quality, water quantity and social/ecological requirements) for the future urban development in the precinct.
- Ensuring no adverse impact to flows and flood behaviour in downstream areas.
- Preparation of a water cycle assessment/water balance modelling.
- Consideration of ecological impacts including sustainable environmental flows to Warriewood Wetlands.
- Preparation of a water quality monitoring plan as a determinant of pre and post development impacts.
- Assessment of site constraints and opportunities including:
  - Potentially feasible water management strategies;
  - Management of environmental flows in creeks;
  - Stormwater re-use options;
  - Source control measures; and
  - WSUD options.
- Consolidation of stormwater quality and quantity controls in order to control construction costs and reduce allocation of valuable land for water management purposes.
- Development of feasible options through consideration of:
  - Compliance with management objectives;
  - Reliability;
  - Operation and Maintenance;
  - Land Take; and
  - Stakeholder Acceptance.

3.1 Water Management Targets

The water management targets set for the Ingleside precinct in consultation with Council and DP&E are provided in **Table 3-1**. These targets have been established with the aim to reduce impacts from the Ingleside Precinct development on the surrounding environment and neighbouring properties.

Table 3-1 Water Management Targets

ELEMENT	TARGET	REFERENCE
Potable Water	Household use – 192 L/day/dwelling (2.5 Pax)	BASIX (40% reduction target of 320L/dwelling)
Non-potable Water	Irrigation – 125 L/day/dwelling Supply with non-potable water supply from rainwater/wastewater re-use	EDAW 2008
Water Quantity (Design Storm Hydrograph)	For the 2 and 100 year ARI events and the 2hr durations: a. Peak flow is +/-5% of predevelopment condition b. Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration c. The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs	Warriewood Water Management Specification

ELEMENT	TARGET	REFERENCE
Water Quality	90% capture of gross pollutants 85% reduction of TSS 65% reduction of TP 45% reduction of TN	Sydney Catchment Management Authority (now Local Land Services)
	Limit impacts on water quality during construction using soil and water management plans and water quality monitoring	Pittwater DCP
Environmental Flows	Flow volume of the post development conditions is to be within +/-5% of pre-development based on a daily water balance (MUSIC) with 31yr simulation period	Warriewood Water Management Specification
Groundwater	Maintain baseflows so that there are no more than +/-10% of pre-development daily volumes represented in a daily water balance model (MUSIC) with 31yr simulation period	Groundwater Dependent Ecosystems (Ecological 2014)

The following sections will provide further discussion on how the water cycle management and flooding objectives and water management targets will be achieved.

The Ingleside Draft Plan is provided in **Figure 3-1**.

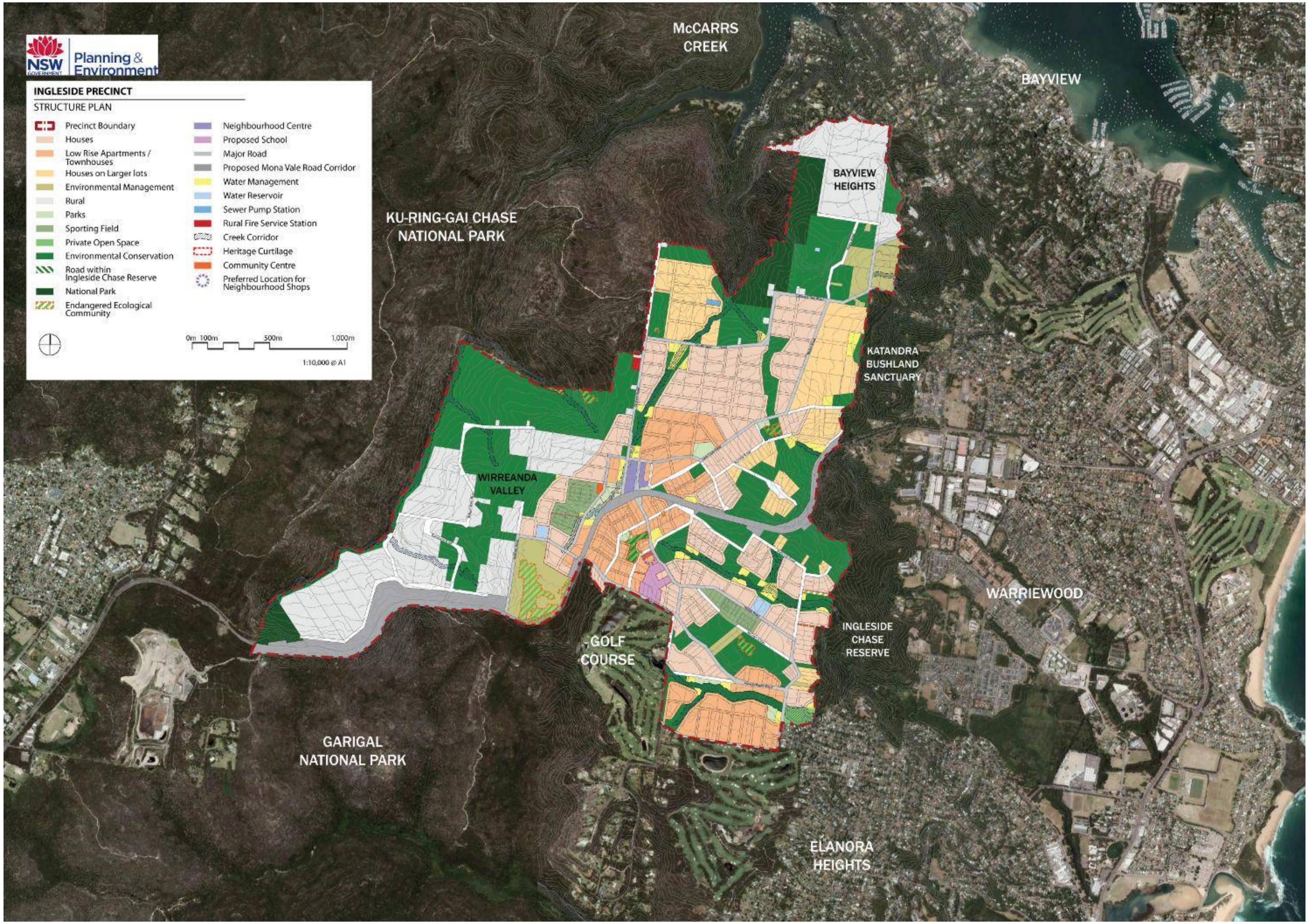

Figure 3-1 Ingleside Draft Plan

4 Flooding Assessment[1]

4.1 Hydrology

This study adopted a traditional hydrological XP_RAFTS model for the entire Ingleside precinct catchment to generate the input hydrographs to a hydraulic SOBEK model which covers the Ingleside Precinct.

An XP_RAFTS model is the most widely used hydrological modelling tool to predict the storm discharge for the pre and post development conditions and to estimate the requirements for stormwater detention. The model allows the user to rapidly update parameters such as impervious percentage, rainfall losses and roughness to assess greenfield development.

The aims of the hydrological analyses were to:

- Assemble a rainfall/runoff model of the existing catchment and the post development catchment;
- Estimate catchment runoff under existing catchment conditions for the 2, 20, 100, 200 and 500 year ARI and PMF events;
- Estimate catchment runoff under post development conditions to ascertain the impacts of the proposed development for the 2 year ARI and 100 year ARI events;
- Assess the impact of climate change by estimating 10%, 20% and 30% increases in 100 year ARI rainfall under post development conditions;
- Size detention basins to reduce the 2 and 100 year ARI peak flows as specified in the water management targets (**Table 3-1**):
  - Peak flow is +/-5% of predevelopment condition;
  - Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration; and
  - The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs.
- Assess the ramifications of climate change on the volumetric requirement for structural flood risk management measures.

The catchment model and parameters are outlined in **Appendix A**.

4.1.1 Existing Conditions

An XP_RAFTS model was developed under the catchment existing conditions to generate hydrographs for inputs to a SOBEK model. The catchment was divided into 64 subcatchments based on topographic features, the likely overland flowpaths and the input requirements of the hydraulic model.

The XP_RAFTS subcatchment layout for the existing scenario is shown in **0**.

A full range of design events was simulated for the existing scenario, including the 2, 20, 100, 200 and 500 year ARI and PMF events. The estimated peak flows for each subcatchment for these design events are summarised in **Appendix A**.

[1] Subject to further amendments to the draft Plan, the flood assessment will be updated post public exhibition.

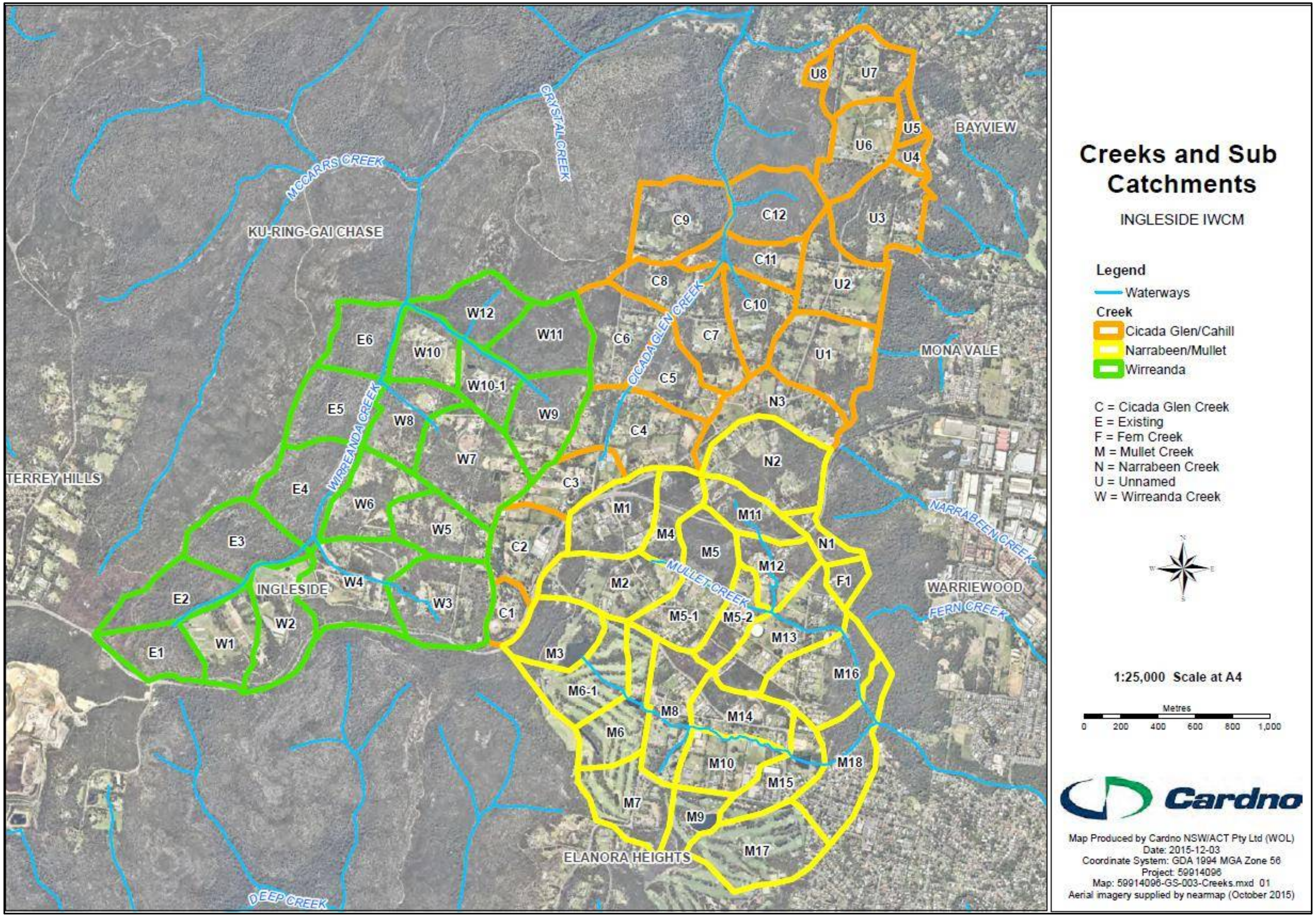

Figure 4-1 XP RAFTS Existing Condition Subcatchment Layout

4.1.2 Results comparison

Since calibration data is not available in the study area, the XP_RAFTS model was validated by comparing the peak flows for 100 year ARI at a common node on Mullet Creek with previous available studies. An assessment of peak flow from the XP_RAFTS models available at the time of reporting found the following 100 year ARI, 2hr peak flows at a common node on Mullet Creek.

- Narrabeen Lagoon – 97.2 m^3/s
- Warriewood FS – 40.4 m^3/s
- Ingleside Precinct WCM – 100.7 m^3/s

The Ingleside peak flow of the 100 year ARI is similar to that of the Narrabeen Lagoon Flood Study (BMT-WBM, 2013). This is not surprising considering that the same hydrological model parameters have been adopted. The reason why the Ingleside flows are slightly higher than those identified in the Narrabeen Lagoon Flood Study is because the catchment slope has generally been estimated higher in the current study. The flows estimated for the Warriewood Valley Flood Study (Lawson & Treloar, 2015) involved a detailed investigation of losses and much higher Bx values that would reduce the discharge. It is interpreted from the Warriewood study that the higher losses/Bx were used to calibrate the model to local stream gauge data. It is evident that in the Narrabeen Lagoon Flood Study higher losses were also estimated in order to calibrate models. It is noted that the loss values in these previous studies were averaged over a large catchment and may not provide adequately conservative values for the Precinct. As a result, industry standard valued recommended by AR&R were adopted and is consistent with the Ingleside model approach.

4.1.3 Developed Conditions

The existing XP_RAFTS model was modified for the development conditions to represent the land uses proposed in the revised Ingleside Concept Plan in August 2014. The key modifications include:

- Configuration of subcatchment layout; and
- Impervious percentage for different land uses.

The catchment was divided into 72 subcatchments by considering the proposed design layout, land uses and the existing subcatchment layout. The XP_RAFTS subcatchment layout for the development scenario is shown in **Figure 4-2**.

The design events of 100 year ARI and 2 year ARI were simulated for the developed conditions. The modelled peak flows for each subcatchment for these design events are summarised in **Appendix A**.

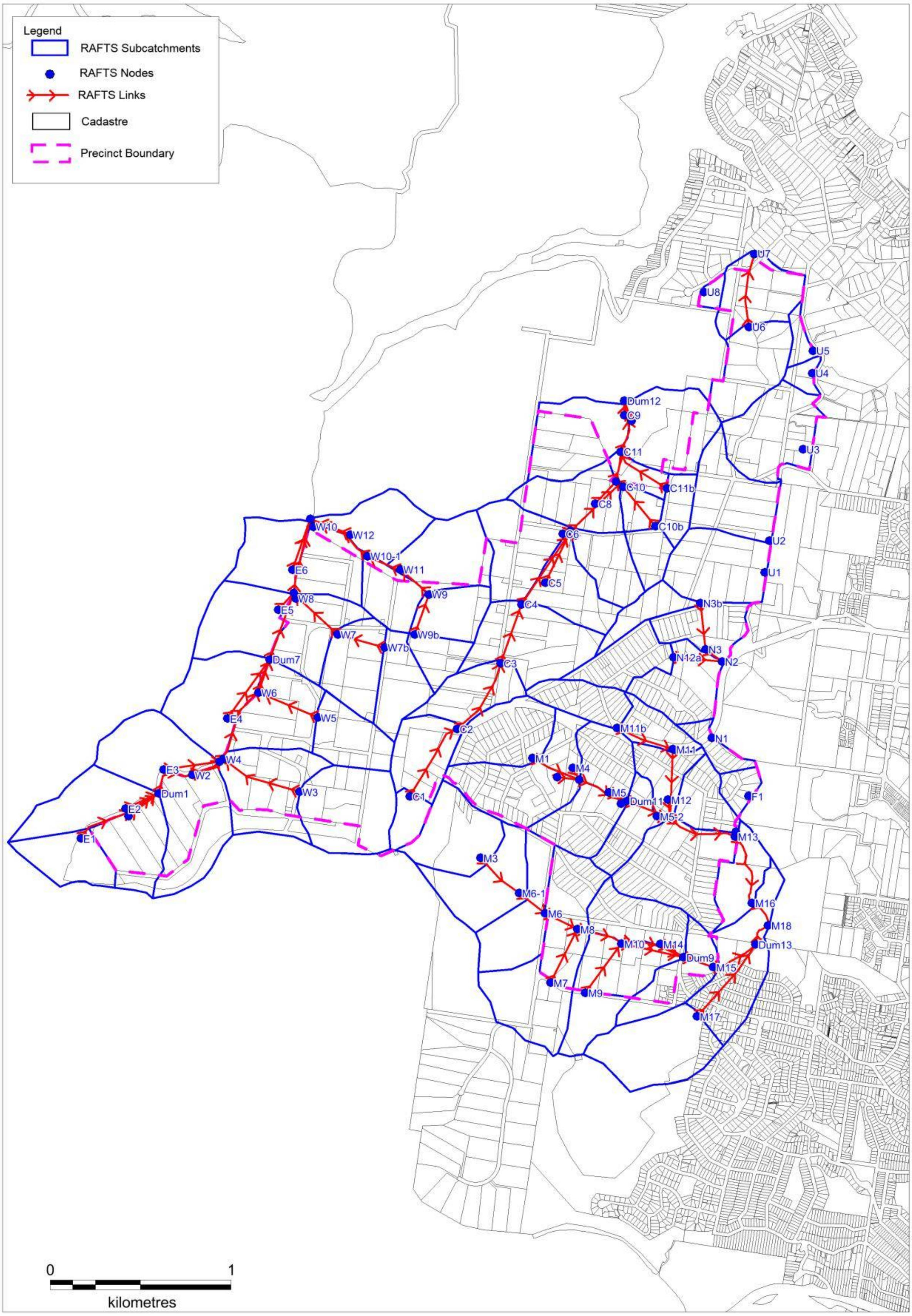

Figure 4-2 XP RAFTS Developed Condition Subcatchment Layout

4.1.4 Basin assessment

A hydrological assessment of possible detention basin options was undertaken. The aim of the assessment was to meet the following water management targets:

- For the 2 year and 100 year ARI events and the 2 hour durations:
  - Peak flow is +/-5% of predevelopment condition;
  - Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration; and
  - The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs.

The potential detention basin locations are shown in **Figure 4-3**, including seven off-line basins and three on-line basins.

The on-line basins are located at the three locations along Mullet Creek and Cicada Glen Creek, to capture flows from all of upstream catchments. These creeks are 1st and 2nd order creeks and as per NOW Controlled Activity Riparian Corridor Guidelines, online basins are allowed on these creeks. The on-line basins will play a key role to meet the specified water management targets for the downstream flows along the creeks under the developed conditions.

The off-line basins would be situated adjacent to the creek within the outer 50% of the Vegetated Riparian Zone. They will capture flows from its local catchment and include a biofiltration area.

The design of the basin size and outlet structures is crucial to control the peak flows downstream and to achieve the optimal efficiency of the detention systems. This study adopted two approaches in sizing off-line basins and on-line basins.

4.1.4.1 Off-line Basins

Off-line basins were estimated using XP_RAFTS model under the developed conditions. Off-line basins generally considered the flows from its location subcatchment.

The basin size and outlet structure for each off-line basin were determined by adjusting the basin design parameters in XP_RAFTS to achieve the targeted downstream peak flows mentioned above. The detailed information regarding these off-line basins are summarised in **Table 4-1**.

Table 4-1 Proposed Off-line Basins

Offline Basin ID	Subcatchment Area (ha)	Peak Depths (m)		Indicative Storage Volume (m³)		100 year ARI Spillways		2 year ARI Outlet (m)
		100 year ARI	**2 year ARI**	**100 year ARI**	**2 year ARI**	**Width (m)**	**Spillway Height (m)**	
B_M1	16.16	2.18	1.23	5,500	3,100	5	1.8	1.4×1.0
B_M13	24.94	2.05	1.11	8,100	4,400	8	1.8	1.6×1.0
B_M11b	9.63	2.14	1.13	2,800	1,500	4	1.8	1.0×0.8
B_N3	44.25	2.40	1.23	12,000	6,200	8	1.8	2.9×0.9
B_U1	19.75	2.14	1.22	5,400	3,100	8	1.8	1.8×1.0
B_U2	18.04	1.90	1.20	4,200	2,700	8	1.8	1.8×1.0
B_C10b	5.988	1.73	1.18	740	510	4.5	1.5	1.0×0.7

B_N3 was designed to capture flows from all of the upstream subcatcments, including N3b, N3, N12a and N12, which the total subcatchment area is 44.25 hectares.

For B_M13 and B_C10b, there is no identical corresponding subcatchment for the existing RAFTS model due to the subcatchment split under the developed conditions. The hydrographs under the existing conditions were obtained by simulating the same subcatchment area as the developed conditions and the impervious percentage under the existing conditions.

The peak flows at downstream end of off-line basins are provided in **Table 4-2**.

Table 4-2 Peak Flows at Downstream Boundary of the Off-line Basins

Off-line Basin	100 year ARI Peak Flow (m^3/s)		100 year ARI Flow Percentage (%)	2 year ARI Peak Flow (m^3/s)		2 year ARI Flow Percentage (%)
	Existing	**Developed**		**Existing**	**Developed**	
B_M1	7.22	7.12	-1.4	2.30	2.40	**4.3**
B_M13	7.17	7.19	0.4	2.08	2.07	**-0.2**
B_M11b	4.43	4.37	-1.4	1.52	1.56	**3.1**
B_N3	17.29	17.23	-0.2	5.64	5.39	**-4.8**
B_U1	9.52	9.13	-4.2	3.09	3.05	**-1.4**
B_U2	8.00	8.16	1.9	2.65	2.71	**2.3**
B_C10b	**3.39**	**3.23**	**-4.9**	**1.23**	**1.18**	**-4.1**

The results indicate that the off-line basins are capable of managing the peak flows within +/-5% of predevelopment condition.

4.1.4.2 On-line Basins

This study proposed three on-line basins, which the locations are shown in **Figure 4-3**. OSD_C3 and OSD_C6 are located along Cicada Glen Creek, whilst OSD_M5 is located along Mullet Creek. The main purpose of these on-line basins is to manage the flows downstream of the study area along these two major creeks in a range of ± 5% of the predevelopment conditions. These downstream flow control locations are shown in **Figure 4-3** as flow measurement lines.

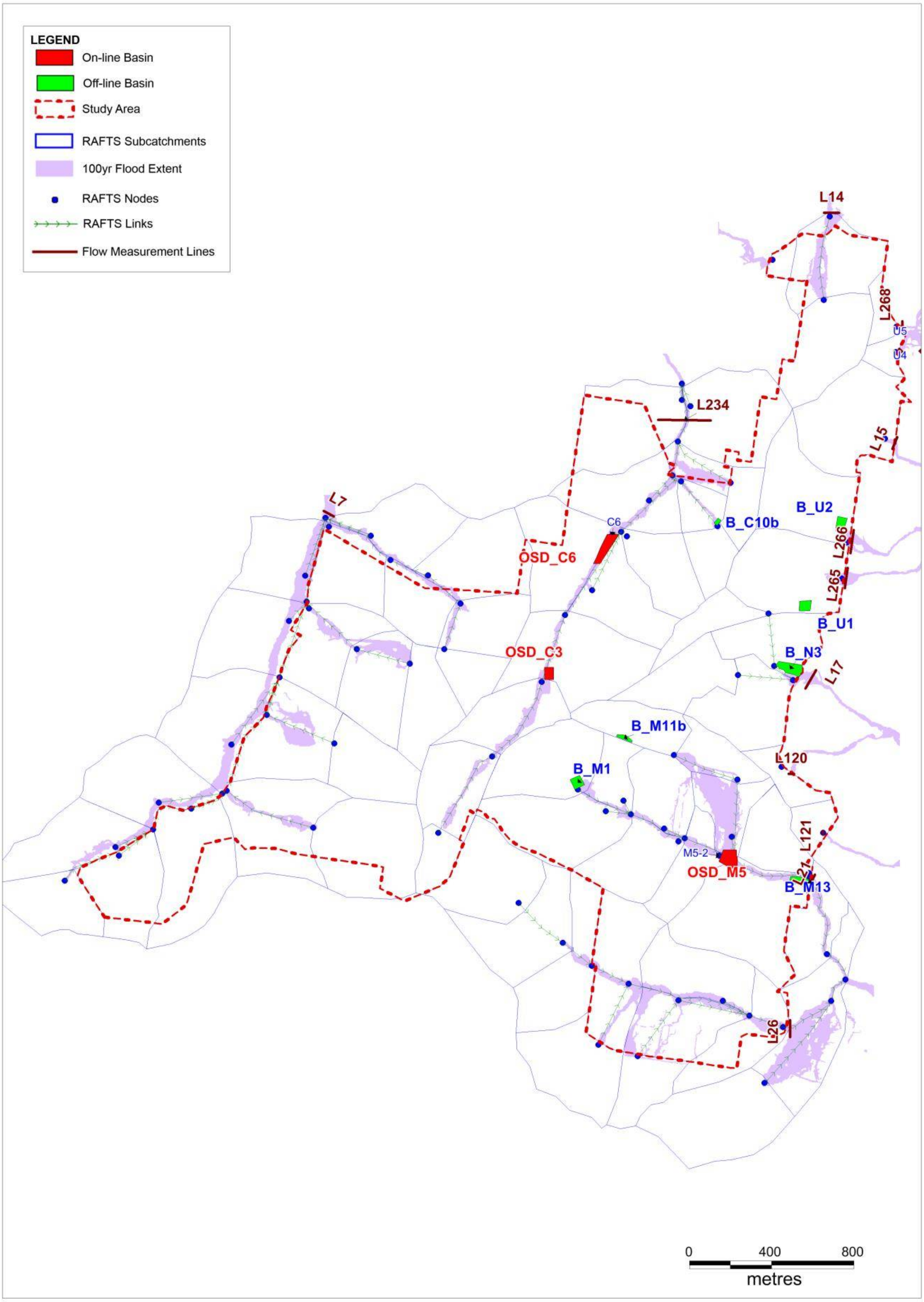

Figure 4-3 Detention Basin Locations

The basin configuration was guided by the following design objectives:

- Locate the basin on-line within the floodway;
- Limit the amount of earthworks required to construct the basin. This was achieved by including the basin bund without excavation of existing floodplain topography where possible;
- Landscape the basin structures so that they complement the riparian vegetation and habitat;
- Adopt maximum batter slopes of 1 (V) : 4 (H) in order to minimise the impact of the basin embankment on existing vegetation; and
- Use of a two stage outlet structure on grade to attenuate the peak 2 year and 100 year ARI flows under developed conditions to pre-development levels.

The on-line detention basins were sized by the following two steps:

- A 1D XP-SWMM model was set up for each on-line basin. The input flows of 100 year ARI and 2 year ARI were extracted from the XP_RAFTS model under the developed conditions. Detention basin storage volumes and basin outlets comprising two stage culverts were sized to attenuate the peak 2 year ARI and 100 year ARI flows under developed conditions to pre-development levels; and
- Information regarding the basin storage and the basin outlet structures estimated by the 1D XP_SWMM model was used as references to design basins into the 1D/2D SOBEK model. It is noted that the basin configurations based on 1D XP_SWMM model and 1D/2D SOBEK model are not exactly the same.

A number of SOBEK models with various basin configurations were simulated. The ultimate basin storage and outlet structures for the on-line basins are summarised in **Table 4-3**.

Table 4-3 Proposed On-line Basins Adopted in SOBEK model

On-line Basin	Indicative Storage Volume (m^3)		100 year ARI Spillway		2 year ARI Outlet (m)
	100 year ARI	**2 year ARI**	**Width (m)**	**Spillway Height (m)**	
OSD_C3	2,600	1,000	9	2.0	**1.3×1.0**
OSD_C6	21,000	10,200	9	2.0	**1.8×1.3**
OSD_M5	**15,000**	**4,900**	**20**	**1.8**	**4.0×1.4**

It was a challenge to design basins in steep terrain to obtain targeted downstream flows in conjunction with a specification on the maximum water depths in the basin. The on-line basin configurations listed in **Table 4-3** were obtained principally to maintain the 2 year ARI and 100 year ARI peak flows within +/-5% of predevelopment conditions.

Consequently in order to assess whether the 100 year ARI and 2 year ARI flows under developed conditions are within the specified targets, it was necessary to compare the flow hydrographs generated by SOBEK at key downstream locations under existing and developed conditions. The hydrographs for 100 year ARI and 2 year ARI under the existing and developed conditions for each flow measurement lines are provided in **Appendix A**.

The peak flow estimated by the 2D SOBEK model with and without basins are summarised in **Table 4-4** and **Table 4-5**. For 11 out of 13 locations, the peak flows for 100 year ARI and 2 year ARI are in the range of +/-5% of predevelopment condition. The hydrographs at these locations also show reasonable agreements under the existing and developed conditions (shown in **Appendix A**)

Note: This study did not consider any detention basin located upstream of flow measurement line L26 since the proposed development does not result in an increase in flows for 100 year ARI and 2 year ARI. In the XP_RAFTS models in this study, a split subcatchment approach was adopted. This means that a subcatchment was split into an impervious area and a pervious area. The peak flow at L26 is the peak convergence flow from this impervious and pervious area. The different time concentrations from the impervious and pervious area are likely to contributing the lower flows under the developed conditions.

The peak flow at L21 for 2 year ARI were very close to the flow measurement target +/-5% of predevelopment conditions. However, the peak flow for 100 year ARI decreased by 9.9% under the developed conditions. In order to improve the flow conveyance along Mullet Creek, it is recommended to undertake creek rehabilitation immediately downstream of the proposed on-line basin M5.

The peak flow decreased by approximately 9.9% and 6.0% for 2 year ARI and 100 year ARI events under the developed conditions.

Table 4-4 Peak Flows at Downstream of the Online Basins

Off-line Basin	100 year ARI Peak Flow (m^3/s)		100 year ARI Flow Percentage (%)	2 year ARI Peak Flow (m^3/s)		2 year ARI Flow Percentage (%)
	Existing	**Developed**		**Existing**	**Developed**	
B_M1	7.22	7.12	**-1.4**	2.30	2.40	**4.3**
B_M13	7.17	7.19	**0.4**	2.08	2.07	**-0.2**
B_M11b	4.43	4.37	**-1.4**	1.52	1.56	**3.1**
B_N3	17.29	17.23	**-0.2**	5.64	5.39	**-4.8**
B_U1	9.52	9.13	**-4.2**	3.09	3.05	**-1.4**
B_U2	8.00	8.16	**1.9**	2.65	2.71	**2.3**
B_C10b	**3.39**	**3.23**	**-4.9**	**1.23**	**1.18**	**-4.1**

Off-line basins were estimated using XP_RAFTS model under the developed conditions. Off-line basins generally considered the flows from its location subcatchment. The results indicate that the off-line basins are capable of managing the peak flows within +/-5% of predevelopment condition as set in the water management targets.

Table 4-5 Peak Flows at Key Downstream Locations

Flow Measurement Line	100 year ARI Peak Flow (m^3/s)		100 year ARI Flow Percentage (%)	2 year ARI Peak Flow (m^3/s)		2 year ARI Flow Percentage (%)
	Existing	**Developed**		**Existing**	**Developed**	
L26	46.04	43.26	**-6.0**	13.37	12.05	**-9.9**
L21	47.03	42.40	**-9.8**	13.92	13.20	**-5.2**
L121	2.17	2.16	**-0.5**	0.94	0.93	**-1.1**
L120	2.47	2.47	**0.00**	1.06	1.06	**0.00**
L17	16.53	16.45	**-0.5**	5.24	5.26	**0.4**
L15	9.34	9.34	**0.00**	3.16	3.16	**0.00**
L265	9.46	9.10	**-3.8**	3.08	3.03	**-1.6**
L266	7.94	8.12	**2.3**	2.67	2.72	**1.9**
L267	1.43	1.43	**0.00**	0.61	0.61	**0.00**
L268	1.58	1.58	**0.00**	0.68	0.68	**0.00**
L14	12.02	12.00	**-0.2**	3.72	3.71	**-0.3**
L234	43.25	45.15	**4.4**	12.26	12.11	**-1.2**
L7	**104.65**	**105.08**	**0.4**	**28.52**	**28.55**	**0.1**

4.1.5 Climate Change Assessment

Climate change assessment will be undertaken following Consultation of the Draft Ingleside Precinct Water Cycle Management and Flooding Assessment.

As part of the assessment, the potential impacts of climate change on the 100year ARI flood behaviour will be assessed by increasing the 100 year ARI rainfall intensities by 30%. Hydrographs for the critical storm durations will be exported from the RAFTS model and imported into the SOBEK model and a comparison of the impact of climate change on 100 year ARI design flood levels and basins sizes will be undertaken.

4.2 Hydraulics

4.2.1 Model Set Up

The flow behaviour during design storm events has been modelled using the SOBEK hydraulic model. The hydrological component is modelled with user defined inflows from the XP_RAFTS model. This is considered the most pragmatic approach to providing a hydraulic model that can assess the impact of urban development options to existing flood behaviour. A combination of 1D and 2D domains are included in SOBEK.

The following describes how the model has been prepared:

- 3m grid for the 2D domain using topographic data of the ALS;
- 1D domain comprising major culverts that were measured during a recent site visit. No other ground survey data or pit and pipe network data is available for incorporation into the 1D domain. All the major hydraulic structures listed in **Table 4-6** were incorporated into the hydraulic model;
- Roughness areas defined are based on the Pittwater Overland Flow Study (Cardno 2013). The averaged roughness across the entire property was used to define buildings in a hydraulic model. **Table 4-7** shows the roughness layout applied in the 2D model which is based on Pittwater Overland Flow Study (Cardno 2013);
- Percentage Impervious defined by analysis of aerial photography;
- Extend the model at least 200m downstream of the precinct;
- The catchment runoff is determined through the hydrological model and is applied to the SOBEK model as flow vs. time inputs. Flows were inserted to the hydraulic model at the low point of the subcatchments; and
- The model boundary is extended more than 200m downstream of the precinct boundary with free outfall in order to correct flood levels to be estimated at the precinct limit.

Table 4-6 Culverts included in the SOBEK model

Address	Type	No.	Size (mm)	Us_depth (m)	Ds_depth (m)	Us_IL (m AHD)	Ds_IL (m AHD)
Chiltern Road (Cicada Glen Ck)	Pipe	1	825	0	0	155.13	154.29
Cicada Glen Rd (Cicada Glen Ck)	Pipe	4	975	0	0	125.80	124.98
Minkara Rd (Bayview Ck)	Pipe	1	1050	1.38	1.45	109.41	108.09
Gilwinga Dr (McCarrs Ck)	Pipe	1	525	0	0	92.86	92.13
Ingleside Rd (Mullet Ck)	Box	1	3360 x 900	1.52	1.57	98.45	98.27
Powder Works Rd (Mullet Ck)	Pipe	3	1800	2.27	2.28	96.52	96.15
Tumburra St (McCarrs Ck)	Pipe	1	1350			113.50	113.30
McCowan Rd (McCarrs Ck)	Pipe	1	1200	0	0	90.58	89.72

Address	Type	No.	Size (mm)	Us_depth (m)	Ds_depth (m)	Us_IL (m AHD)	Ds_IL (m AHD)
Mona Vale Rd (MulletCk)*	Pipe	1	750	1.17	1.17	139.47	139.27
Mona Vale Rd (Narabeen Ck)*	Box	1	2750 x 1540	2.21	2.22	99.75	94.37

* Included data from Council's pit and pipe information

Table 4-7 Roughness Values for 2D Domain

Classification	Adopted 2D Roughness Value
Open Space	0.030
Roads	0.015
Coastline	0.030
Bushland	0.080
Ocean	0.020
Open Channel	0.040
Residential/Urban Areas	0.100
Rural Residential	0.050
Golf Course	0.040

4.2.2 Existing Scenarios

Flood mapping for existing conditions is included in **Appendix B**. Based on the results the following preliminary comments can be made about the likely nature of flooding:

- In most locations steep grade creeks carry major overland flows to mainstream flooding areas downstream. These creeks are generally cut into a sandy valley floor with exposed bedrock, cascading runs and an irregular channel shape. The channel banks are generally loose sand stabilised by riparian vegetation;
- The development of the site will result in significant increases in unmitigated discharges from the site given the majority of the Precinct has pervious surfaces. The sandy soil's ability to infiltrate is demonstrated by the high losses used in the flood studies when undertaking calibration;
- Unlike most other WCM studies, the main focus in this precinct will relate to safe conveyance of overland flow through the precinct as opposed to consideration of impacts to flood storage as there is only small floodplain pockets within the precinct limiting floodplain storage capacity;
- The critical duration for the precinct is short duration events (2 hours), which can otherwise be described as flash flooding; and
- The impact of the urban development on flood levels and extents within the precinct would not be significant, however sensitive locations downstream such as downstream of Cicada Glen Creek would be significant affected by unmitigated flows from upstream.

4.2.3 Developed Scenarios

This study provided the model results for 100 year and 2 year ARI under the developed conditions. Flood mapping for developed conditions is included in **Appendix B**.

In general, the proposed development results in an increase in flood levels along the overland flowpaths. An increase in the flood levels by up to 0.15m for 100 year ARI occurred along Mullet Creek. The flood levels increase by less than 0.05m along the overland flowpaths downstream of subcatchment U1, U2 and N3. However, the flood levels have a more significant increase (up to 0.3m) for 100 year ARI along Cicada Glen Creek. Thought it results in an increase in flood levels for some properties along the Creek, it does not increase the number of properties affected by flooding.

4.2.4 Developed Scenarios with Basins

Basins were modelled in the SOBEK model using two different approaches. For off-line basins, the outflow hydrographs from the line basins extracted from the XP_RAFTS model were directly used as the corresponding input flows into the SOBEK model. For the three on-line basins, the SOBEK model incorporated these on-line basins into the modelled terrain grid.

The model results of developed scenarios with basins for 100 year and 2 year ARI are shown in Figures in **Appendix B**. The results indicate that when basins are incorporated into the design, the proposed development does not increase flood levels at almost all of the downstream flows, except for Cicada Glen Creek. It was found that the flood levels only increase by less than 0.05m for 100 year and 2 year ARIs downstream of Cicada Glen Creek.

The proposed basins are capable of attenuating the flows for 100 year and 2 year ARI to ±5% predevelopment conditions. It also ensures that the proposed development does not have significant flood impact along all downstream overland flowpaths.

4.2.5 Basin concept and cost estimates

Basin concept designs and cost estimates will be undertaken following Exhibition of the Draft Ingleside Precinct Water Cycle Management and Flooding Assessment.

5 Flood Emergency Response[2]

When determining the flood risk to life for a developable area the flood hazard for an area does not directly imply the danger posed to people in the floodplain. This is due to the capacity for people to respond and react to flooding, ensuring they do not enter floodwaters.

To help minimise the flood risk to occupants, it is important that developments have provisions to facilitate appropriate flood emergency response. There are two main forms of flood emergency response that may be adopted by people within the floodplain:

- Evacuation: The movement of occupants out of the floodplain before the property becomes flood affected; and
- Shelter-in-place: The movement of occupants to a building that provides refuge above the flood level on the site or near the site before their property becomes flood affected.

This report section assesses the emergency response implications of development of the Ingleside precinct, specifically an assessment of:

- The impact development may have on emergency services such as the NSW State Emergency Service (SES);
- Potential evacuation routes from the Ingleside precinct; and
- The future need for emergency response in the Ingleside development precinct using the Flood Emergency Response Planning (FERP) Classification of Communities Guideline.

5.1.1 Regional Emergency Response

The emergency response procedures for a region are generally outlined in Emergency Management Plans (EMPANs) and associated sub-plans.

The NSW State EMPLAN describes the NSW approach to emergency management, the governance and coordination arrangements and roles and responsibilities of agencies. For flood emergencies the responsible agency is the NSW SES.

For the purpose of emergency management, in 2012 NSW was broken up into a series of Emergency Management Regions. The Ingleside Precinct lies within the Sydney Metropolitan Region. Prior to 2012 these regions were known as Emergency Management Districts.

Regional EMPLANs are being developed for each Emergency Management Region. However, until the new plans are passed and available, the District Emergency Management Plans (DISPLANs) remain in place.

A DISPLAN describes the arrangements at the District level to effectively and efficiently prevent, prepare for, respond to and recover from emergencies and also provides policy direction for the preparation of relevant local and sub-plans.

A Flood Plan is a sub-plan of a DISPLAN and is generally prepared by the SES in conjunction with Council. This emergency response plan is directly targeted at addressing the risk to life in the event of severe flooding.

There is no existing Floodplan or DisPLAN for the Northern Beaches of Sydney therefore there is no defined regional emergency response for the Ingleside precinct. In the following sections some assumptions have been made based on the NSW State EMPLAN and known flood behaviour of the local area regarding likely SES response procedures and regional evacuation routes.

5.1.2 Evacuation Route Assessment

Evacuation involves the movement of people from a flood affected location to one that is flood free. Evacuation may occur by car, foot, boat, helicopter or other method. The key limitations to evacuation are flood free access, mobility of people being evacuated and time available to evacuate.

[2] Subject to further amendments to the draft Plan, the flood assessment will be updated post public exhibition.

One of the primary advantages of flood evacuation is intended to be the removal of flood isolation. Flood isolation can be considered in a number of ways:

Isolation from medical services: In the event of a medical emergency; a pre-existing condition, injury, or sudden onset event such as heart attack, medical services may not be able to be accessed; and

Isolation from supplies: Isolation from drinking water, food, amenities, and communication lines.

It is assumed that isolation from medical services poses a greater risk to life than isolation from supplies for the short durations of isolation likely to be experienced in the Ingleside precinct. Therefore evacuation should be determined by access to the nearest medical emergency centre, which in the case of Ingleside is the Mona Vale hospital to the east.

There is one major regional road through the Ingleside precinct, Mona Vale Road. It is assumed that this is the regional evacuation route for the western Northern Beaches suburbs. As shown in **Figure 5-1**, a regional evacuation route has been identified that accesses the Mona Vale hospital, with the minimal amount of road flooding.

The PMF floodplain extents shown in **Figure 5-1** are based on those modelled in the Pittwater Overland Flow Flood Study (Cardno, 2013) prepared for Pittwater Council. While these models were more broad scale than those conducted within this Water Cycle Management Study, they provide an indication of the wider floodplain extents for the entire Pittwater LGA, within which evacuation from the Ingleside Precinct needs to be considered.

The evacuation route follows Mona Vale Road into the suburb of Mona Vale before diverting right onto Foley Street and onto Warriewood Road through the north side of the suburb of Warriewood. The route diverts left from Warriewood Road onto Hill Street, on to Elimatta Road, crossing Mona Vale Road and to the hospital through east Mona Vale.

Accessing this regional evacuation route for the Ingleside precinct is done via local evacuation routes as shown in **Figure 5-1**. Similar to the regional evacuation route these represent the least flood affected routes for the precinct to evacuate.

While the majority of nominated routes are flood free for all events including the PMF event, there are a number of locations where route overtopping occurs as summarised in **Table 5-1**. The location of the crossing locations are numbered in **Figure 5-1**.

The discussion regarding the Mona Vale Road crossings (Locations 1, 2, and 3) have been based on hydraulic modelling conducted as part of the Mona Vale Road Upgrade Hydraulic Assessment (Cardno, 2014) prepared for NSW Roads and Maritime Services (RMS). In this study detailed assessment was conducted of both the existing and proposed Mona Vale Road cross drainage network for the 100 year ARI event. As PMF event modelling was not conducted, assumptions have been below made regarding cross drainage capacity in this event.

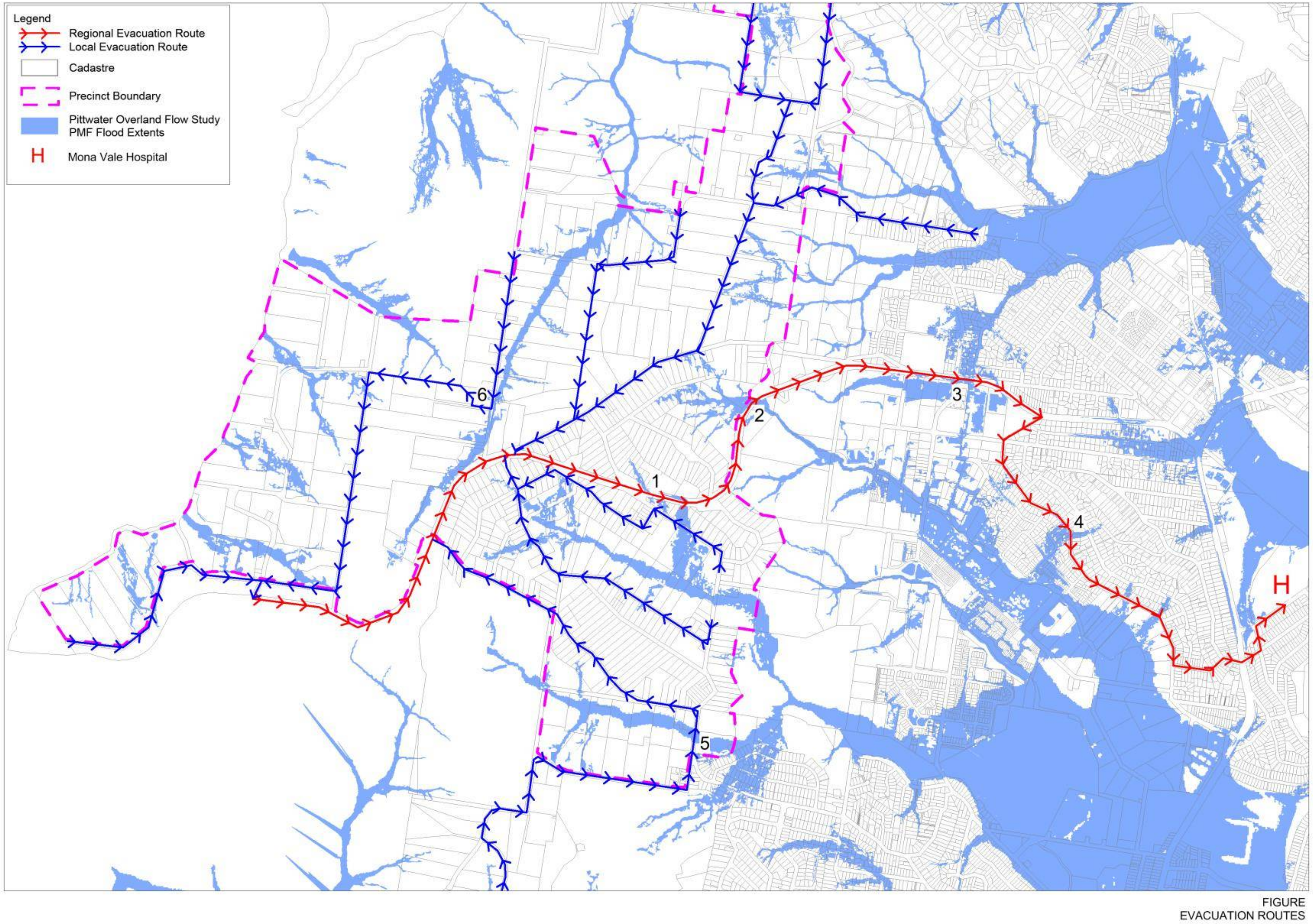

Figure 5-1 Flood Evacuation Routes for Ingleside Precinct

Table 5-1 Evacuation Route Crossing Summary

Location ID	Evacuation Route	Description	Comment
1	Regional – Mona Vale Road	Overland flow converges from small upstream catchment (8 ha), minimal pipe capacity under road, overtops in events greater than 100yr ARI as shallow, high velocity sheet flow. No significant cross drainage upgrade is proposed for Mona Vale Road upgrade.	Overland flow affectation from a small catchment, the duration of overtopping is expected to be equivalent to the duration of the rainfall event. This is not perceived as a significant overtopping location.
2	Regional – Mona Vale Road	Flow converges upstream of Mona Vale Road in upper Narrabeen Creek. High road embankment and large culvert (a twin culvert is proposed to be installed as part of Mona Vale Road upgrade) mean overtopping is likely to occur in the PMF event only, with overtopping flow likely to be shallow, high velocity sheet flow.	Overland flow affectation from a relatively large upstream catchment (37 ha), however as the culvert capacity is significant overtopping duration is expected to be minimal. This is not perceived as a significant overtopping location.
3	Regional – Mona Vale Road	It was concluded in the Mona Vale Road upgrade that the upstream flowpath to the south of Mona Vale Road is diverted south towards the Warriewood Valley through a constructed trunk drainage line and overland flowpath.	Overtopping of Mona Vale Road is unlikely under any design event.
4	Regional – Warriewood Road	Overland flow converges from small upstream catchment, likely to overtop in events more frequent than 100yr ARI as shallow, high velocity sheet flow.	Overland flow affectation from a small catchment, the duration of overtopping is expected to be equivalent to the duration of the rainfall event. This is not perceived as a significant overtopping location.
5	Local – Powder Works Road	Significant upper tributary of Mullet Creek overtops Powderworks Road via low-lying crossing. Likely to overtop in events more frequent than 100yr ARI as deep, high velocity flow.	When overtopped this crossing may pose significant hazard for evacuees and should not be crossed while flooding. Large upstream catchment, however time of overtopping is not expected to exceed 2 hours.
6	Local – Chiltern Road	Overland flow from Cicada Glen Creek flows along Chiltern Road in extreme events. The intersection with the proposed road extension to the west is on the fringe of the PMF extents so evacuation via this route should be possible.	Significant flow along Chiltern Road occurs near the proposed intersection however not perceived as a significant overtopping location.

As can be seen from **Table 5-1** the only location where an evacuation route may be severely flood affected for extended periods may be at Powderworks Road. This crossing is the evacuation route for a small portion of the proposed medium density residential land for the Ingleside precinct. The risk associated with this Powderworks Road affectation is considered negligible as the duration of overtopping is not expected to exceed 2 hours, and as the proposed developable land is not affected by mainstream flooding. Both of these factors indicate that the chance of a medical emergency for the short duration that the road is overtopped is of negligible concern. It is noted that the vast majority of Pittwater LGA is isolated from access to hospitals due to flooding of access roads, and as a result Pittwater Council has adopted a policy of encouraging shelter-in-place in situations such as that caused by the Powderworks Road crossing.

Therefore it can be concluded that the majority of the Ingleside development precinct has access to Mona Vale Hospital if necessitated through medical emergency during a flooding event,

5.1.3 Flood Emergency Response Planning Classification

The Flood Emergency Response Planning (FERP) Classification of Communities Guideline (NSW Government, 2007) was prepared by two state government agencies in 2007; the Department of Environment and Climate Change (DECC, now OEH), and State Emergency Service (SES). The guideline provide a basis for the flood emergency response categorisation of floodplain communities.

The categories are focussed on SES requirements and look to classify land based on evacuation and access availability during flood events. The Flood Emergency Response Planning classifications assist emergency managers with identifying the type and scale of information needed for emergency response planning, and assist planners in identifying suitable areas for development.

In accordance with the guideline, FERP Classifications are to account for all flooding events up to and including the Probable Maximum Flood (PMF) therefore this has been adopted as the design flood event in this emergency response assessment. This represents a worst-case flooding scenario.

As can be seen in **Figure 5-1**, the majority of developable area in the Ingleside precinct is flood free in all events up to and including the PMF event. Discussion in **Section 5.1.2** shows that for the majority of the Ingleside Precinct also has suitable evacuation route access to Mona Vale Road Hospital.

Therefore the Ingleside development precinct is classified as "Indirectly Affected", which is defined as:

> *There will be areas outside the limit of flooding which will not be inundated and will not lose road access, never the less they may be indirectly affected as a result of flood damaged infrastructure, due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services they may require resupply or in the worst case, evacuation*

This is perceived as the FERP classification with the least amount of flood risk.

5.1.4 Recommended Flood Emergency Response

As the vast majority of the Ingleside precinct is flood free in all events up to and including the PMF event, with flood free access to most locations; shelter-in-place is the recommended emergency response for all future residents of the Ingleside precinct, due to the following reasons:

- For most properties there is no risk of flood affectation, therefore the major reason to evacuate is not applicable and there is no risk to life associated with not evacuating. In fact as evacuation routes are overtopped in some locations the flood risk associated with evacuation is considered higher than sheltering-in-place; and
- Due to excessive road cut-offs during extreme flooding events across Pittwater LGA there is a potential risk of traffic congestion along evacuation routes, to ease this the best practice for non-flood affected properties is to shelter-in-place until flooding has eased. This approach will not only assist more flood affected residents but also emergency response services such as the NSW SES.

The only time that evacuation is the recommended emergency response is for the limited number of properties that are flood affected within the Ingleside development precinct, or in the event of a medical emergency occurring. In this instance the evacuation routes summarised in **Section 5.1.2** will provide access to Mona Vale Road.

6 Water Cycle Management Strategy[3]

6.1 Water Cycle Management

Water Cycle Management (WCM) is a holistic approach that addresses competing demands placed on a region's water resources, whilst optimising social benefits and enhancing and protecting the environmental values of receiving waters.

A conceptual diagram of the water cycle is shown in **Figure 6-1**.

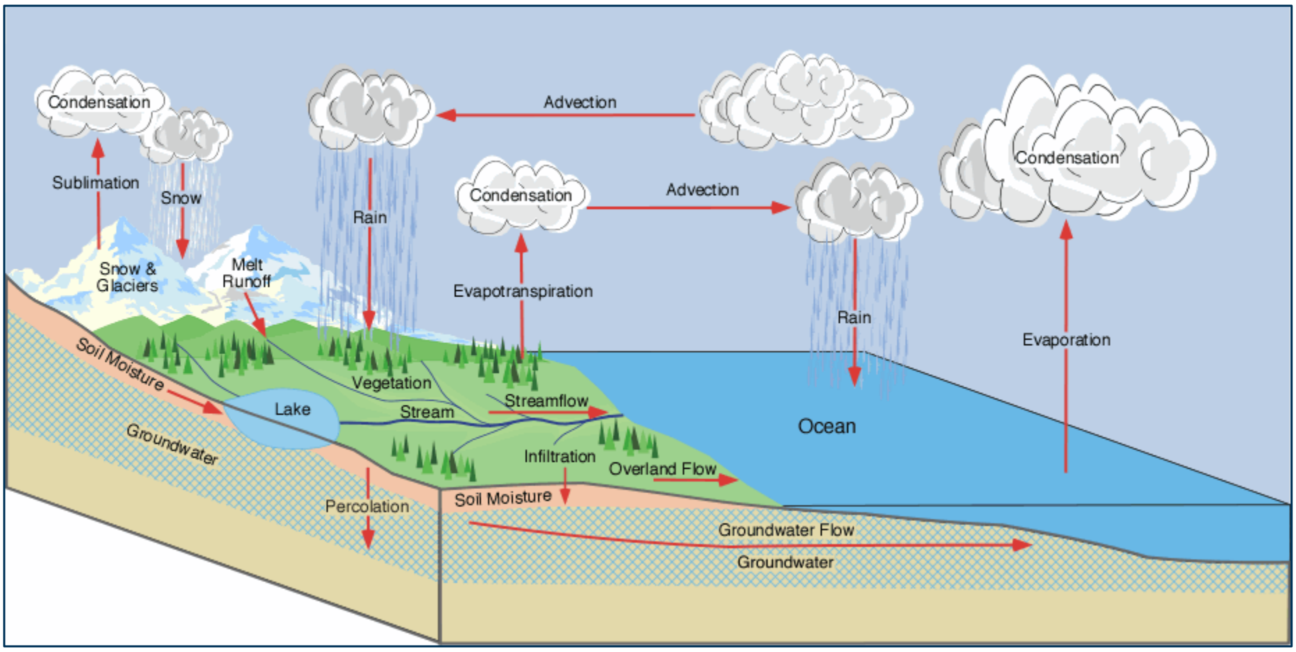

Figure 6-1 Total Water Cycle (Source http://www.physicalgeography.net)

6.2 Water Cycle Management Strategy

This WCM strategy will inform where water management controls are to be located in the Draft Structure Plan and document requirements for the preparation of a site specific Development Control Plan (DCP). The strategy focuses on better ways of managing and integrating the available water resources by looking beyond the traditionally separate consideration of water supply, wastewater and stormwater services.

6.2.1 Water supply

6.2.1.1 Potable

Efficient use of potable water within the Precinct will be maximised through demand management measures such as water saving devices.

6.2.1.2 Non-potable

Efficient use of non-potable water within the Precinct will be maximised through use of rainwater and/or recycled wastewater.

6.2.2 Wastewater

Wastewater servicing within the precinct will include a combination of existing sewer infrastructure, extensions to existing sewer infrastructure and on-site treatment.

[3] Subject to further amendments to the draft Plan, the Water Cycle Management will be updated post public exhibition.

6.2.3 Stormwater

A key component of Water Cycle Management is Water Sensitive Urban Design (WSUD). WSUD manages the impacts of stormwater from development with the aim of protecting and improving waterway health by mimicking the natural water cycle as closely as possible.

Some of the commonly used WSUD structures are listed in **Table 6-1**.

Table 6-1 Typical WSUD devices

Device	Description
Gross Pollutant Traps (GPTs)	GPTs are structures that trap litter and coarse sediment.
Grass Swales	Grass swales are a method of replicating a more natural water cycle, whereby nutrients, sediments and other pollutants with potential to cause water quality issues are captured or absorbed by the vegetation as the stormwater runoff flows through the swale.
Infiltration trenches	Infiltration trenches collect and hold water below ground for disposal to the groundwater table. The trench is an excavation filled with porous material. Stormwater infiltrates from the walls and base of the trench while sediments and some dissolved pollutants are retained in the porous material.
Bioretention systems	Bioretention basins, also known as raingardens, filter stormwater runoff through densely planted surface vegetation and an engineered filter media such as sand. Bioretention basins can have the added benefit of providing detention to alleviate flooding issues as well as treating stormwater runoff.
Constructed wetlands	Constructed wetlands provide a natural way to treat stormwater before it enters the local waterways. They allow sediments to settle and remove a significant amount of pollutants by adhesion to vegetation and aerobic decomposition.
Porous paving	Porous paving allows water to pass through and captures suspended solids and pollutants, before discharging into the drainage network or to the groundwater table.
Green roofs/walls	A green roof is a roof surface that is partially or completely planted with vegetation over a waterproof membrane. A green wall is an external wall that is partially or completely covered with vegetation on specially designed supporting structures. They help slowing stormwater runoff, and assist with water reuse.

WCM measures proposed for the Precinct are outlined in **Table 6-2**.

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Table 6-2 Water Cycle Management Measures for Ingleside Precinct

Element	Management Measure	Description
Water Supply	Provide South and North Ingleside with centralized potable water supply	Reduce potable water demand by supplying rainwater for toilet flushing, laundry, hot water use and garden irrigation for residential areas.
	Rainwater Tanks	Reduce potable water demand by supplying rainwater for toilet flushing and garden irrigation intended for all land use.
	Stormwater Harvesting	Reduce potable water demand by supplying harvested stormwater for irrigation of sport fields.
Wastewater	Connect to sewer infrastructure	Rural and large lot residential land uses: On-site treatment and retention for collection, treatment and re-use or transpiration bed.
	On-site or central treatment where no connection to sewer is available	Developed Land Uses (excluding rural) – Collect and reticulate to Warriewood Wastewater Treatment Plant.
Stormwater	Gross Pollutant Traps (GPT)	Neighbourhood scale control of gross pollutants, suspended solids and phosphorous in purpose designed devices. Proprietary products are most appropriate for underground drainage systems and trash racks/deflectors are most appropriate for the inlets to detention basins.
	Detention basins with biofiltration	Detention basins have been proposed to control stormwater quantity at the confluence of local drainage lines and perennial streams. The offline detention basins will incorporate a bio-filter at the low point to treat low flows from frequent storms. The bio-filter will be sized to meet the targets set in Table 3-1.
	Bioretention basins	The basins will incorporate a GPT at the inlet and a bio-filter area at the low point to provide biological treatment of low flows from frequent storms. The bioretention system will be sized to meet targets set in **Table 3-1**.
	Retention basins	In addition to the required detention capacity, the detention basins will be provided with a water retention component to assist with meeting the targets set in **Table 3-1**.

Element	Management Measure	Description
	Monitoring	A water quality monitoring plan is to be developed both with baseline data and additional on-site sampling for water quality in the nearest riparian watercourse. Water quality monitoring probes for automated water quality sampling are recommended to establish baseline water quality data prior to urban development. The probes should remain in place and continue to monitor water quality both during and following construction. Additional on-site sampling is to be undertaken upstream and downstream of the development input to the water course along with sampling from the development itself. Reporting of the testing results is to be included throughout all stages of the planning process. Auditing and corrective action should be outlined in a Soil & Water Management Plan.
Groundwater	Infiltration	Urban development modifies the ability for the ground to recharge groundwater levels during wet weather. Promoting infiltration with the use of bioretention assists with replicating the groundwater recharge processes.

6.3 Stormwater Quality and Quantity Management

6.3.1 Modelling Methodology

Water quality and quantity modelling of the proposed development has been undertaken using Model for Urban Stormwater Improvement Conceptualisation (MUSIC) software. MUSIC modelling has been undertaken for three scenarios:

- Existing Scenario – based on pre-developed Precinct conditions
- Developed Scenario – based on the proposed Ingleside Precinct Structure Plan, without any WCM measures; and
- Mitigated Scenario – based on the proposed Ingleside Precinct Structure Plan with WCM measures.

The RAFTS model developed for the flooding assessment divided the catchment into approximately 57 sub-catchments. While this level of detail is required for the site hydrology and hydraulic analysis, it is not necessary for water quality and quantity modelling. This is because the water treatment devices capture runoff from large areas and treatment at subcatchment level will not achieve improved results.

For this WCM strategy, to assess the impacts of the development on stormwater quality and quantity the RAFTS catchment delineation was revised based on the waterways that the Precinct drains into and is provided in . The three waterway catchments include – Wirreanda Creek draining to McCarrs Creek, Cicada Glen Creek draining to MacCarrs Creek, and Narrabeen Creek and Mullet Creek draining to Warriewood Valley. The RAFTS sub-catchments were therefore consolidated into the 3 waterway catchments. The catchment delineation and subcatchment layout for the Precinct is provided in **Figure 6-3**.

MUSIC has been set-up such that runoff and pollutant generated can be estimated separately for each of the waterway catchments. The MUSIC model set up for existing and developed scenarios is provided in **Figure 6-4** and **Figure 6-5**.

The model parameters and assumptions including sizing of WCM measures that were adopted in the modelling are provided in **Appendix C**.

6.3.1.1 Water Quality

The aims of the water quality modelling were to assess the impacts of the proposed development on stormwater quality and estimate the sizes of the WCM measures required to meet the water quality objectives for the Precinct as set out in **Table 6-3**. The critical pollutants modelled are Gross Pollutants, Total Nitrogen (TN), Total Phosphorous (TP) and Total Suspended Solids (TSS).

Table 6-3 MUSIC Pollutant Reduction Targets

Pollutant	% Reduction Target*
TSS	85%
TP	65%
TN	45%
Gross Pollutants	90%

* Reduction based on comparison of developed conditions with and without water quality treatment measures.

MUSIC software is used to assess the effectiveness of the WCM devices by measuring the pollutants generated after treatment against the developed scenario where no water quality treatment measures are installed.

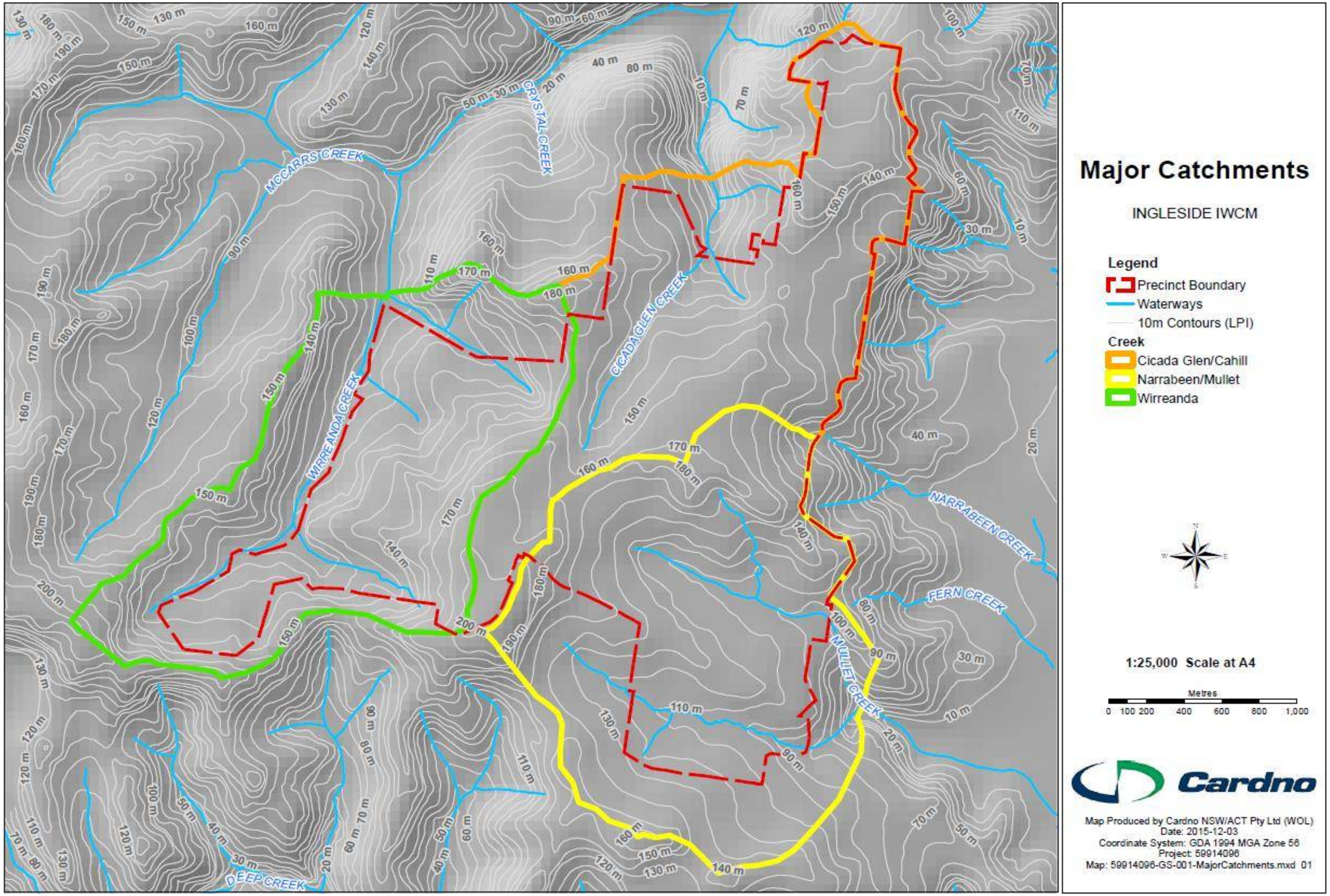


Figure 6-2 Waterway catchments

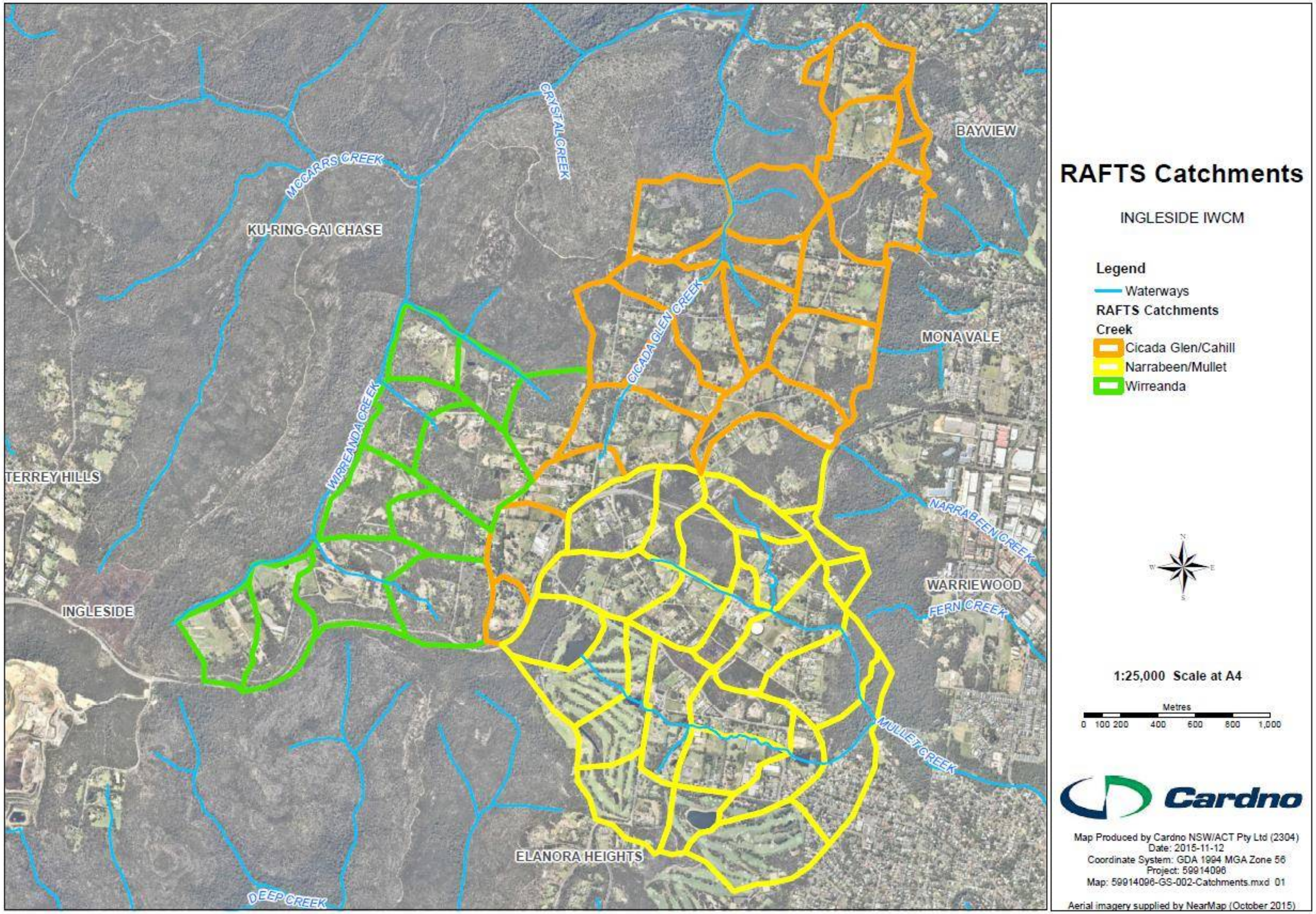


Figure 6-3 MUSIC catchment delineation

6.3.1.2 Water Quantity

The aims of the water quantity modelling were to assess the impacts of the proposed development on stormwater quantity and estimate the WCM measures required to meet the environmental flows and groundwater flows objectives for the Precinct as set out in **Table 6-4**.

Table 6-4 Environmental Flow and Groundwater Flow Targets

Parameter	Target*
Environmental Flows	+/- 5%
Groundwater Flows	+/- 10%

*Difference based on comparison of existing condition and developed condition with water management devices.

MUSIC software is used to develop a water balance model to assess the effectiveness of the WCM devices by measuring the environmental and groundwater flows for the developed scenario against the existing scenario.

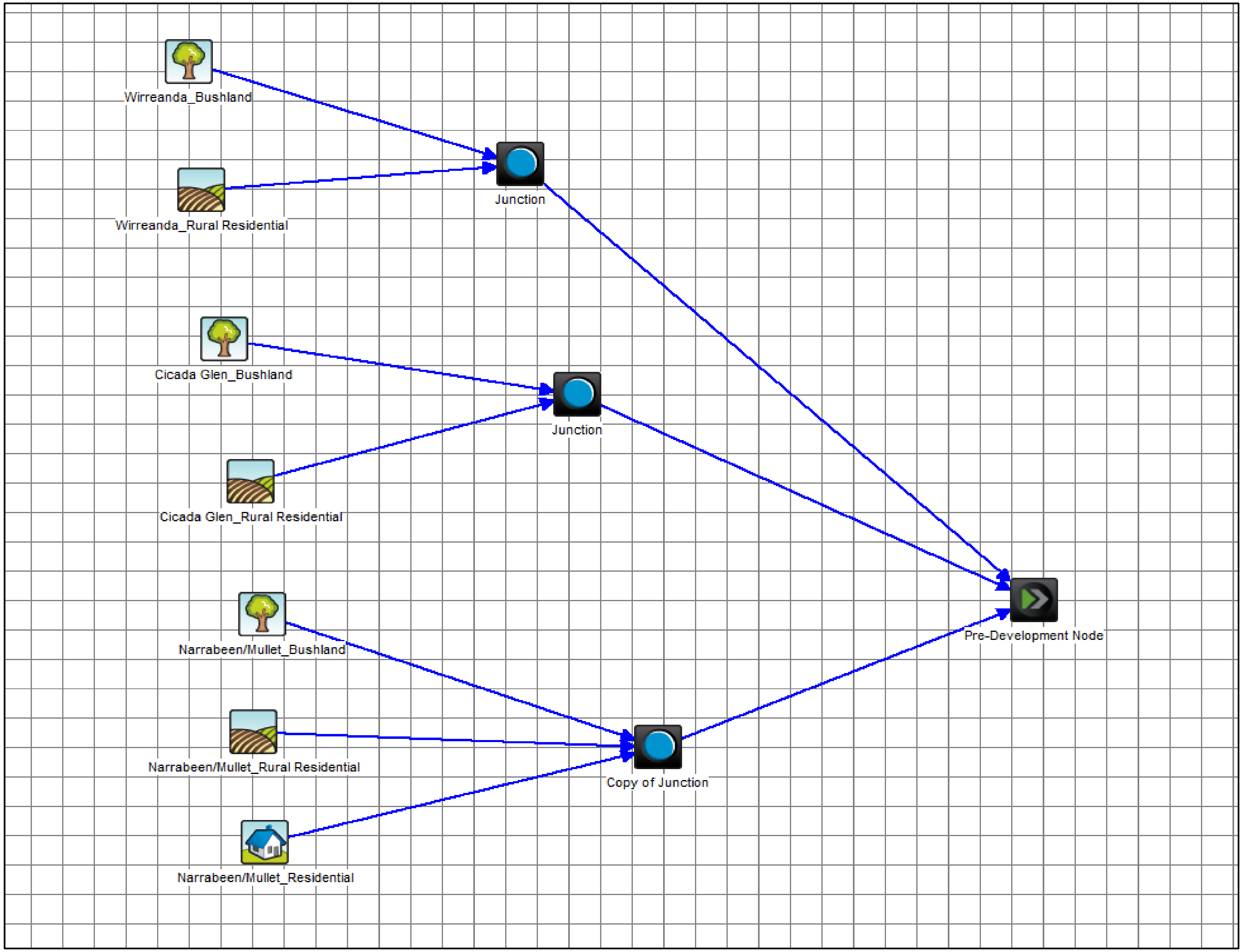


Figure 6-4 MUSIC model – Existing Scenario

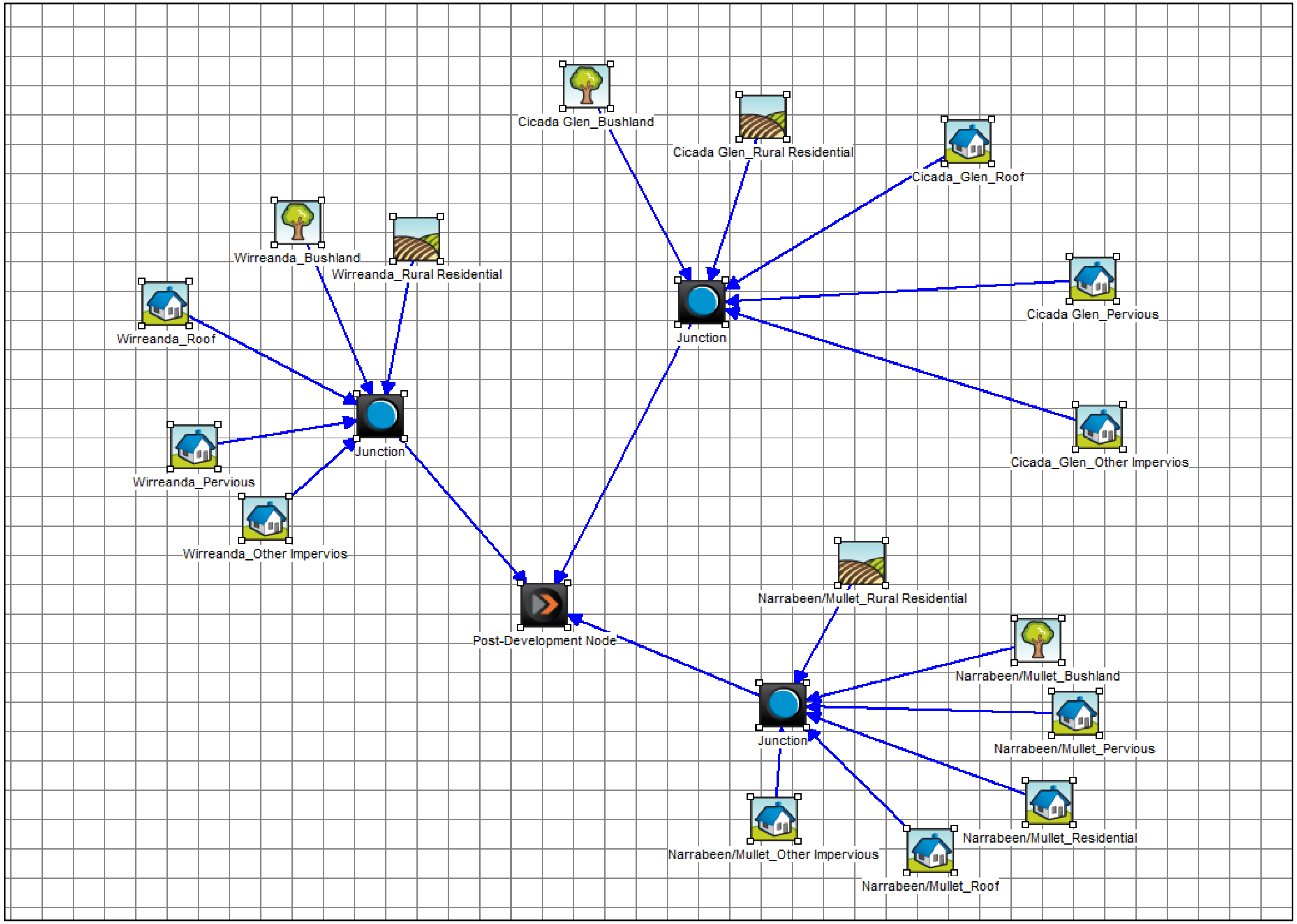


Figure 6-5 MUSIC model – Developed Scenario

6.3.2 Water Cycle Management Measures

Runoff generated from the precinct can be separated into 3 main sources:

- Runoff generated from roof (rainwater runoff);
- Runoff generated from roads and pavements/footpaths (stormwater runoff); and
- Runoff generated from pervious surfaces (stormwater runoff). Some of this runoff is lost to infiltration (groundwater flows).

In order to achieve the stormwater quality and quantity targets the following treatment train is proposed for all three catchments in the Precinct:

Lot Scale

- Rainwater tanks to be provided for all environmental living, low density, medium density, mixed use, school and community centre land uses for at source treatment and re-use of roof water for toilet, laundry, hot water and outdoor purposes.

Regional Scale

- Gross pollutant traps to be provided to capture larger pollutants and sediments before discharge into the bioretention basins;
- Bioretention basins “raingardens” to be provide (online and offline) for effective removal of fine sediments and nutrients;
- Detention basins to be constructed with a permanent water storage component for further removal of sediments and also increase evapotranspiration; and
- Stormwater harvesting to be provided for re-use of runoff in irrigation of sports fields.

The WCM measures proposed in this study should be reconsidered at the time of construction to ensure they are still industry best practice and suitable for the development. However, it should also be ensured that they meet the WCM targets specified in this report.

6.3.3 MUSIC Modelling Results

The MUSIC model set up for mitigated scenarios is provided in **Figure 6-6**.

6.3.3.1 Water Quality Results

The mitigated scenario model was developed incorporating the treatment train as described above, with results compared against the developed scenario to determine the pollutant loads across the three catchments.

Results of the MUSIC analysis in **Table 6-5** indicate that, by including the nominated treatment train, the water quality improvement objectives set out in this water cycle management strategy are achieved for the precinct.

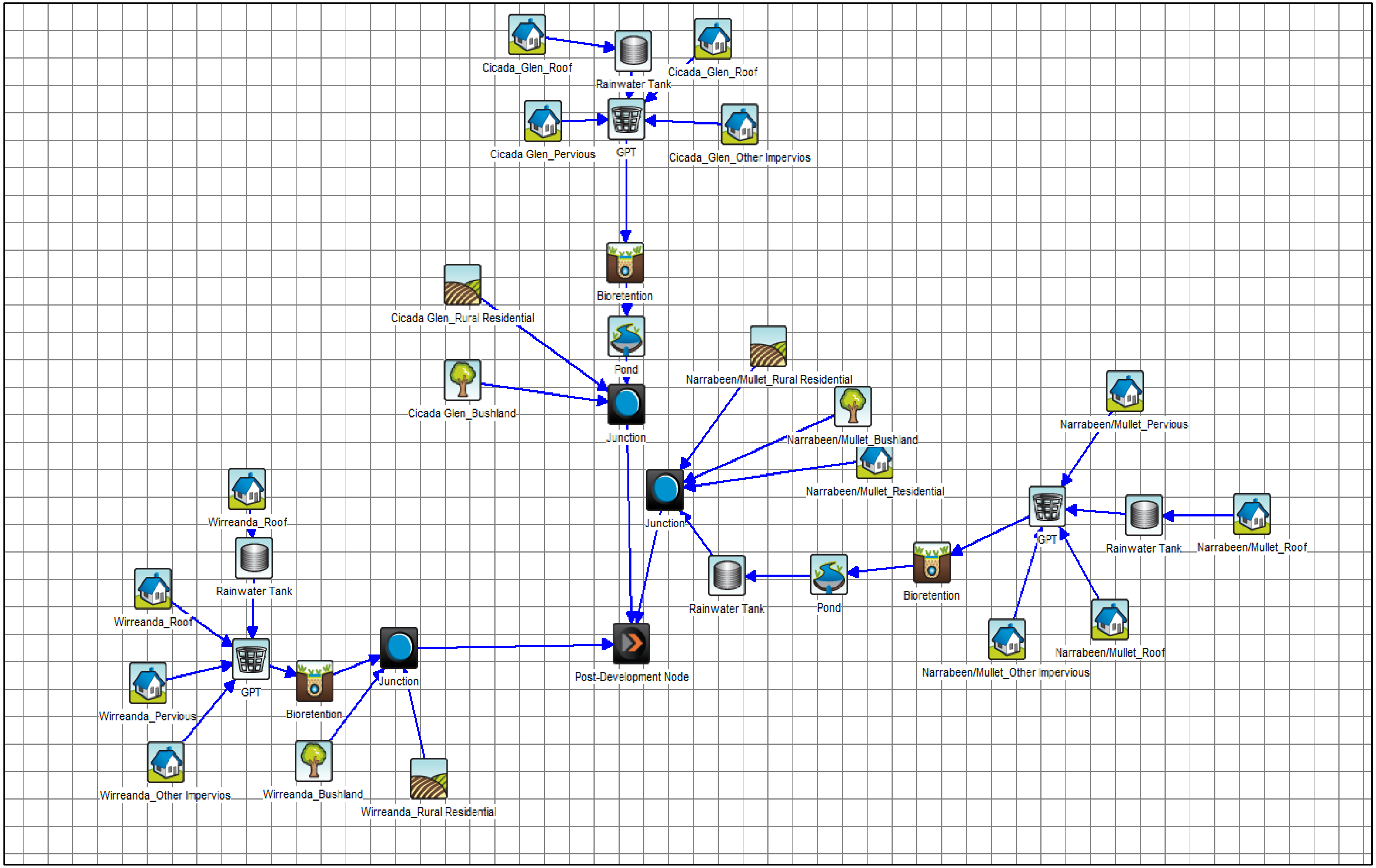


Figure 6-6 MUSIC Model – Mitigated Scenario

Table 6-5 MUSIC Model Water Quality Results

Waterway Catchment	Wirreanda Creek				Cicada Glen Creek				Narrabeen/Mullet Creek			
Pollutants	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	Gross Pollutants (kg/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	Gross Pollutants (kg/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	Gross Pollutants (kg/yr)
Source Load	5,070	8.56	63.6	645	183,000	312	2,340	0	234,000	395	2,950	29,000
Output	574	2.19	21.4	0	17,200	58.7	644	0	165,000	64.1	694	0
Reduction	89%	74%	66%	100%	91%	81%	72%	100%	93%	84%	76%	100%
Target	85%	65%	45%	90%	85%	65%	45%	90%	85%	65%	45%	90%

6.3.3.2 Water Quantity results

The mitigated scenario model was developed incorporating the treatment train as described above, with results compared against the existing scenario to determine the environmental and groundwater flows across the three catchments.

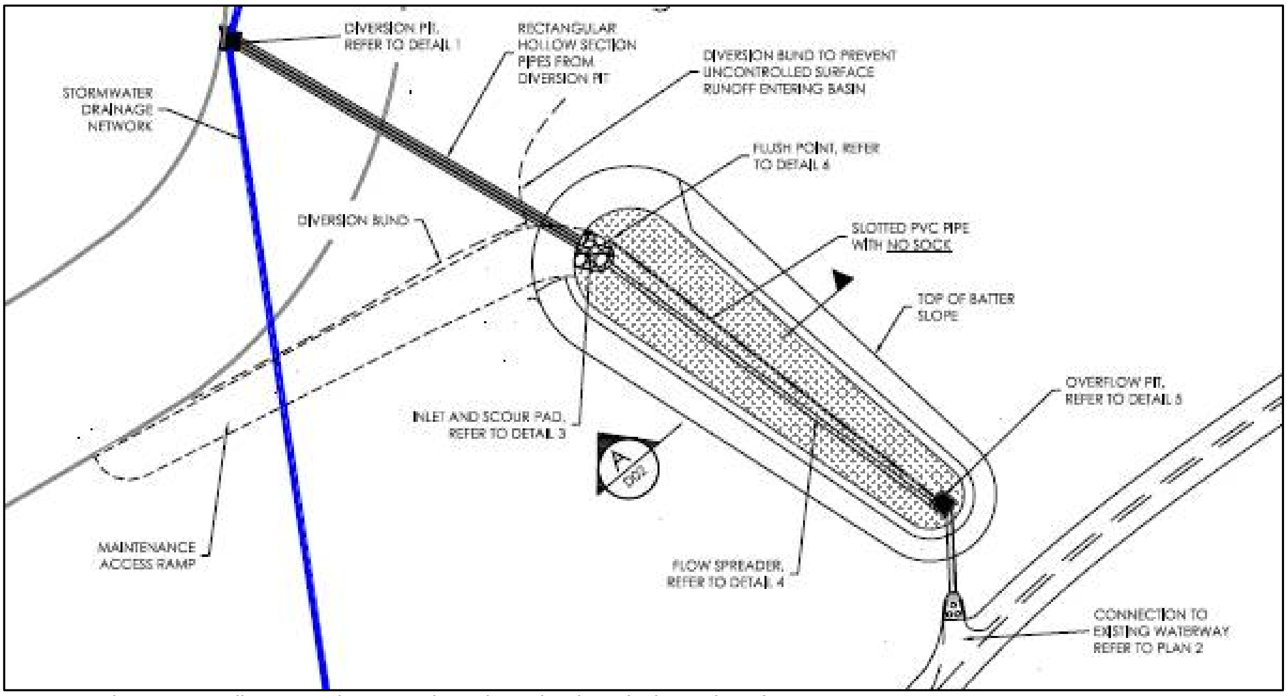
Results of the MUSIC analysis in **Table 6-6** indicate that, by including the nominated treatment train, the water quantity objectives set out in this water cycle management strategy are achieved for the Precinct.

Table 6-6 MUSIC Model Water Quantity Results

	Environmental Flows				Groundwater Flows			
Waterway Catchment	Existing Scenario	Mitigated Scenario	Difference	Target	Existing Scenario	Mitigated Scenario	Difference	Target
Wirreanda Creek	211	220	+4%	+/-5%	482	479	-1%	+/- 10%
Cicada Glen Creek/ Cahill Creek	632	660	+4%	+/-5%	555	606	+9%	+/- 10%
Narrabeen/ Mullet Creek	1,785	1,869	+5%	+/-5%	1,746	1,867	+7%	+/- 10%

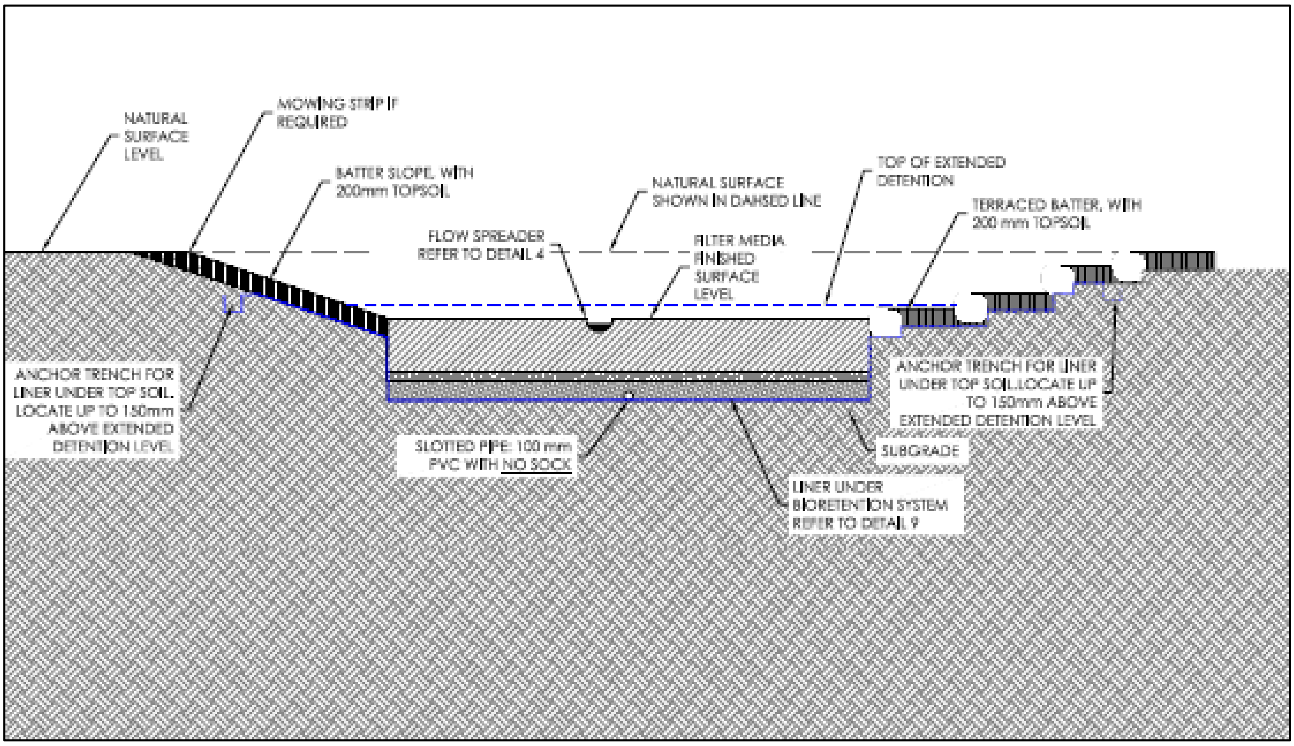
6.3.4 Concept Design and Sketches

Typical details for bioretention measures are outlined in **Figure 6-7** and **Figure 6-10**.



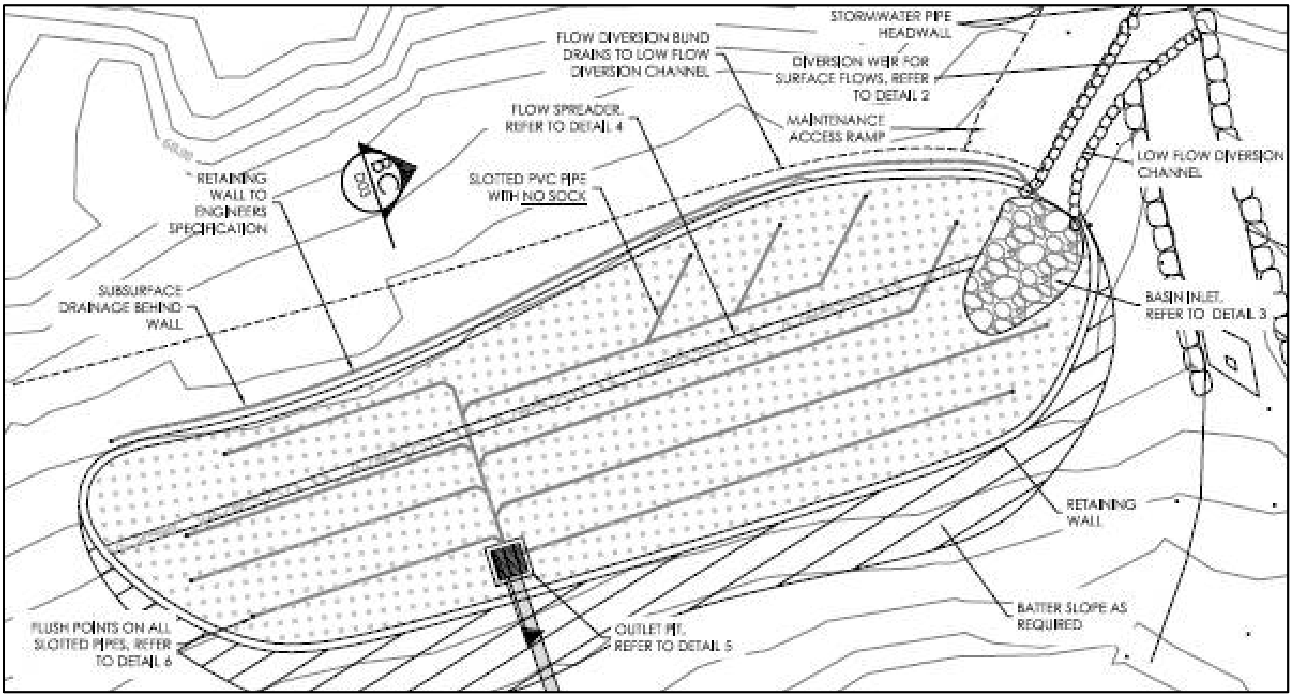
Source: Sydney Metropolitan CMA (now Local Land Services) Typical Drawings for WSUD

Figure 6-7 Typical Bioretention Layout – Flat Terrain



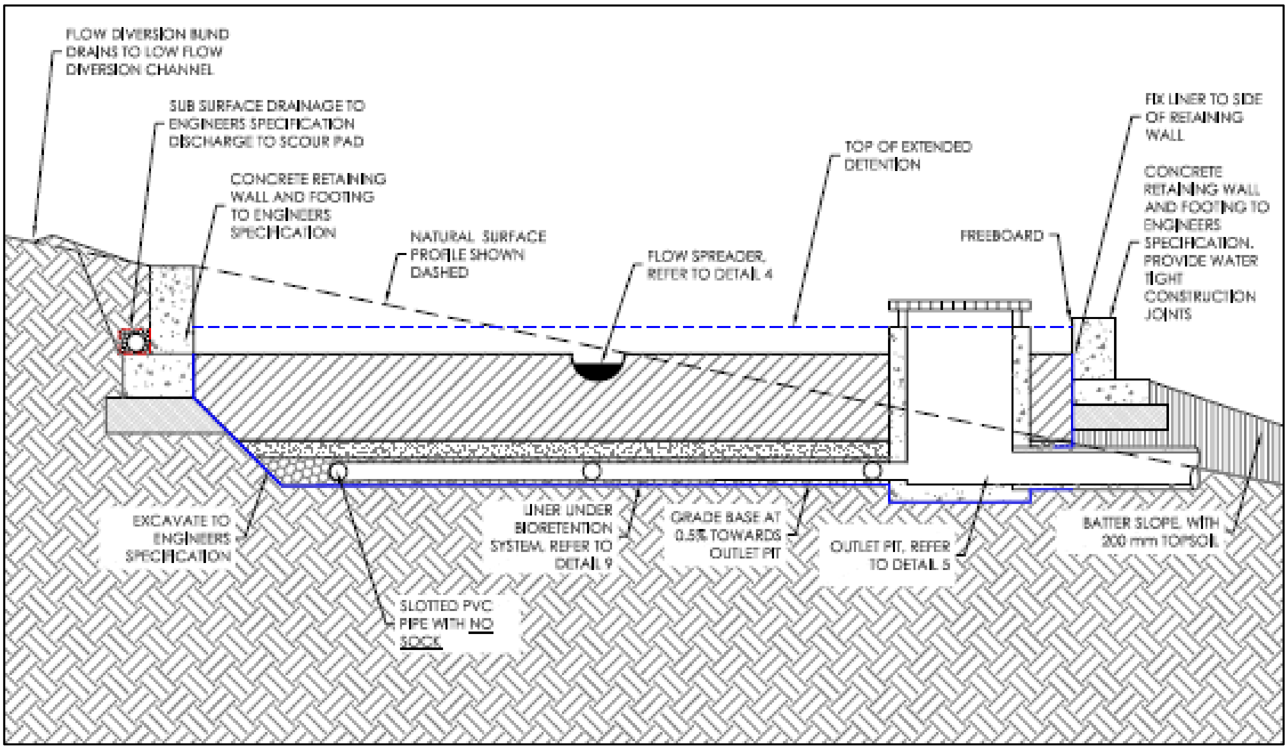
Source: Sydney Metropolitan CMA (now Local Land Services) Typical Drawings for WSUD

Figure 6-8 Typical Bioretention Detail – Flat Terrain



Source: Sydney Metropolitan CMA (now Local Land Services) Typical Drawings for WSUD

Figure 6-9 Typical Bioretention Layout – Steep Terrain



Source: Sydney Metropolitan CMA (now Local Land Services) Typical Drawings for WSUD

Figure 6-10 Typical Bioretention Detail – Steep Terrain

6.3.4.2 *Detention Basin Designs*

Concepts designs for the retarding basins with permanent water storage and bioretention will be undertaken following Exhibition of the Draft Ingleside Precinct Water Cycle Management and Flooding Assessment.

6.3.5 Operation and Maintenance

The operation of WSUD measures is reliant on periodic maintenance to ensure that elements of the measure are in good working order. WSUD measures comprise, for the most part, natural materials which can be quickly degraded by high volumes of stormwater. Stormwater can contain gross pollutants and sediment that can degrade elements such as filtration media, plants and drainage structures. In addition, stormwater can reach high velocities that can cause scour and erosion.

Gross Pollutant Traps (GPTs) need to be regularly maintained to remove captured pollutants. Often these devices are located underground and can become neglected if maintenance routines are not observed. Failure to maintain GPTs can exacerbate stormwater pollution by potentially releasing nutrients bound to sediments captured in GPTs.

In light of these issues it is recommended that the WSUD measures be included in the public domain so that they are visible to the public and are accepted as part of the landscape. Segregation of WSUD measures with fencing and dense peripheral vegetation can lead to the WSUD measure becoming isolated and neglected. Integration of the WSUD measures and the open spaces should promote regular maintenance to ensure that the amenity of the public open space.

The construction period of the Precinct is one of the main threats to fouling of WSUD measures if the construction is not staged in a way that will protect the measures. Release of sediments into stormwater during construction is common and although soil and water management controls are put in place, they are often neglected and fail during storms. The following recommendations are made to protect the measures from fouling during construction of the Precinct:

- Locate the WSUD measure off-line until the commissioning phase of the development. This will ensure that any stormwater generated during construction is routed around the WSUD measures;
- Delay landscaping of the WSUD measures to the final stages of construction to reduce the risk of surface degradations and plant loss; and
- Temporarily create a small inlet zone to retarding basins and bio-filters that will accept small amounts of local stormwater during construction. This will allow plants to establish in the greater area of the basin/filter without risk of fouling.

The typical design life of the WSUD measures post construction is highly dependent on the maintenance regime. If a maintenance regime such as that provided in **Table 6-7** is followed then the life of the WSUD elements will be maximised and a reliable level of pollution collection will be achieved. Note that an establishment period will be required to ensure that vegetation included in the WSUD measure is healthy and robust. A vegetation management plan should be provided with the detailed design of measures such as retarding basins and bio-filters that includes full details on the procurement and establishment of plants.

Table 6-7 WSUD maintenance schedule

WSUD Measure	Maintenance Action	Frequency	Waste Management	Responsible Party
Rainwater Tanks	Clean out first flush device of any sediment and debris build up	Quarterly or after each storm event of 10mm in rainfall depth or more	Dispose of in-organic material to waste disposal facility	Property Manager/ Owner
	Drain tank and clean sediment/organic matter and tank base	Bi-annually	Use organic material as mulch	Property Manager/ Owner
Gross Pollutant Trap (GPT)	Remove collected pollutants	Quarterly or after each storm event of 20mm in rainfall depth or more	Dispose of in-organic material to waste disposal facility	Council
	Check inlet and outlet structures for signs of blockage	Annually	Dispose of in-organic material to waste disposal facility	Council
	Replace filter mesh	Every 5 years	Nearest waste disposal facility	Council
Detention Basins	Remove collected pollutants on the surface	Quarterly or after each storm event of 20mm in rainfall depth or more	Dispose of in-organic material to waste disposal facility Use organic material as mulch	Council
	Check surfaces for any signs of erosion or displacement of surface treatments/ vegetation	Quarterly or after each storm event of 20mm in rainfall depth or more for the first 24 months and annually thereafter	No waste- collect dislodged materials and re-use	Council
	Replace damaged plants	Annually	Use organise material as mulch	Council
	Check integrity of basin inlet and outlet structures and replace scour protection where necessary	Annually or after each storm event of 100mm or more	Use organise material as mulch Replace rock where appropriate	Council
	Check integrity of basin walls and make appropriate structural repairs where necessary	Annually or after each storm event of 100mm or more	No waste- collect dislodged materials and re-use	Council

WSUD Measure	Maintenance Action	Frequency	Waste Management	Responsible Party
Swales/Bioretention	Remove pollutants collected on surface	Quarterly or after each storm event of 20mm in rainfall depth or more	Dispose of in-organic material to waste disposal facility Use organic material as mulch	Council
	Flush stand pipes of bio-filter	Half yearly or after each storm event of 20mm in rainfall depth or more	Collect materials flushed into stormwater pits and re-use mulch	Council
	Check surfaces for any signs of erosion or displacement of scour protection/soil/mulch	Quarterly or after each storm event of 20mm in rainfall depth or more for the first 24 months and annually thereafter	No waste- collect dislodged materials and re-use	Council
	Replace damaged plants	Annually	Use organic material as mulch	Council
	Replace filtration media	5 years	Dispose of in-organic material to waste disposal facility Use organic material as mulch	Council
Stormwater Harvesting	Clean out GPT device of any sediment and debris build up	Quarterly or after each storm event of 10mm in rainfall depth or more	Dispose of in-organic material to waste disposal facility	Council
	Drain tank and clean sediment/organic matter and tank base	Bi-annually	Use organic material as mulch	Council

This maintenance schedule should be used as a preliminary maintenance guide for the WSUD measures recommended.

7 Riparian Corridor and Biodiversity Assessment

An assessment of the riparian lands and biodiversity values within the Ingleside Precinct has been undertaken by Eco Logical Australia to identify constraints and opportunities within the Precinct.

Most watercourses within the Precinct have been impacted by exotic weeds and stormwater runoff, although within less disturbed sub-catchments some remain in near intact condition. Categorisation of each stream within the Precinct was undertaken using the Strahler stream order methodology as outlined by the DPI Water (Department of Primary Industries). The Strahler system is based on waterways being assigned an “order” according to the number of additional tributaries associated with each waterway. Numbering occurs from the top of the catchment with the smallest headwaters being assigned as 1st Order. Stream order number increases downstream through the catchment as same-order tributaries merge and form larger streams.

20 stream reaches were mapped. These comprised of five 2nd order and fifteen 1st order stream. The Strahler stream order categorisation for Ingleside precinct is provided in **Figure 7-1**.

DPI allows a range of activities/land uses within the outer edge of riparian corridors so long as they have minimal environmental harm. Detention basins, online and within the other 50% of the Vegetated Riparian Zone (VRZ) width, is permissible. The Vegetated Riparian Zone (VRZ) contains the areas formerly referred to as the core riparian zone (CRZ) and the vegetated buffer (VB).

The Draft Biodiversity Assessment Report (Eco Logical 2016) recommends a provision of vegetation buffer along the conservation areas to retain wildlife corridors and protect conservation areas. The riparian corridors will be contained within the wildlife corridors.

7.1 Concept sketches

WSUD measures are to be located external to the VRZ according to the requirements of the NOW. This ensures that the water quality management occurs outside of the riparian habitat areas and that the water being discharged to the waterway has been treated to best practice levels.

Some items that may be included to soften the basins and increase visual amenity include

- Naturalisation of the shape of the basin based on the topography and adjacent assets;
- Variable batter slopes, heights and alignments to give the basins a more natural appearance;
- Including a water feature e.g. a wetland or a pond in the base of the basin instead of a biofilter. This option may preclude other uses because the wetland or pond may occupy the full basin footprint; and
- Planting of native vegetation.

Concept designs for the detention basins and bio-filters will be provided following completion of the detention basin concept designs.

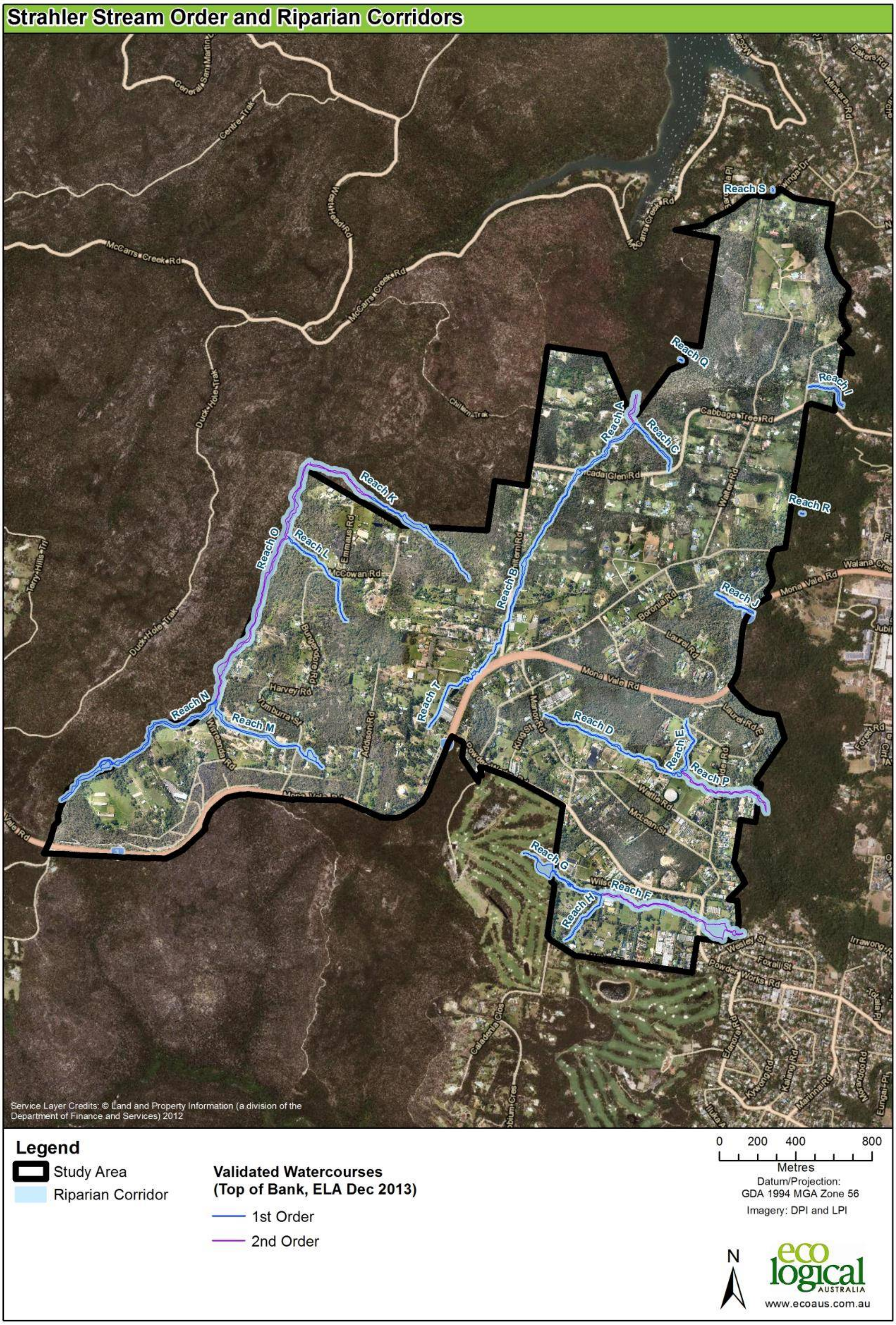


Figure 7-1 Strahler Stream Order and Corresponding Riparian Corridors (Eco Logical, 2016)

8 Water Quality Monitoring Program

The following water quality monitoring program has been prepared to establish the general framework for water quality monitoring within and downstream of the Ingleside Precinct for the purpose of managing any impacts associated with the proposed land development. It is recommended that this monitoring program be further refined through consultation with key stakeholders including Council.

8.1 Introduction

Degradation of surface water quality is a key risk associated with the development of the Ingleside Precinct. A water quality monitoring program is therefore required as a determinant of pre development conditions and to identify any development impacts.

This water quality monitoring program has been aligned with the monitoring program previously implemented to quantify and assess surface water impacts associated with the nearby Warriewood Valley land development, the details of which are presented within the Warriewood Valley Urban Land Release Water Management Specification ("the specification", Lawson and Treloar, 2001). This program draws upon both the strengths and the learnings of the Warriewood Valley water quality monitoring program, and has been tailored to suit the Ingleside catchment with its high sensitivity receiving environment (Ku-ring-gai Chase National Park).

8.2 Objectives

The objectives of the monitoring program are to establish a mechanism for the quantification of baseline water quality and creek ecosystem health within and downstream of the development precinct, and to establish the systems and processes that would be required to identify any deviations from these baseline conditions. Such deviations from baseline conditions would inform management decisions through early detection of any significant risk to the health of the waterway or the public from pollution and habitat change during and after the land development period.

Subsequent sections of this report detail the framework and methodology for the water quality program, including the:

- Monitoring locations;
- Monitoring frequency;
- Monitoring parameters;
- Trigger levels;
- Reporting mechanisms and timeframes; and
- Recommended corrective actions.

Consistent with AS/NZ5667: 1998 "Water Quality Sampling" (www.standards.com.au) and ANZECC (2000), the water quality monitoring program has been tailored to both the characteristics of the catchment, the creek system and prevailing climatic conditions.

8.3 Types of Monitoring

There are three types of monitoring proposed for this program:

- Water Quality Monitoring (discrete sampling);
- Sediment Toxicant Monitoring; and
- Biological Monitoring.

This combination of monitoring types is intended to provide a comprehensive and robust dataset with which to evaluate both short and long term impacts upon water quality and ecosystem health as follows:

- Water quality monitoring (discrete water quality sampling) will be undertaken to act as an early indicator of potential impacts or threats to ecosystem health through the collection of rapid and time series comparable results;
- Biological monitoring will be undertaken to directly measure the overall health of the ecosystem (using representative biological indicators); and
- Sediment toxicant monitoring will be undertaken given the important role sediment quality plays in freshwater and marine ecosystem health, and because many pollutants can be attached to sediments and given the potential for pollutants to flux between the stream bed and the water column.

8.4 Existing Data

A water quality dataset exists for the Warriewood Valley, which was collected in the course of the Warriewood Valley Urban Land Release.

This includes:

- Data collected as part of the Integrated Water Management Strategy (1997) which involved surface sampling at five sites to provide a limited baseline dataset;
- Dry weather and wet weather event monitoring via automatic samplers installed at the three water level recording sites i.e. Narrabeen Creek at Macpherson Street, Fern Creek at Garden Street and Mullet Creek at Garden Street since 1998; and
- Monthly campaign sampling of over 28 sites within the Valley for in-situ assessment of physico-chemical parameters since 2000.

Minimal data is available for creeks draining the western part of the Precinct; however some data has been collected through the monitoring undertaken by Laxton in 2002.

8.4.1 Baseline Monitoring

One round of baseline monitoring for the biological monitoring program was undertaken in spring 2014. This monitoring event involved sites on Wirreanda, Cicada Glen and McCarrs Creeks, and incorporated aquatic habitat descriptions, Macroinvertebrate monitoring and limited water quality monitoring (for physio-chemical parameters only).

The objectives, methodology and results of this baseline monitoring event are presented within the report titled *Ingleside Precinct Aquatic Macroinvertebrate Monitoring Spring 2014 Data Report*, Cardno 2014 provided in **Appendix D**. This baseline biological monitoring event is aligned with the methodology presented within this water quality monitoring program, and consistent with the recommendations of the baseline biological monitoring report, additional sites for ongoing monitoring have been identified on Mullet Creek.

8.5 Lessons Learned from Previous Programs

Review of the lessons learned from similar experiences in Warriewood (outlined in Section 2.2.2.3 of this report) suggest that the primary area for the improvement of the water quality monitoring program lies in the enforcement of monitoring rigour and the timely reporting of results and findings (‘Learning 1’) Additionally, concerns were raised around the degree to which risks posed by contaminated sites were incorporated into the previous monitoring programs (‘Learning 2’).

In response to these learnings, monitoring rigour and reporting timeframes have been tightened, specifically:

- Timeframes for the reporting of monitoring results to stakeholders (including Council) have been established;
- Timeframes for implementation of corrective actions have been established;
- Requirements around follow up monitoring to verify that corrective actions have been effective have been established;

- Requirements for self-reporting of conformance with minimum reporting timeframes have been set; and
- Provisions for regular audit and oversight have been made, to ensure conformance with the requirements of the program.

Additionally, a review of the "List of NSW Contaminated Sites Notified to the EPA" would be carried out prior to the finalisation of the parameters that would be monitored. Relevant reports associated with site contamination would be obtained and reviewed; these used to inform the list of monitoring parameters (where such sites exist in close proximity to monitoring locations).

8.6 The Receiving Environment and Monitoring Sites

The precinct incorporates a number of surface drainage lines, the largest of which are Wirreanda Creek and Cicada Glen Creek, both of which flow north into McCarrs Creek and ultimately into Pittwater. The third of the major drainage lines, Mullet Creek, flows east into the Warriewood Wetlands and from there into Narrabeen Lagoon.

Monitoring sites would be common to all three types of monitoring, and would be established within the major creeks that may be impacted by works in the precinct (Wirreanda, Cicada Glen and Mullet Creeks). All monitoring locations are to be situated in the creek channel to obtain samples and measurements representative of the main body of the creek.

Monitoring sites would be established with the aim of characterising water quality (a) upstream or in the upper reaches of the development precinct, (b) within or immediately downstream of the development precinct (impact area), and (c) downstream of the development precinct though upstream to the creek's discharge point or the confluence of major tributaries. Reference monitoring sites would be established at a comparable elevation in the landscape upon a morphologically similar creek situated in an undisturbed location (e.g. within Ku-ring-gai Chase National Park).

The Ingleside development precinct is situated on the crest of a hill; the headwaters of Wirreanda, Cicada Glen and Mullet Creeks are consequently situated either completely or largely within the precinct. As a result it is noted that upstream monitoring locations would be unlikely to serve as true reference monitoring locations. Data obtained from such upstream sites would nevertheless provide a useful tool for comparison with downstream sites.

Monitoring sites would be selected according to the following criteria:

- Safe access to the site;
- Avoiding upstream point sources of pollution (or the ability to simultaneously monitor the point source and the upstream location);
- Ensure generally well mixed flow conditions, so that the water quality sample is representative of the conditions at the monitoring site;
- Avoid the presence of physical structures that may influence water quality, such as weirs;
- Power supply for event monitoring equipment (where necessary), and
- Compatibility with the existing monitoring activities undertaken by Council.

Subject to approval from the land or asset owner, all monitoring sites would be established with the necessary signage to provide a permanent identification of the sampling location for the purpose of longer term repeatability and consistency.

The sites on Wirreanda, Cicada Glen and McCarrs Creeks were sampled in the course of the first baseline biological sampling event. It is proposed that sites on Mullet Creek would be incorporated into this monitoring program for future monitoring events.

8.6.1 Site Designation

It is proposed that nine monitoring sites would be established in and around the Precinct. Two impact sites would be located on Wirreanda Creek, two impacts sites on Cicada Glen Creek, three impact sites on Mullet

Creek and two sites would be located upstream of the confluence of Wirreanda Creek and McCarrs Creek, which would act as upstream reference sites for the monitoring program as shown in **Figure 8-1**. The incorporation of reference creeks would allow for a comparative framework from which the monitoring program can validly assess any impacts as a result of the Project. The location of the sites selected would aid in the investigation of impacts not only within the precinct area itself, but also downstream outside of the project site. The exact location and the suitability of each site to the monitoring program would be determined during the first day of the field investigations.

8.7 Monitoring Methodology

8.7.1 Water and Sediment Quality

Water quality monitoring (discrete sampling) and sediment toxicant monitoring would follow established industry practice, and may utilise auto-samplers and high-level sampling apparatus as required, provided samples are able to be collected and analysed within the laboratory specified holding times.

Visual assessment for litter and foreign objects would be undertaken by walking along both the left and right banks of the creek, and counting the number of visible pieces of litter (e.g. 50mm in size and above) within a 20 linear metre stretch of creek bank. The litter transect would be clearly demarcated or marked on relevant plans.

The specific monitoring methodology for the water quality and sediment monitoring programs should be confirmed following consultation with key stakeholders, such that consistency with existing programs can be achieved. The methodology chosen shall follow industry standard practice and would be demonstrably robust.

The monitoring approach proposed for the biological monitoring program is detailed in subsequent sub-sections. In the event monitoring locations or monitoring dates for the water quality monitoring program diverge from those sites or dates in which the biological monitoring is conducted, physio-chemical parameters would be measured in the course of the biological monitoring program, to inform the assessment of aquatic ecosystem health.

8.7.2 Aquatic Habitat Assessment

At each site, environmental parameters would be recorded, including water quality, in-stream and riparian vegetation and morphological features. Habitat assessments would be done before biota are sampled to ensure they are representative of average site conditions. Photographs would also be taken to show the aquatic habitats present at each site. Photographs taken in subsequent events would be taken from the same location.

At each site, the cover of any submerged and emergent aquatic plants would be assessed. Species would be identified in the field using handbooks, such as *Waterplants of Australia* by Sainty and Jacobs (2003). Species that cannot be identified in the field would be retained for identification in the office/laboratory.

Consistent with the baseline monitoring event (Cardno, 2014), the characteristics of the riparian zone such as its width, nature of vegetation (native, exotic, mixture), structure and completeness of vegetation (whether or not it overhangs the bank of the waterway) would be assessed, as would the distribution of snags within the creek.

Morphological features that would be assessed include substratum, channel length, width-depth ratio, bank stability and composition, silt cover, erosional / depositional features such as gravel bars, cross-section shape and plan shape features, such as pools, riffles and runs.

A standardised description of adjacent land and condition of riverbanks, channel and bed would then be recorded using a modified version of the Riparian, Channel and Environmental Inventory (RCE) modified for Australian conditions by Chessman et al. (1997). These parameters have been assessed during the baseline monitoring event; subsequent events would seek to identify changes to these features.

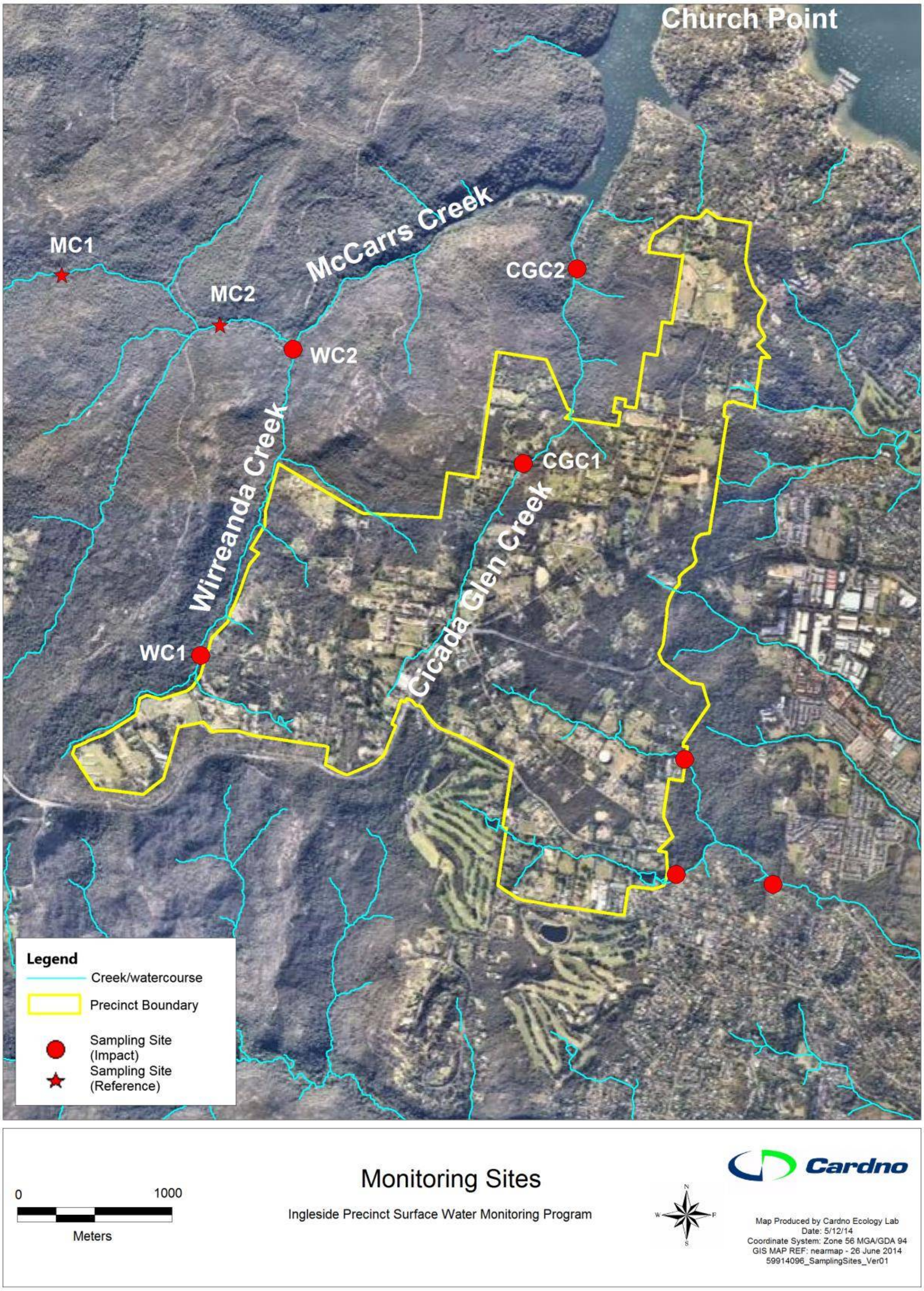


Figure 8-1 Proposed Indicative Water Quality and Sediment Monitoring Locations

8.7.3 Macroinvertebrate Sampling (AUSRIVAS)

At each site, the AUSRIVAS rapid assessment methodology will be used to characterise assemblages of macroinvertebrates associated with "edge" and "riffle" habitats as appropriate to available habitats. Sampling will be done in accordance with the AUSRIVAS protocol, using habitat definitions listed in that documentation (http:ausrivas.canberra.edu.au).

Animals would be removed from samples, identified to species level and the frequency of each species recorded in accordance with the methodology specified in the AUSRIVAS manual. Emphasis would be placed on obtaining the maximum species diversity by searching for small or cryptic species, in addition to collecting colourful or mobile species, and collecting no more than ten individuals of very abundant taxa.

The statistical analyses proposed falls into the following categories:

- General findings (number of individuals, number of species, dominant taxa comments on distribution of macroinvertebrates compared to those published in the scientific literature);
- Computation of AUSRIVAS indices (e.g. observed vs. expected number of taxa, SIGNAL scores and impairment bands); and
- Multivariate and univariate analyses of selected variables or sets of variables to examine spatial variability in macroinvertebrate assemblages during the baseline phase of the monitoring program.

8.8 Monitoring Period and Frequency

Water quality, sediment toxicant and biological monitoring would be carried out in the following project stages:

- Pre-construction (baseline monitoring);
- Construction Phase; and
- Post-Construction Phase.

Water quality monitoring is to be undertaken under both dry weather (low flow) and wet weather (high flow) conditions; other types of monitoring would not generally timed to coincide with particular flow conditions. Each monitoring event would incorporate the monitoring of all sites specified in **Section 8.6.1** and all standard monitoring parameters.

Indicative minimum monitoring frequencies proposed for the program are presented in **Table 8-1.**

Table 8-1 Monitoring Frequency

Type of Monitoring	Pre-Construction	Construction	Post Construction
Water Quality Monitoring (Low Flow)	10 or more events (carried out where possible ≥ one month apart)	Monthly	Quarterly
Water Quality Monitoring (High Flow)	Six or more events (carried out where possible ≥ one month apart)	Monthly	Quarterly
Sediment Toxicant Monitoring	Four or more events carried out (carried out where possible ≥ one month apart).	Quarterly	Annually
Biological Monitoring	One baseline monitoring event	Immediately following construction	Annually

For the pre-construction (baseline) monitoring period the frequencies outlined in **Table 8-1** are the minimum that would be required to obtain a robust dataset. In the pose-construction phase monitoring period, monitoring would be conducted for a period of time sufficient to quantify post-construction phase impacts of the development on water quality.

Indicative dry and wet sampling scenarios are:

- Wet weather (higher flow) monitoring would be carried out within 24 hours following a precipitation event exceeding 20 mm in 24 hours (as measured either on-site or at Terry Hills). It is noted that due to the location of the site (at the top of the catchment) sampling may not be possible when the flow is still "high"; and
- Dry weather (lower flow) monitoring would be carried out no sooner than seven days following a rainfall event exceeding 20 mm within 24 hours, and would be carried out no sooner than three days following rainfall exceeding 5mm in 24 hours. The term 'dry weather' does not preclude some rain in the catchment prior to sampling.

8.9 Responsibility

It is the intent of this monitoring program, that baseline, construction phase and post construction phase monitoring be undertaken by the land developer, under the oversight of Council. A three year post construction monitoring period is likely to be suitable for assessing the impacts of the development. Following this period, the monitoring program may be continued by Council or their delegates upon the discretion of Council.

Monitoring should be undertaken by appropriately trained, qualified and experienced persons.

8.10 Monitoring Parameters and Trigger Levels

A suite of monitoring parameters (**Table 8-2**) has been established for the program, which include commonly encountered surface water pollutants typically associated with the construction and post construction phases of land development projects. This represents the minimum suite of parameters, and the suite may be expanded as required where other potential pollutants are identified.

Consistent with ANZECC (2000), Cardno recommends local trigger levels be utilised in preference to default trigger levels derived from broader scale published guidelines. This is particularly the case for physio-chemical parameters, which often vary significantly from creek to creek as a result of differences in morphology, geology and location within the landscape. Published trigger levels for toxicants on the other hand, are generally robust enough to protect ecosystem health from chemical pollutants. It is envisaged that the land developer or their delegates would prepare SSTL, following completion of the baseline monitoring. Council would review the methodology and results used to derive the trigger levels, and confirm the acceptability of the SSTL's pior ti the commencement of construction.

Cardno acknowledge however the challenges involved in obtaining a sufficiently large and temporally representative baseline dataset for the purpose of developing site specific trigger levels. Consequently we propose that a local trigger level is developed for physio-chemical parameters and litter and the default trigger values are adopted from ANZECC (2000) for chemical pollutants and sediment contaminants, specifically *Trigger Levels for Toxicants (Table 3.4.1 of ANZECC, 2000) and Sediment Quality Guidelines (Table 3.5.1 of ANZECC, 2000).*

For physical parameters, triggers would be developed for each parameter at each monitoring location and a separate trigger level would be established for low and high flow conditions. Where comparable data exists from other monitoring programs (e.g.. data collected in McCarrs Creek by Laxton, 2002 and data collected by Pittwater Council within the Warriewood Valley), this may be used to inform the derivation of local trigger levels.

The procedure for applying the trigger levels is detailed in **Section 8.11**.

Table 8-2 Monitoring Parameters and Trigger Levels

Type of Monitoring	Parameters	Trigger Level
	Physio-chemical:	Local trigger levels would be developed using sufficient baseline data and statistically

Type of Monitoring	Parameters	Trigger Level
	• pH; • Temperature (°C); • Electrical Conductivity (EC); • Dissolved Oxygen (DO, as mg/L and % saturation); • Oxidation reduction potential (mV); and • Turbidity (NTU). *Other:* • Litter and foreign objects.	valid methods, having consideration for seasonal and temporal variations in the water physio-chemistry. Suitable methods may include: • The mean + y SD of the baseline data – (for normally distributed datasets, where y SD approximates the range of baseline data); • The relative difference between the mean of the baseline dataset (impact creek) and the discrete monitoring result from the impact creek with respect to the mean of the baseline dataset (analogue creek) and the discrete monitoring result from the analogue creek.
Water Quality Monitoring (Low Flow)	*Chemical:* • Major anions and cations; • 15 metals (see notes); • Total Recoverable Hydrocarbons (TRH); • Oil and Grease; • Methylene Blue Active Substances (MBAS – screening analyte for surfactants); • Total Phosphorous (TP); • Filterable Reactive Phosphorous (FRP); • Total Nitrogen (TN); • NOX as N; • Ammonia as N; and • Nitrate.	The default trigger levels published in: • ANZECC (2000) Trigger Levels for Toxicants (fresh water - 99% protection level for northward flowing creeks and 95% protection level for eastward flowing creeks). **Note:** • Trigger levels would not be prepared for anions and cations; • A detection of TRH, oil / grease or MBAS constitutes an exceedance of the trigger level and would be considered cause for further investigation.
Water Quality Monitoring (High Flow)	*Physio-chemical:* • pH; • Electrical Conductivity (EC); • Dissolved Oxygen (DO); • Turbidity. • *Chemical:* • Major anions and cations; • 15 metals (see notes);	Refer to the low-flow trigger levels (above).

Type of Monitoring	Parameters	Trigger Level
	• Total Recoverable Hydrocarbons (TRH); • Oil and Grease; • Methylene Blue Active Substances (MBAS – screening analyte for surfactants); • Total Phosphorous (TP); • Filterable Reactive Phosphorous (FRP); • Total Nitrogen (TN); • NOX as N; • Ammonia as N; and • Nitrate.	
Sediment Toxicant Monitoring	• 15 metals (see notes); • Total Recoverable Hydrocarbons (TRH); • Oil and Grease; • Total Phosphorous (TP); • Total Nitrogen (TN).	Refer to the low-flow trigger levels (above). **Note:** A detection of TRH or oil / grease constitutes an exceedance of the trigger level and would be cause for further investigation.
Biological Monitoring	• Aquatic Habitat Assessment; • Water quality; • Macroinvertebrate sampling and assessment.	AUSRIVAS indices would be calculated (e.g. observed vs. expected number of taxa, SIGNAL scores and impairment bands.

Note: 15 Metals refers to the heavy metals of the NEPM suite (As, B, Ba, Be, Cd, Cr, Co, Cu, Mn, Ni, Pb, Se, V, Zn, Hg).

Metals are to be reported in the form of total metals.

8.11 Acceptance Criteria and Corrective Actions

Compliance will be assessed based on an absolute compliance with the trigger values adopted.

In the event of a trigger level exceedance, a corrective action should be initiated. The process for initiating and undertaking corrective actions is depicted below in **Figure 8-2**.

Step 1

Review the exceedance with respect to potential causative factors, baseline data, and data from analogue sites.

Step 1

Review the exceedance with respect to potential causative factors, baseline data, and data from analogue sites.

Step 2

Within 24 hours:

a) Inform key stakeholders including Council;

b) Undertake a preliminary investigation of potential pollutant sources; and

c) Rectify pollutant sources as necessary.

Step 3

Within 48 hours:

Undertake a follow-up round of monitoring.

“Have pollutant concentrations returned to below the trigger level? No

Yes

Step 4

Close out the incident, and provide documentary evidence that water quality has returned to satisfactory levels and sufficient controls have been put in place to reduce the severity and / or frequency of future incidents of this type.

Figure 8-2 Corrective Action Process

The following define the proposed timeframes for key actions (construction phase only):

- Lodging an environmental incident within the project’s EHS system – 24 hours;
- Rectification and close out of environmental incidents – 14 days;
- Source rectification for identified sediment export beyond precinct boundaries, hydrocarbon / chemical releases to surface water – immediate rectification and clean up;

- Reporting of environmental incidents (including trigger level exceedances) to stakeholders (including Council) – 24 hours;
- Reporting of monitoring results – 30 days;
- Follow up monitoring to verify that corrective actions have been effective – 48 hours following an incident.

8.12 Quality Assurance / Quality Control

Measurement accuracy is critical in determining possible impacts from the development process, and attention to the design and implementation of the monitoring plan will assist in resolving any uncertainties. The accuracy of the measurements using in-situ probes or laboratory detection limits are to be clearly stated wherever the data is reported.

Table 8-3 provides details of the minimum QA/QC requirements to be implemented in the course of the monitoring program.

Table 8-3 QA/QC Requirements

Type of Monitoring	QA/QC Requirements
Water Quality Monitoring (low and high flow), Sediment Toxicant Monitoring	• Equipment calibration; • Equipment decontamination; • Sample and measurement logging using standardised forms; • Use of standardised procedures and systems; • All samples to be collected and transported to the analytical laboratory under a Chain of Custody (CoC) system and within an insulated receptacle containing cooling media; • Use of correct sample receptacles and adherence to laboratory holding times; • Laboratories used for this monitoring program must be NATA accredited for the analyses carried out; and • Collection of field duplicate (blind replicate) and field triplicate samples at a frequency of one per 20 primary samples.
Biological Monitoring	As per AUSRIVAS manual.

8.13 Occupational Health and Safety

Consistent with the Work Health and Safety Act (2011), the risks associated with fieldwork must be identified and controlled to an acceptable level prior to the commencement of the monitoring program.

Key hazards associated with fieldworks for the program include but may not be limited to:

- Remote area work and communications;
- Driving hazards;
- Slips, trips and falls;
- Bites and stings from venomous animals;
- Work near or over water;
- Dermal contact with contaminated water, field or laboratory chemicals; and
- Bushfires.

8.14 Audit and Oversight

An audit schedule would be prepared for the detailed water quality monitoring program in consultation with key stakeholders including Council and the Environmental Management Representative (where applicable).

8.15 Reporting

The timely reporting of monitoring results is a key component of this monitoring program, and it is an element from previous monitoring programs where opportunities for improvement were identified.

Reporting requirements for the monitoring program are summarised in **Table 8-4**.

Table 8-4 Reporting Requirements

Type of Monitoring	Reporting Frequency
Pre-construction (baseline)	Baseline monitoring results would be compiled and presented within a baseline monitoring report.
Construction Phase	Reporting of incidents (includes trigger level exceedances) to key stakeholders including Council within 24 hours of receipt of data; Water quality results to be reported to stakeholders on a monthly basis in the Environmental Compliance Reports.
Post-Construction Phase	Data to be presented within bi-annual water quality reports.

All reports shall include the following information:

- The objectives of the monitoring program;
- Any limitations encountered;
- A map indicating the location of the monitoring sites;
- A summary of precipitation received in the month;
- A summary of the sampling techniques;
- A summary of the analytical techniques, including detection limits;
- QA/QC procedures undertaken;
- Monitoring results, discussion and conclusions;
- The details of any trigger level exceedances and corresponding corrective actions undertaken (construction and post construction phases);
- The results of any monitoring undertaken to verify the effectiveness of controls implemented (construction and post construction phases); and
- Any recommendations that may be required to refine the monitoring program or improve local water quality.

9 Conclusions

This Water Cycle Management Strategy has been prepared to inform the Precinct Planning process and support the rezoning process for the Ingleside Precinct. It presents guiding principles for WCM across the precinct and preliminary management measures. This includes conceptual sizes and locations for elements of the stormwater management network, including detention and water quality treatment infrastructure, and maintenance requirements in determining the best water cycle management option. Indicative layouts of basins and bioretention systems have been provided. This will be subject to more detailed assessment during the design phase based on detailed site survey, detailed geotechnical and soil investigations, and also when the final development plan for the sub-catchments is finalised.

In summary the methodology that was adopted in this study is as follows:

- Sizing of detention basins using XP-RAFTS modelling to match pre-development and post development with mitigation hydrographs;
- Demonstrating that the basin designs from XP-RAFTS modelling deliver the required performance through hydraulic modelling using TUFLOW; and
- Sizing treatment measures using MUSIC such that they meet the water quality and quantity objectives. This includes:
  - Rainwater harvesting will be provided for all residential and commercial/retail areas;
  - GPT units will be provided upstream of bioretention basins, detention basins/retention ponds and stormwater harvesting system. Additionally, it was assumed that GPTS will be located at all other outflows into the waterways;
  - Bioretention systems will be placed upstream of online detention basins and will be located outside of the 100 year ARI event. Where offline basins are used, bioretention systems will be placed in the floor of the basin. They will also be placed in areas not draining to regional retarding basins;
  - Detention basins provided for flood mitigation will include a permanent water storage component; and
  - Stormwater harvesting for re-use in irrigation of sports field.

This has helped achieve the detention, water quality, environmental flow and groundwater flow targets.

Ingleside Precinct
Water Cycle
Management and
Flooding Assessment

APPENDIX A

APPENDIX

A

HYDROLOGY

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A. Hydrology

A.1 The Hydrological Model Parameters

A number of parameters are required in the development of the RAFTS model. The important parameters include initial and continuing rainfall loss rate, and Manning roughness. The parameters adopted in the XP_RAFTS model are listed in **Table A-1**

Table A-1 Parameters adopted in the XP-RAFTS model

Land Zone	Initial Loss (mm)	Continuing Loss (mm/hr)	Hydraulic Roughness
Impervious Area	1.5	0	0.015
Pervious Area	10	2.5	0.035

The following justification is offered for the selection of the above parameters:

- They are consistent with the most recent Flood Study undertaken in the vicinity (Narrabeen Lagoon Flood Study, 2013);
- They are consistent with recommendations of AR&R;
- They are cognisant of studies undertaken in the upper parts of a catchment where flash flooding scenarios would be expected. For these scenarios shorter duration storms are more critical and the adoption of higher initial losses can lead to an underestimation of discharge and related flood levels; and
- Antecedent moisture conditions are variable and in cases where a flood may be preceded by a sustained period of rainfall the higher losses are not realistic and could lead to an underestimation of discharge and flood levels.

A.2 Current modelling approach

A.2.1 <u>Design Storm Bursts</u>

Design rainfall depths and temporal patterns were developed using standard techniques provided in AR&R (1999). IFD parameters obtained from the Bureau of Meteorology for the centre of the catchment are presented in **Table A-2**.

Table A-2 Design IFD Parameters for Ingleside Precinct

Parameter	Value
2 Year ARI 1 hour Intensity	40.33 mm/h
2 Year ARI 12 hour Intensity	9.19 mm/h
2 Year ARI 72 hour Intensity	2.73 mm/h
50 Year ARI 1 hour Intensity	83.99 mm/h
50 Year ARI 12 hour Intensity	18.05 mm/h
50 Year ARI 72 hour Intensity	5.82 mm/h
Skew	0

Parameter	Value
F_2	4.3
F_{50}	15.88
Temporal Pattern Zone	1

The synthetic design storms were assumed to be uniformly distributed across the catchments. Considering the size of the study catchments an aerial reduction factor was not applied.

Table A-3 Design Rainfall Intensities (mm/hr)

Time	Return Period (years)				
mins	2	20	100	200	500
45	47.343	82.220	108.71	120.42	136.29
60	40.33	70.841	94.108	104.42	118.43
90	31.883	55.586	73.616	81.587	92.412
120	26.893	46.634	61.621	68.238	77.215
180	21.099	36.307	47.823	52.896	59.770

The Probable Maximum Precipitation (PMP) was estimated using the publication "The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method" (Commonwealth Bureau of Meteorology, 2003). PMP parameters shown in **Table A-4** were estimated based on the ellipse distribution shown in **Figure A-1**. A weighted average intensity was calculated as shown in **Table A-5** and applied to the model.

Table A-4 PMP Calculation Values

Parameter					
PMP Ellipse	Area Enclosed	Area Between	Moisture Adjustment Factor	Elevation Adjustment Factor	Percentage Rough
A	2.613	2.613	0.72	1	100
B	10.84	8.227	0.72	1	100
C	12.34	1.5	0.72	1	100

Table A-5 PMP Rainfall Intensities (mm/hr)

Duration					
15 min	30 min	45 min	1 h	1.5 h	2 h
600.00	440.00	360.00	320.00	273.33	240.00

A.2.2 Catchment discretisation

The catchment was delineated into 64 sub-catchments. This was undertaken using the 2m contours provided by Pittwater Council. The sub-catchment delineation provides for generation of flow hydrographs at key confluence or inflow points to the hydraulic model.

A.2.3 Imperviousness

The area of impervious and pervious surfaces within each subcatchment under Existing Conditions was based on the Nearmap aerial photography of the precinct.

A.2.4 Vector Average Slope

The vector average slope for each subcatchment was determined through interrogation of the model DTM where a line was drawn between the high point and the low point of each sub-catchment to calculate slope.

A.2.5 Surface Roughness

For each subcatchment, a surface roughness was entered for each surface type. The adopted surface roughness values were 0.015 for impervious surfaces and 0.035 for pervious area.

A.2.6 Hydrograph Routing

Simple lagging of hydrographs was adopted for the drainage lines. The time of travel (or lag) for each reach (link) was calculated as the length of the reach divided by an average velocity of flow of 0.9 m/s. The 0.09m/s velocity was adopted from Book 4, Australian Rainfall & Runoff (1998).

A.2.7 BX Value (Global Storage Factor)

The value of BX equal to 1 was adopted to be consistent with Narrabeen Lagoon Flood Study (BMT WBM 2013).

Table A-6 summarises the key catchment parameters adopted in the XP-RAFTS model, including catchment area, impervious percentage and vectored estimated from the available topographic information and aerial photography. Subcatchment boundaries and node locations are provided in **Figure A-2**.

Table A-6 XP-Rafts Subcatchment properties

Id	Area (ha)	Impervious Area (%)	Slope (%)
C1	6.06	5%	2.05
C10	13.69	5%	8.20
C11	11.69	1%	9.94
C12	17.51	1%	16.52
C2	15.53	5%	2.67
C3	12.28	20%	4.03
C4	24.20	5%	4.93
C5	13.43	5%	5.25
C6	17.15	5%	7.80
C7	15.01	5%	7.30
C8	9.77	2%	7.62

Id	Area (ha)	Impervious Area (%)	Slope (%)
C9	19.42	2%	11.96
E1	11.90	1%	14.38
E2	15.64	1%	10.00
E3	17.61	1%	8.01
E4	20.10	1%	13.14
E5	16.82	1%	13.06
E6	13.30	1%	15.10
F1	3.95	1%	15.85
M1	16.71	15%	5.96
M10	13.48	20%	3.79
M11	10.11	2%	5.85
M12	11.18	5%	6.87
M13	21.05	10%	3.66
M14	13.55	10%	4.51
M15	13.11	30%	6.06
M16	20.69	10%	11.39
M17	22.28	2%	5.51
M18	21.20	40%	9.42
M2	19.29	10%	7.24
M3	14.26	12%	10.64
M4	10.57	2%	7.81
M5	10.78	1%	9.96
M5-1	12.19	10%	5.23
M5-2	9.26	5%	4.67
M6	15.94	3%	5.86
M6-1	17.09	2%	7.94
M7	16.57	2%	7.27

Id	Area (ha)	Impervious Area (%)	Slope (%)
M8	17.36	10%	4.67
M9	8.10	18%	6.99
N1	4.56	1%	14.94
N2	23.36	2%	7.88
N3	17.49	10%	6.01
U1	21.86	5%	7.59
U2	18.06	5%	7.39
U3	20.41	5%	9.25
U4	2.60	1%	13.58
U5	2.89	1%	13.58
U6	16.10	5%	4.32
U7	15.25	5%	8.14
U8	1.76	5%	15.08
W1	14.64	2%	9.67
W10	12.36	2%	6.78
W10-1	10.29	2%	7.53
W11	17.12	1%	10.94
W12	13.75	1%	15.69
W2	18.38	2%	6.54
W3	22.80	2%	9.60
W4	24.07	2%	6.49
W5	14.11	2%	7.34
W6	15.91	2%	9.34
W7	25.65	2%	10.40
W8	14.47	1%	7.94
W9	17.07	2%	8.83

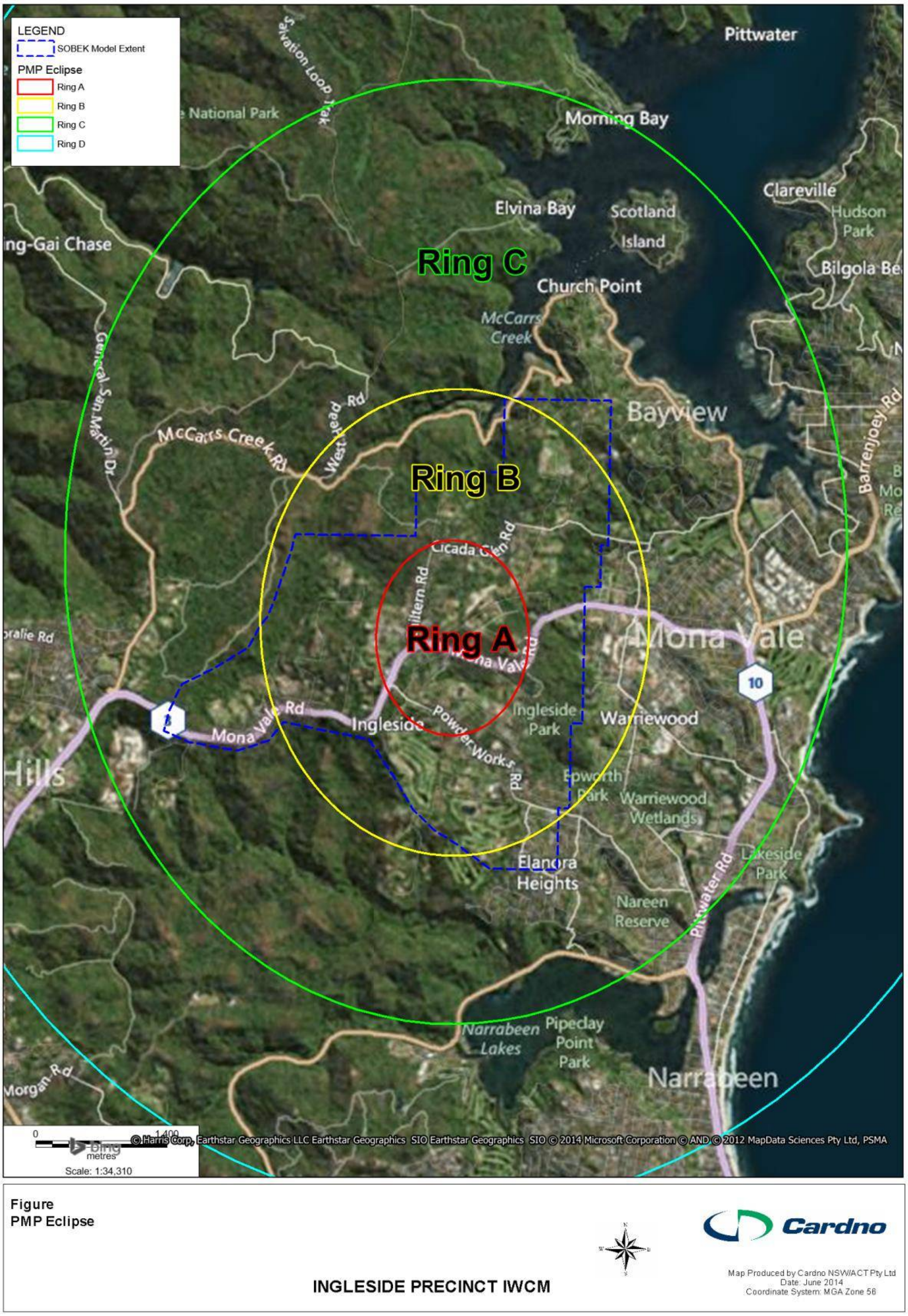

Figure A-1 PMP Spatial Distribution Eclipse

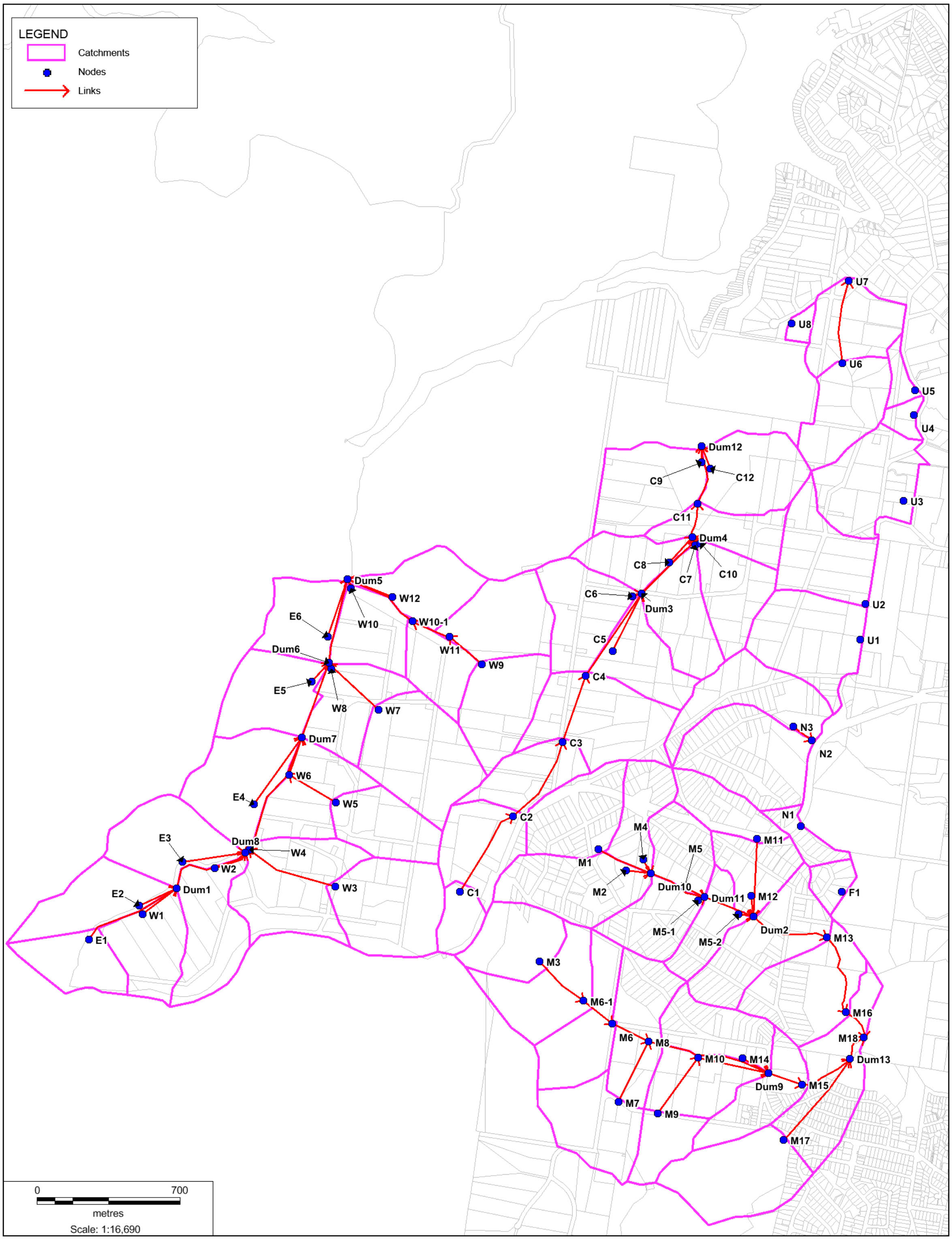

Figure
Sub-Catchments Node Location

INGLESIDE PRECINCT IWCM

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Map Produced by Cardno NSW/ACT Pty Ltd
Date: June 2014
Coordinate System: MGA Zone 56

Figure A-2 Sub-Catchment Boundaries and Node Locations

A.3 Results

The XP_RAFTS model was run to estimate the 2, 20, 100, 200 and 500 year ARI, and PMF design flood events. These hydrographs were in turn exported to the SOBEK 1D/2D model. The subcatchment layout and node locations and names for the hydrological given in **Figure A-2**.

The estimated peak flows at all locations within the study catchment are summarised in **Table A-7 to Table A-12** for the 2, 20, 100, 200 and 500 year ARI, and PMF for the 45 minutes, 1 hour, 1.5 hour, 2 hour, 3 hour, storm burst durations and the PMF 15 minute, 30 minute, 45 minute, 1 hour, 1.5 hour, 2 hour and 3 hour design flood events respectively.

The estimated peak flows at all locations within the study catchment for the 2, 20, 100, 200 and 500 year ARI, and PMF design floods are summarised in **Table A-13**.

Table A-7 Estimated 2 year ARI Peak Flows (m^3/s) under Existing Conditions at all Locations

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m^3/s)	Critical Duration
U8	0.3	0.4	0.5	0.4	0.3	0.5	1.5hr
U6	1.5	1.7	1.7	1.9	1.5	1.9	2hr
U7	2.9	3.3	3.6	3.8	3.0	3.8	2hr
W7	3.0	3.5	3.6	4.0	3.1	4.0	2hr
E1	1.6	2.1	2.4	2.4	1.9	2.4	2hr
E2	2.0	2.3	2.5	2.7	2.1	2.7	2hr
W1	1.8	2.2	2.3	2.5	2.0	2.5	2hr
Dum1	5.2	6.3	6.6	7.0	5.3	7.0	2hr
E3	2.0	2.4	2.5	2.7	2.1	2.7	2hr
W2	1.9	2.2	2.3	2.5	2.0	2.5	2hr
W3	2.6	3.1	3.2	3.5	2.8	3.5	2hr
W4	5.0	5.7	6.0	6.4	5.2	6.4	2hr
Dum8	13.9	16.1	16.4	17.6	14.2	17.6	2hr
E4	2.6	3.1	3.3	3.6	2.9	3.6	2hr
W5	1.6	1.9	2.0	2.2	1.7	2.2	2hr
W6	3.4	4.0	4.3	4.7	3.6	4.7	2hr
Dum7	16.9	19.4	20.2	21.6	18.1	21.6	2hr
E5	2.2	2.7	2.9	3.1	2.5	3.1	2hr
W8	1.7	2.0	2.1	2.3	1.8	2.3	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m^3/s)	Critical Duration
Dum6	19.4	22.5	24.4	25.7	22.4	25.7	2hr
E6	1.8	2.3	2.6	2.7	2.1	2.7	2hr
W10	1.4	1.7	1.7	1.9	1.5	1.9	2hr
W9	2.0	2.4	2.5	2.7	2.2	2.7	2hr
W11	4.1	4.8	5.1	5.5	4.4	5.5	2hr
W10-1	5.2	6.1	6.6	7.0	5.5	7.0	2hr
W12	1.9	2.4	2.7	2.8	2.2	2.8	2hr
Dum5	23.7	27.2	29.6	31.0	28.3	31.0	2hr
F1	0.6	0.8	1.0	0.9	0.7	1.0	1.5hr
N1	0.7	0.9	1.1	1.1	0.8	1.1	1.5hr
N3	1.8	2.1	2.2	2.4	1.9	2.4	2hr
N2	4.3	5.0	5.2	5.6	4.5	5.6	2hr
U1	2.4	2.7	2.8	3.1	2.4	3.1	2hr
U2	2.0	2.3	2.4	2.7	2.1	2.7	2hr
U3	2.4	2.8	2.9	3.2	2.6	3.2	2hr
U4	0.4	0.6	0.6	0.6	0.4	0.6	1.5hr
M1	1.7	2.0	2.3	2.3	1.9	2.3	1.5hr
M2	2.1	2.5	2.6	2.7	2.3	2.7	2hr
M4	1.3	1.5	1.6	1.7	1.4	1.7	2hr
Dum10	5.0	5.7	6.3	6.7	5.3	6.7	2hr
M5-1	1.3	1.5	1.5	1.6	1.3	1.6	2hr
M5	1.4	1.7	1.8	2.0	1.5	2.0	2hr
Dum11	7.3	8.5	9.3	9.7	7.7	9.7	2hr
M11	1.1	1.3	1.4	1.5	1.2	1.5	2hr
M5-2	1.0	1.1	1.2	1.3	1.0	1.3	2hr
M12	1.3	1.5	1.6	1.7	1.4	1.7	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m³/s)	Critical Duration
Dum2	10.4	12.1	13.0	13.8	11.0	13.8	2hr
M13	11.9	13.9	14.9	15.8	12.7	15.8	2hr
M16	12.6	15.1	16.2	17.3	14.3	17.3	2hr
M3	1.9	2.2	2.6	2.6	2.1	2.6	2hr
M6-1	3.8	4.5	5.0	5.2	4.1	5.2	2hr
M6	5.4	6.3	6.9	7.3	5.7	7.3	2hr
M7	1.8	2.2	2.2	2.5	1.9	2.5	2hr
M8	8.8	10.3	11.0	11.7	9.2	11.7	2hr
M9	1.0	1.2	1.5	1.4	1.2	1.5	1.5hr
M10	2.7	3.1	3.5	3.6	2.9	3.6	2hr
M14	1.3	1.5	1.5	1.6	1.3	1.6	2hr
Dum9	11.2	13.2	14.4	15.1	12.3	15.1	2hr
M15	11.7	14.0	15.4	16.2	13.4	16.2	2hr
M17	2.1	2.4	2.5	2.7	2.1	2.7	2hr
Dum13	13.8	16.3	17.7	18.6	15.4	18.6	2hr
M18	26.6	32.2	34.8	37.1	31.2	37.1	2hr
U5	0.5	0.6	0.7	0.7	0.5	0.7	1.5hr
OUT-E	32.9	38.9	42.7	45.4	40.1	45.4	2hr
C1	0.5	0.6	0.6	0.6	0.5	0.6	2hr
C2	1.6	1.8	1.9	2.0	1.8	2.0	2hr
C3	2.4	2.7	2.9	3.1	2.7	3.1	2hr
C4	4.4	5.0	5.1	5.4	4.7	5.4	2hr
C5	1.4	1.6	1.6	1.8	1.4	1.8	2hr
C6	1.9	2.3	2.4	2.6	2.1	2.6	2hr
Dum3	6.6	7.4	7.9	8.1	6.9	8.1	2hr
C8	1.2	1.4	1.5	1.6	1.3	1.6	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m³/s)	Critical Duration
C7	1.7	2.0	2.1	2.3	1.8	2.3	2hr
C10	1.6	1.9	2.0	2.2	1.8	2.2	2hr
Dum4	9.5	10.8	11.1	11.7	9.8	11.7	2hr
C11	10.7	11.8	12.1	12.8	10.6	12.8	2hr
C9	2.5	2.9	3.1	3.4	2.7	3.4	2hr
C12	2.4	3.0	3.3	3.5	2.7	3.5	2hr
Dum12	13.4	14.7	15.8	16.1	13.3	16.1	2hr
OUT-N	71.5	81.5	87.6	92.1	82.5	92.1	2hr

Table A-8 Estimated 20 year ARI Peak Flows (m3/s) under Existing Conditions at All Locations

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
U8	0.7	0.8	0.9	0.8	0.5	0.9	1.5hr
U6	3.4	4.0	4.0	4.3	3.5	4.3	2hr
U7	6.4	7.6	8.1	8.1	6.5	8.1	2hr
W7	6.7	8.0	8.8	8.9	7.0	8.9	2hr
E1	3.8	4.6	4.8	4.8	3.5	4.8	1.5hr
E2	4.2	5.2	5.7	5.7	4.4	5.7	2hr
W1	3.9	4.8	5.3	5.3	4.1	5.3	2hr
Dum1	11.7	13.4	13.3	13.8	11.2	13.8	2hr
E3	4.5	5.3	5.8	6.0	4.7	6.0	2hr
W2	4.5	5.2	5.5	5.8	4.6	5.8	2hr
W3	5.9	7.1	7.7	7.9	6.2	7.9	2hr
W4	11.1	13.2	13.9	14.0	10.8	14.0	2hr
Dum8	30.3	34.8	36.5	36.6	29.3	36.6	2hr
E4	5.8	7.0	7.7	7.6	5.7	7.7	1.5hr
W5	3.6	4.3	4.6	4.8	3.7	4.8	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
W6	7.6	8.9	9.4	9.7	7.5	9.7	2hr
Dum7	37.4	43.0	44.0	44.4	36.1	44.4	2hr
E5	4.9	6.0	6.5	6.5	4.8	6.5	1.5hr
W8	3.8	4.5	4.9	5.0	3.9	5.0	2hr
Dum6	43.8	50.2	51.0	52.2	43.6	52.2	2hr
E6	4.3	5.2	5.4	5.3	3.9	5.4	1.5hr
W10	3.2	3.7	4.0	4.1	3.3	4.1	2hr
W9	4.5	5.4	5.9	6.0	4.6	6.0	2hr
W11	8.8	10.7	11.5	11.6	9.0	11.6	2hr
W10-1	11.4	13.8	14.3	14.8	11.4	14.8	2hr
W12	4.5	5.4	5.6	5.5	4.0	5.6	1.5hr
Dum5	51.5	58.9	60.1	62.2	54.9	62.2	2hr
F1	1.5	1.7	1.8	1.7	1.2	1.8	1.5hr
N1	1.7	2.0	2.1	1.9	1.3	2.1	1.5hr
N3	4.2	4.8	5.4	5.5	4.4	5.5	2hr
N2	9.9	11.5	12.5	12.9	10.2	12.9	2hr
U1	5.5	6.3	6.8	7.0	5.7	7.0	2hr
U2	4.6	5.3	5.8	6.0	4.7	6.0	2hr
U3	5.3	6.3	7.0	7.1	5.6	7.1	2hr
U4	1.0	1.2	1.2	1.1	0.8	1.2	1.5hr
M1	4.1	4.6	5.5	5.3	4.3	5.5	1.5hr
M2	4.8	5.5	6.4	6.4	5.1	6.4	1.5hr
M4	2.8	3.4	3.7	3.8	2.9	3.8	2hr
Dum10	11.1	13.4	14.3	14.6	11.6	14.6	2hr
M5-1	3.0	3.4	3.8	3.8	3.1	3.8	2hr
M5	3.1	3.7	4.0	4.1	3.1	4.1	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
Dum11	16.3	19.8	20.0	21.5	16.6	21.5	2hr
M11	2.6	3.0	3.2	3.3	2.6	3.3	2hr
M5-2	2.3	2.6	2.7	2.9	2.3	2.9	2hr
M12	2.9	3.4	3.7	3.8	3.0	3.8	2hr
Dum2	23.2	27.5	28.1	29.6	22.9	29.6	2hr
M13	26.9	31.5	32.2	33.6	26.4	33.6	2hr
M16	28.5	33.4	34.6	36.2	29.1	36.2	2hr
M3	3.9	5.0	5.6	5.4	4.1	5.6	1.5hr
M6-1	8.3	10.1	10.8	10.7	8.3	10.8	1.5hr
M6	12.1	14.6	15.0	15.3	11.9	15.3	2hr
M7	4.2	4.9	5.3	5.5	4.3	5.5	2hr
M8	19.9	23.7	23.9	25.1	19.6	25.1	2hr
M9	2.2	2.9	3.2	3.0	2.3	3.2	1.5hr
M10	6.2	7.4	7.6	7.9	6.3	7.9	2hr
M14	3.1	3.5	3.8	3.9	3.2	3.9	2hr
Dum9	25.6	30.0	30.2	31.7	25.4	31.7	2hr
M15	27.0	31.4	31.9	33.5	27.2	33.5	2hr
M17	5.0	5.8	5.9	6.3	5.1	6.3	2hr
Dum13	31.7	36.5	37.0	38.6	31.3	38.6	2hr
M18	61.3	71.2	72.8	76.0	63.0	76.0	2hr
U5	1.1	1.3	1.3	1.3	0.9	1.3	1.5hr
OUT-E	74.9	84.7	87.3	91.7	78.5	91.7	2hr
C1	1.2	1.3	1.4	1.4	1.2	1.4	2hr
C2	4.0	4.5	4.5	4.7	3.9	4.7	2hr
C3	5.7	6.5	6.6	6.8	5.8	6.8	2hr
C4	10.0	11.4	11.6	11.8	9.7	11.8	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
C5	3.2	3.7	3.8	4.0	3.3	4.0	2hr
C6	4.4	5.2	5.7	5.8	4.6	5.8	2hr
Dum3	14.6	16.7	17.5	17.6	14.5	17.6	2hr
C8	2.6	3.2	3.4	3.5	2.7	3.5	2hr
C7	3.8	4.5	4.9	5.1	4.0	5.1	2hr
C10	3.6	4.3	4.7	4.9	3.7	4.9	2hr
Dum4	20.9	23.0	23.8	24.2	20.1	24.2	2hr
C11	22.9	25.1	26.7	26.7	22.0	26.7	2hr
C9	5.4	6.6	7.2	7.2	5.5	7.2	2hr
C12	5.6	6.7	7.1	7.0	5.1	7.1	1.5hr
Dum12	28.2	31.9	33.1	33.7	28.0	33.7	2hr
OUT-N	156.7	175.1	179.7	185.9	162.0	185.9	2hr

Table A-9 Estimated 100 year ARI Peak Flows (m3/s) under Existing Conditions at All Locations

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
U8	0.9	1.1	1.1	1.0	0.6	1.1	1.5hr
U6	5.1	5.7	5.9	6.1	4.9	6.1	2hr
U7	9.1	10.7	11.1	11.1	8.6	11.1	1.5hr
W7	9.4	11.1	11.8	11.8	8.9	11.8	2hr
E1	5.5	6.2	6.2	6.1	4.3	6.2	1.5hr
E2	6.1	7.2	7.5	7.5	5.5	7.5	1.5hr
W1	5.7	6.7	7.0	7.0	5.2	7.0	1.5hr
Dum1	16.1	17.7	18.1	17.9	14.3	18.1	1.5hr
E3	6.3	7.4	8.0	7.9	6.0	8.0	1.5hr
W2	6.3	7.3	7.7	7.8	6.1	7.8	2hr
W3	8.3	9.8	10.4	10.4	7.9	10.4	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
W4	16.0	18.6	18.5	18.3	14.1	18.6	1hr
Dum8	42.5	48.7	48.9	48.3	37.7	48.9	1.5hr
E4	8.3	9.7	10.0	9.9	7.2	10.0	1.5hr
W5	5.0	6.0	6.4	6.4	4.8	6.4	1.5hr
W6	10.6	12.6	12.7	12.8	9.9	12.8	2hr
Dum7	53.2	59.9	58.7	58.7	47.5	59.9	1hr
E5	7.2	8.3	8.5	8.3	6.0	8.5	1.5hr
W8	5.3	6.2	6.7	6.6	5.0	6.7	1.5hr
Dum6	62.6	69.9	68.2	68.8	57.3	69.9	1hr
E6	6.1	6.9	7.0	6.8	4.8	7.0	1.5hr
W10	4.4	5.2	5.5	5.5	4.2	5.5	1.5hr
W9	6.3	7.4	7.9	7.9	5.9	7.9	1.5hr
W11	12.5	14.9	15.2	15.3	11.5	15.3	2hr
W10-1	16.2	18.9	18.8	19.3	14.6	19.3	2hr
W12	6.3	7.2	7.2	7.1	5.0	7.2	1.5hr
Dum5	73.3	82.2	81.1	82.3	72.1	82.3	2hr
F1	2.0	2.2	2.3	2.2	1.4	2.3	1.5hr
N1	2.3	2.5	2.6	2.5	1.7	2.6	1.5hr
N3	5.9	6.7	7.6	7.4	5.8	7.6	1.5hr
N2	13.9	16.1	17.4	17.3	13.4	17.4	1.5hr
U1	7.6	8.8	9.5	9.5	7.3	9.5	2hr
U2	6.3	7.4	8.0	8.0	6.1	8.0	1.5hr
U3	7.4	8.8	9.5	9.4	7.1	9.5	1.5hr
U4	1.3	1.5	1.5	1.4	0.9	1.5	1.5hr
M1	5.7	6.6	7.6	7.2	5.6	7.6	1.5hr
M2	6.7	7.7	8.8	8.5	6.6	8.8	1.5hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
M4	4.0	4.7	5.0	5.0	3.7	5.0	1.5hr
Dum10	15.7	18.9	19.1	19.8	15.1	19.8	2hr
M5-1	4.2	4.7	5.3	5.2	4.0	5.3	1.5hr
M5	4.4	5.2	5.3	5.3	3.8	5.3	1.5hr
Dum11	23.2	27.3	26.9	28.4	21.5	28.4	2hr
M11	3.6	4.2	4.4	4.5	3.4	4.5	2hr
M5-2	3.2	3.6	3.8	3.9	3.0	3.9	2hr
M12	4.0	4.7	5.2	5.1	3.8	5.2	1.5hr
Dum2	32.8	37.6	37.7	38.8	29.9	38.8	2hr
M13	37.9	43.1	43.1	43.9	34.5	43.9	2hr
M16	40.9	46.2	46.4	47.4	37.9	47.4	2hr
M3	5.8	7.0	7.4	7.0	5.1	7.4	1.5hr
M6-1	11.9	14.2	14.2	14.0	10.6	14.2	1hr
M6	17.2	20.3	19.8	20.4	15.4	20.4	2hr
M7	5.8	6.8	7.3	7.3	5.6	7.3	2hr
M8	28.4	32.8	32.3	33.5	25.5	33.5	2hr
M9	3.2	3.9	4.2	3.9	2.9	4.2	1.5hr
M10	8.7	10.3	10.1	10.6	8.3	10.6	2hr
M14	4.5	4.9	5.5	5.5	4.3	5.5	2hr
Dum9	36.8	41.5	40.7	41.8	32.9	41.8	2hr
M15	38.9	43.6	43.0	44.1	35.2	44.1	2hr
M17	7.2	8.2	8.4	8.7	6.9	8.7	2hr
Dum13	45.6	50.8	49.8	50.7	40.8	50.8	1hr
M18	88.0	98.8	98.0	100.7	81.9	100.7	2hr
U5	1.5	1.6	1.7	1.6	1.1	1.7	1.5hr
OUT-E	107.2	117.8	118.1	121.1	101.7	121.1	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
C1	1.7	2.0	1.9	2.0	1.6	2.0	2hr
C2	5.7	6.4	6.4	6.6	5.3	6.6	2hr
C3	8.3	9.4	9.3	9.5	7.7	9.5	2hr
C4	14.2	15.9	15.9	16.3	13.3	16.3	2hr
C5	4.6	5.2	5.5	5.6	4.4	5.6	2hr
C6	6.1	7.2	7.8	7.7	5.9	7.8	1.5hr
Dum3	20.7	23.2	23.6	23.8	19.4	23.8	2hr
C8	3.7	4.4	4.6	4.6	3.4	4.6	2hr
C7	5.3	6.3	6.8	6.7	5.2	6.8	1.5hr
C10	5.0	6.0	6.5	6.4	4.8	6.5	1.5hr
Dum4	29.3	31.8	32.4	32.3	26.7	32.4	1.5hr
C11	32.0	34.6	36.0	35.5	29.2	36.0	1.5hr
C9	7.8	9.2	9.5	9.4	6.9	9.5	1.5hr
C12	8.0	9.1	9.1	8.9	6.3	9.1	1.5hr
Dum12	39.1	43.6	44.0	45.0	36.7	45.0	2hr
OUT-N	221.4	243.6	242.4	248.0	211.5	248.0	2hr

Table A-10 Estimated 200 year ARI Peak Flows (m3/s) under Existing Conditions at All Locations

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
U8	1.1	1.2	1.2	1.1	0.7	1.2	1.5hr
U6	5.8	6.5	6.7	6.9	5.6	6.9	2hr
U7	10.4	12.3	12.6	12.5	9.8	12.6	1.5hr
W7	10.8	12.7	13.4	13.3	9.9	13.4	1.5hr
E1	6.2	7.0	7.0	6.8	4.8	7.0	1.5hr
E2	7.0	8.3	8.5	8.4	6.1	8.5	1.5hr
W1	6.6	7.7	8.0	7.8	5.8	8.0	1.5hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
Dum1	18.0	19.8	20.6	20.2	16.0	20.6	1.5hr
E3	7.2	8.5	9.0	8.9	6.7	9.0	1.5hr
W2	7.1	8.3	8.8	8.8	6.8	8.8	1.5hr
W3	9.5	11.2	11.8	11.7	8.8	11.8	1.5hr
W4	18.4	21.2	21.0	20.6	15.9	21.2	1hr
Dum8	48.4	55.5	55.1	54.4	42.4	55.5	1hr
E4	9.6	11.0	11.2	11.0	8.0	11.2	1.5hr
W5	5.8	6.8	7.2	7.2	5.4	7.2	1.5hr
W6	12.2	14.3	14.3	14.5	11.1	14.5	2hr
Dum7	60.5	68.0	65.9	65.6	53.4	68.0	1hr
E5	8.3	9.4	9.5	9.3	6.7	9.5	1.5hr
W8	6.1	7.2	7.6	7.5	5.6	7.6	1.5hr
Dum6	71.1	78.9	76.3	76.9	64.3	78.9	1hr
E6	7.0	7.8	7.8	7.6	5.3	7.8	1.5hr
W10	5.0	6.0	6.3	6.2	4.7	6.3	1.5hr
W9	7.2	8.6	9.0	8.9	6.6	9.0	1.5hr
W11	14.4	17.0	17.1	17.2	12.9	17.2	2hr
W10-1	18.5	21.6	21.1	21.7	16.3	21.7	2hr
W12	7.3	8.1	8.2	7.9	5.5	8.2	1.5hr
Dum5	82.9	92.5	91.9	91.9	80.6	92.5	1hr
F1	2.3	2.5	2.6	2.4	1.6	2.6	1.5hr
N1	2.6	2.8	2.9	2.8	1.8	2.9	1.5hr
N3	6.7	7.7	8.7	8.4	6.5	8.7	1.5hr
N2	15.8	18.4	19.8	19.6	15.1	19.8	1.5hr
U1	8.6	10.1	10.8	10.8	8.3	10.8	1.5hr
U2	7.2	8.5	9.2	9.0	6.9	9.2	1.5hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
U3	8.5	10.1	10.7	10.6	7.9	10.7	1.5hr
U4	1.5	1.6	1.7	1.6	1.1	1.7	1.5hr
M1	6.4	7.7	8.6	8.2	6.3	8.6	1.5hr
M2	7.6	8.9	10.0	9.6	7.3	10.0	1.5hr
M4	4.6	5.5	5.6	5.6	4.1	5.6	1.5hr
Dum10	17.8	21.6	21.5	22.5	17.1	22.5	2hr
M5-1	4.7	5.4	6.1	5.9	4.5	6.1	1.5hr
M5	5.2	5.9	6.0	5.9	4.3	6.0	1.5hr
Dum11	26.5	30.9	30.4	32.0	24.1	32.0	2hr
M11	4.0	4.7	5.1	5.1	3.8	5.1	1.5hr
M5-2	3.6	4.1	4.4	4.4	3.4	4.4	2hr
M12	4.6	5.5	5.8	5.8	4.3	5.8	1.5hr
Dum2	37.3	42.5	42.5	43.5	33.6	43.5	2hr
M13	43.1	49.0	48.5	49.3	38.8	49.3	2hr
M16	46.7	52.5	52.2	53.1	42.5	53.1	2hr
M3	6.8	8.0	8.3	7.8	5.7	8.3	1.5hr
M6-1	13.7	16.2	15.9	15.8	11.9	16.2	1hr
M6	19.8	23.1	22.2	23.0	17.3	23.1	1hr
M7	6.6	7.8	8.3	8.3	6.3	8.3	1.5hr
M8	32.5	37.2	36.4	37.6	28.6	37.6	2hr
M9	3.7	4.4	4.7	4.3	3.2	4.7	1.5hr
M10	10.0	11.7	11.4	12.0	9.3	12.0	2hr
M14	5.1	5.6	6.3	6.2	4.9	6.3	1.5hr
Dum9	42.1	47.3	45.8	46.8	36.8	47.3	1hr
M15	44.6	49.8	48.3	49.4	39.3	49.8	1hr
M17	8.3	9.3	9.7	9.9	7.9	9.9	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
Dum13	52.1	57.9	56.2	56.8	45.7	57.9	1hr
M18	100.2	111.8	110.1	112.7	91.5	112.7	2hr
U5	1.7	1.8	1.9	1.8	1.2	1.9	1.5hr
OUT-E	121.8	133.4	132.1	135.1	113.3	135.1	2hr
C1	2.0	2.3	2.2	2.3	1.9	2.3	2hr
C2	6.6	7.4	7.5	7.5	6.0	7.5	2hr
C3	9.6	10.8	10.7	10.8	8.8	10.8	2hr
C4	16.2	18.2	18.1	18.6	15.0	18.6	2hr
C5	5.1	5.9	6.3	6.3	4.9	6.3	2hr
C6	6.9	8.2	8.9	8.7	6.6	8.9	1.5hr
Dum3	23.5	26.3	26.6	26.9	21.9	26.9	2hr
C8	4.2	5.1	5.2	5.2	3.8	5.2	1.5hr
C7	6.1	7.2	7.8	7.6	5.8	7.8	1.5hr
C10	5.8	6.9	7.3	7.2	5.3	7.3	1.5hr
Dum4	33.0	36.0	36.7	36.4	30.2	36.7	1.5hr
C11	36.0	39.3	40.7	40.1	32.9	40.7	1.5hr
C9	9.0	10.5	10.6	10.5	7.7	10.6	1.5hr
C12	9.1	10.2	10.2	10.0	7.0	10.2	1.5hr
Dum12	44.2	49.5	49.7	50.8	41.3	50.8	2hr
OUT-N	250.7	275.3	272.3	278.0	236.4	278.0	2hr

Table A-11 Estimated 500 year ARI Peak Flows (m3/s) under Existing Conditions at All Locations

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
U8	1.2	1.3	1.4	1.3	0.8	1.4	1.5hr
U6	6.8	7.7	8.1	8.2	6.5	8.2	2hr
U7	12.3	14.4	14.7	14.6	11.4	14.7	1.5hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
W7	12.7	15.0	15.4	15.3	11.3	15.4	1.5hr
E1	7.3	8.0	8.1	7.8	5.4	8.1	1.5hr
E2	8.4	9.7	9.8	9.6	7.0	9.8	1.5hr
W1	7.8	9.1	9.1	9.0	6.5	9.1	1.5hr
Dum1	20.7	22.9	23.8	23.2	18.3	23.8	1.5hr
E3	8.5	10.0	10.4	10.3	7.7	10.4	1.5hr
W2	8.3	9.8	10.3	10.2	7.9	10.3	1.5hr
W3	11.2	13.2	13.7	13.5	10.0	13.7	1.5hr
W4	21.6	24.8	24.2	23.7	18.3	24.8	1hr
Dum8	56.4	64.8	63.3	62.6	48.9	64.8	1hr
E4	11.3	12.9	12.9	12.7	9.0	12.9	1.5hr
W5	6.8	8.1	8.4	8.3	6.2	8.4	1.5hr
W6	14.2	16.8	16.6	16.8	12.7	16.8	2hr
Dum7	70.3	78.8	75.3	75.2	61.3	78.8	1hr
E5	9.7	10.9	10.9	10.7	7.6	10.9	1hr
W8	7.2	8.5	8.7	8.6	6.4	8.7	1.5hr
Dum6	82.4	91.1	87.1	87.7	73.6	91.1	1hr
E6	8.2	9.0	9.0	8.7	6.1	9.0	1hr
W10	6.0	7.0	7.3	7.2	5.4	7.3	1.5hr
W9	8.6	10.1	10.3	10.2	7.5	10.3	1.5hr
W11	17.0	19.8	19.7	19.8	14.8	19.8	1hr
W10-1	21.7	24.9	24.2	25.0	18.6	25.0	2hr
W12	8.5	9.3	9.3	9.0	6.3	9.3	1.5hr
Dum5	95.7	106.3	106.3	106.2	91.9	106.3	1hr
F1	2.6	2.8	2.9	2.8	1.8	2.9	1.5hr
N1	3.0	3.2	3.3	3.1	2.1	3.3	1.5hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
N3	7.8	9.1	10.2	9.8	7.5	10.2	1.5hr
N2	18.3	21.7	23.1	22.7	17.3	23.1	1.5hr
U1	10.0	11.8	12.6	12.5	9.4	12.6	1.5hr
U2	8.4	9.9	10.6	10.4	7.9	10.6	1.5hr
U3	10.1	11.9	12.4	12.2	9.0	12.4	1.5hr
U4	1.7	1.9	2.0	1.8	1.2	2.0	1.5hr
M1	7.4	9.1	10.1	9.5	7.2	10.1	1.5hr
M2	8.8	10.7	11.6	11.1	8.4	11.6	1.5hr
M4	5.5	6.4	6.5	6.4	4.7	6.5	1.5hr
Dum10	21.0	25.3	25.0	26.0	19.7	26.0	2hr
M5-1	5.5	6.4	7.1	6.8	5.2	7.1	1.5hr
M5	6.1	6.9	6.9	6.8	4.9	6.9	1.5hr
Dum11	30.8	35.7	35.4	36.9	27.6	36.9	2hr
M11	4.8	5.6	5.9	5.8	4.4	5.9	1.5hr
M5-2	4.2	4.8	5.2	5.2	3.9	5.2	1.5hr
M12	5.5	6.5	6.8	6.6	4.9	6.8	1.5hr
Dum2	43.2	49.4	49.2	49.9	38.8	49.9	2hr
M13	50.4	56.8	55.9	56.5	44.7	56.8	1hr
M16	54.7	60.8	60.1	60.8	48.9	60.8	1hr
M3	8.0	9.4	9.6	9.0	6.4	9.6	1.5hr
M6-1	16.1	18.8	18.3	18.2	13.6	18.8	1hr
M6	23.2	26.8	25.5	26.5	19.8	26.8	1hr
M7	7.8	9.2	9.7	9.5	7.2	9.7	1.5hr
M8	37.8	43.3	42.0	43.2	32.8	43.3	1hr
M9	4.3	5.2	5.4	5.0	3.6	5.4	1.5hr
M10	11.7	13.6	13.4	13.8	10.6	13.8	2hr

Node	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
M14	5.9	6.7	7.5	7.2	5.7	7.5	1.5hr
Dum9	49.1	54.8	52.7	53.5	42.0	54.8	1hr
M15	51.9	57.6	55.5	56.5	44.8	57.6	1hr
M17	9.6	11.0	11.5	11.6	9.1	11.6	2hr
Dum13	60.6	66.9	64.6	65.0	52.5	66.9	1hr
M18	116.7	129.6	126.8	128.8	104.4	129.6	1hr
U5	1.9	2.1	2.2	2.0	1.3	2.2	1.5hr
OUT-E	141.8	153.9	151.3	154.2	129.0	154.2	2hr
C1	2.4	2.7	2.6	2.7	2.2	2.7	2hr
C2	7.8	8.7	8.8	8.8	7.0	8.8	1.5hr
C3	11.3	12.7	12.4	12.6	10.4	12.7	1hr
C4	18.9	21.3	21.3	21.6	17.5	21.6	2hr
C5	6.0	6.9	7.5	7.4	5.7	7.5	1.5hr
C6	8.2	9.7	10.3	10.0	7.5	10.3	1.5hr
Dum3	27.2	30.8	30.8	31.2	25.3	31.2	2hr
C8	5.1	5.9	6.0	5.9	4.3	6.0	1.5hr
C7	7.1	8.5	9.0	8.8	6.6	9.0	1.5hr
C10	6.9	8.2	8.5	8.3	6.1	8.5	1.5hr
Dum4	38.0	41.4	42.6	42.2	34.8	42.6	1.5hr
C11	41.4	45.4	46.9	46.5	37.9	46.9	1.5hr
C9	10.7	12.2	12.3	12.1	8.7	12.3	1.5hr
C12	10.7	11.7	11.7	11.4	8.0	11.7	1hr
Dum12	51.0	57.2	57.8	58.6	47.5	58.6	2hr
OUT-N	290.2	317.6	313.1	318.4	270.3	318.4	2hr

Table A-12 Estimated PMF Peak Flows (m3/s) under Existing Conditions at All Locations

Node	15min	30min	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
U8	3.7	3.0	2.5	2.3	2.0	1.8	1.5	3.7	15min
U6	19.3	21.6	19.7	19.0	16.9	15.0	12.2	21.6	30min
U7	30.5	37.7	36.6	34.8	32.1	29.1	23.6	37.7	30min
W7	40.1	38.1	34.1	31.4	27.2	24.2	20.2	40.1	15min
E1	22.0	19.2	16.5	14.8	12.9	11.7	9.8	22.0	15min
E2	25.8	23.8	20.9	19.3	16.7	14.9	12.5	25.8	15min
W1	24.1	22.3	19.6	18.1	15.6	13.9	11.7	24.1	15min
Dum1	54.5	60.5	55.1	50.7	45.0	40.1	33.0	60.5	30min
E3	26.5	25.9	23.2	21.4	18.6	16.6	13.8	26.5	15min
W2	25.5	26.1	23.7	21.9	19.4	17.2	14.2	26.1	30min
W3	35.2	33.7	30.3	27.8	24.1	21.5	17.9	35.2	15min
W4	53.3	63.8	58.6	55.4	49.3	43.9	36.3	63.8	30min
Dum8	133.2	163.4	154.1	146.3	131.5	117.5	96.2	163.4	30min
E4	34.6	31.4	27.2	24.9	21.5	19.3	16.2	34.6	15min
W5	21.6	20.8	18.7	17.2	14.9	13.3	11.1	21.6	15min
W6	41.0	42.9	38.6	36.0	31.7	28.1	23.4	42.9	30min
Dum7	143.3	188.8	196.6	194.2	179.0	161.5	133.5	196.6	45min
E5	29.5	26.5	22.9	20.8	18.0	16.2	13.6	29.5	15min
W8	22.6	21.5	19.2	17.7	15.3	13.7	11.4	22.6	15min
Dum6	148.9	206.4	235.7	243.2	230.3	211.1	175.9	243.2	1hr
E6	24.5	21.4	18.4	16.5	14.4	13.0	10.9	24.5	15min
W10	18.8	18.2	16.3	15.0	13.1	11.6	9.7	18.8	15min
W9	26.7	25.4	22.7	20.9	18.1	16.2	13.5	26.7	15min
W11	50.1	50.0	44.9	41.3	36.2	32.2	26.9	50.1	15min
W10-1	59.9	63.6	57.4	53.4	47.1	41.8	34.8	63.6	30min
W12	25.5	22.2	19.1	17.1	14.9	13.5	11.3	25.5	15min

Node	15min	30min	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
Dum5	201.5	241.8	285.2	304.6	302.7	280.9	237.5	304.6	1hr
F1	8.1	6.7	5.5	5.0	4.4	4.0	3.3	8.1	15min
N1	9.1	7.6	6.4	5.7	5.1	4.6	3.8	9.1	15min
N3	23.6	24.7	22.7	20.9	18.5	16.3	13.5	24.7	30min
N2	56.4	57.9	52.6	48.6	43.1	38.2	31.5	57.9	30min
U1	30.9	31.4	28.5	26.2	23.1	20.5	17.0	31.4	30min
U2	26.2	26.3	23.8	21.8	19.1	17.0	14.0	26.3	30min
U3	31.5	30.3	27.2	25.0	21.6	19.3	16.1	31.5	15min
U4	5.3	4.4	3.6	3.3	2.9	2.7	2.2	5.3	15min
M1	22.9	23.9	21.9	20.0	17.7	15.6	12.9	23.9	30min
M2	27.4	27.9	25.4	23.3	20.4	18.1	15.0	27.9	30min
M4	17.2	15.9	14.1	13.0	11.2	10.0	8.4	17.2	15min
Dum10	61.3	64.7	58.6	55.5	49.1	43.4	35.8	64.7	30min
M5-1	16.6	17.3	15.9	14.5	12.9	11.4	9.4	17.3	30min
M5	18.7	16.9	14.6	13.3	11.5	10.4	8.7	18.7	15min
Dum11	83.1	92.7	86.1	81.1	72.6	64.7	53.3	92.7	30min
M11	15.0	14.8	13.3	12.2	10.7	9.5	7.9	15.0	15min
M5-2	12.8	13.1	12.0	11.0	9.8	8.7	7.1	13.1	30min
M12	17.3	16.6	14.9	13.7	11.8	10.6	8.8	17.3	15min
Dum2	111.0	128.6	121.6	115.2	103.6	93.1	76.5	128.6	30min
M13	120.0	144.3	141.0	136.2	124.0	111.6	92.2	144.3	30min
M16	121.1	148.0	152.8	152.3	142.2	129.9	107.6	152.8	45min
M3	24.3	22.4	19.3	17.7	15.2	13.7	11.5	24.3	15min
M6-1	47.2	47.0	41.8	38.1	33.3	29.8	24.9	47.2	15min
M6	64.8	68.9	61.6	57.0	50.1	44.6	37.2	68.9	30min
M7	24.4	24.1	21.8	20.1	17.5	15.6	12.9	24.4	15min

Node	15min	30min	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
M8	102.8	113.3	103.6	96.7	85.7	76.3	63.2	113.3	30min
M9	13.3	12.5	11.0	10.0	8.6	7.7	6.5	13.3	15min
M10	33.0	35.4	32.2	30.0	26.3	23.3	19.4	35.4	30min
M14	17.0	18.5	17.0	16.1	14.3	12.6	10.4	18.5	30min
Dum9	111.1	135.4	138.5	135.0	123.3	111.0	91.9	138.5	45min
M15	112.1	139.1	148.2	147.1	134.9	122.4	101.6	148.2	45min
M17	27.6	30.2	27.5	26.3	23.4	20.7	17.0	30.2	30min
Dum13	124.3	164.7	174.0	171.7	157.8	143.1	118.4	174.0	45min
M18	242.7	309.4	334.2	338.4	315.1	290.1	240.9	338.4	1hr
U5	5.9	4.9	4.0	3.6	3.2	2.9	2.4	5.9	15min
OUT-E	279.6	340.1	412.9	438.1	416.8	391.7	326.5	438.1	1hr
C1	6.1	7.6	7.1	6.9	6.2	5.6	4.6	7.6	30min
C2	17.4	24.3	24.2	23.4	21.9	19.8	16.2	24.3	30min
C3	22.7	33.2	35.2	35.0	33.2	30.7	25.3	35.2	45min
C4	42.6	55.1	57.5	57.9	55.5	51.6	43.3	57.9	1hr
C5	18.1	18.8	17.2	16.0	14.2	12.5	10.3	18.8	30min
C6	25.7	25.2	22.7	20.9	18.2	16.1	13.4	25.7	15min
Dum3	55.4	77.3	81.7	83.8	81.4	77.2	65.4	83.8	1hr
C8	15.9	14.7	13.1	12.0	10.4	9.3	7.8	15.9	15min
C7	22.6	22.1	19.9	18.3	15.9	14.1	11.7	22.6	15min
C10	21.7	20.5	18.3	16.8	14.5	13.0	10.8	21.7	15min
Dum4	81.1	104.8	111.5	115.2	112.2	106.8	92.1	115.2	1hr
C11	92.3	114.5	120.5	124.9	122.0	116.3	100.3	124.9	1hr
C9	32.6	29.9	26.1	24.0	20.7	18.6	15.6	32.6	15min
C12	31.9	28.2	24.2	21.7	19.0	17.1	14.4	31.9	15min
Dum12	110.6	141.4	147.8	152.9	151.4	143.9	125.5	152.9	1hr

Node	15min	30min	45min	1hr	1.5hr	2hr	3hr	Max Flow (m3/s)	Critical Duration
OUT-N	508.6	736.3	849.7	907.3	887.5	840.9	710.6	907.3	1hr

Table A-13 Estimated 2 year, 20 year, 100 year, 200 year, 500year ARI and PMF Peak Flows (m3/s) under Existing Conditions at All Locations

Node	2yr		20yr		100yr		200yr		500yr		PMF	
	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur
U8	0.5	1.5hr	1	1.5hr	1.1	1.5hr	1	1.5hr	1	1.5hr	4	15min
U6	1.9	2hr	4	2hr	6.1	2hr	7	2hr	8	2hr	22	30min
U7	3.8	2hr	8	2hr	11.1	1.5hr	13	1.5hr	15	1.5hr	38	30min
W7	4.0	2hr	9	2hr	11.8	2hr	13	1.5hr	15	1.5hr	40	15min
E1	2.4	2hr	5	1.5hr	6.2	1.5hr	7	1.5hr	8	1.5hr	22	15min
E2	2.7	2hr	6	2hr	7.5	1.5hr	9	1.5hr	10	1.5hr	26	15min
W1	2.5	2hr	5	2hr	7.0	1.5hr	8	1.5hr	9	1.5hr	24	15min
Dum1	7.0	2hr	14	2hr	18.1	1.5hr	21	1.5hr	24	1.5hr	60	30min
E3	2.7	2hr	6	2hr	8.0	1.5hr	9	1.5hr	10	1.5hr	26	15min
W2	2.5	2hr	6	2hr	7.8	2hr	9	1.5hr	10	1.5hr	26	30min
W3	3.5	2hr	8	2hr	10.4	2hr	12	1.5hr	14	1.5hr	35	15min
W4	6.4	2hr	14	2hr	18.6	1hr	21	1hr	25	1hr	64	30min
Dum8	17.6	2hr	37	2hr	48.9	1.5hr	56	1hr	65	1hr	163	30min
E4	3.6	2hr	8	1.5hr	10.0	1.5hr	11	1.5hr	13	1.5hr	35	15min
W5	2.2	2hr	5	2hr	6.4	1.5hr	7	1.5hr	8	1.5hr	22	15min
W6	4.7	2hr	10	2hr	12.8	2hr	15	2hr	17	2hr	43	30min
Dum7	21.6	2hr	44	2hr	59.9	1hr	68	1hr	79	1hr	197	45min
E5	3.1	2hr	6	1.5hr	8.5	1.5hr	9	1.5hr	11	1hr	29	15min
W8	2.3	2hr	5	2hr	6.7	1.5hr	8	1.5hr	9	1.5hr	23	15min
Dum6	25.7	2hr	52	2hr	69.9	1hr	79	1hr	91	1hr	243	1hr
E6	2.7	2hr	5	1.5hr	7.0	1.5hr	8	1.5hr	9	1hr	25	15min
W10	1.9	2hr	4	2hr	5.5	1.5hr	6	1.5hr	7	1.5hr	19	15min

Node	2yr		20yr		100yr		200yr		500yr		PMF	
	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur
W9	2.7	2hr	6	2hr	7.9	1.5hr	9	1.5hr	10	1.5hr	27	15min
W11	5.5	2hr	12	2hr	15.3	2hr	17	2hr	20	1hr	50	15min
W10-1	7.0	2hr	15	2hr	19.3	2hr	22	2hr	25	2hr	64	30min
W12	2.8	2hr	6	1.5hr	7.2	1.5hr	8	1.5hr	9	1.5hr	25	15min
Dum5	31.0	2hr	62	2hr	82.3	2hr	93	1hr	106	1hr	305	1hr
F1	1.0	1.5hr	2	1.5hr	2.3	1.5hr	3	1.5hr	3	1.5hr	8	15min
N1	1.1	1.5hr	2	1.5hr	2.6	1.5hr	3	1.5hr	3	1.5hr	9	15min
N3	2.4	2hr	5	2hr	7.6	1.5hr	9	1.5hr	10	1.5hr	25	30min
N2	5.6	2hr	13	2hr	17.4	1.5hr	20	1.5hr	23	1.5hr	58	30min
U1	3.1	2hr	7	2hr	9.5	2hr	11	1.5hr	13	1.5hr	31	30min
U2	2.7	2hr	6	2hr	8.0	1.5hr	9	1.5hr	11	1.5hr	26	30min
U3	3.2	2hr	7	2hr	9.5	1.5hr	11	1.5hr	12	1.5hr	31	15min
U4	0.6	1.5hr	1	1.5hr	1.5	1.5hr	2	1.5hr	2	1.5hr	5	15min
M1	2.3	1.5hr	5	1.5hr	7.6	1.5hr	9	1.5hr	10	1.5hr	24	30min
M2	2.7	2hr	6	1.5hr	8.8	1.5hr	10	1.5hr	12	1.5hr	28	30min
M4	1.7	2hr	4	2hr	5.0	1.5hr	6	1.5hr	7	1.5hr	17	15min
Dum10	6.7	2hr	15	2hr	19.8	2hr	22	2hr	26	2hr	65	30min
M5-1	1.6	2hr	4	2hr	5.3	1.5hr	6	1.5hr	7	1.5hr	17	30min
M5	2.0	2hr	4	2hr	5.3	1.5hr	6	1.5hr	7	1.5hr	19	15min
Dum11	9.7	2hr	21	2hr	28.4	2hr	32	2hr	37	2hr	93	30min
M11	1.5	2hr	3	2hr	4.5	2hr	5	1.5hr	6	1.5hr	15	15min
M5-2	1.3	2hr	3	2hr	3.9	2hr	4	2hr	5	1.5hr	13	30min
M12	1.7	2hr	4	2hr	5.2	1.5hr	6	1.5hr	7	1.5hr	17	15min
Dum2	13.8	2hr	30	2hr	38.8	2hr	44	2hr	50	2hr	129	30min
M13	15.8	2hr	34	2hr	43.9	2hr	49	2hr	57	1hr	144	30min
M16	17.3	2hr	36	2hr	47.4	2hr	53	2hr	61	1hr	153	45min

Node	2yr		20yr		100yr		200yr		500yr		PMF	
	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur
M3	2.6	2hr	6	1.5hr	7.4	1.5hr	8	1.5hr	10	1.5hr	24	15min
M6-1	5.2	2hr	11	1.5hr	14.2	1hr	16	1hr	19	1hr	47	15min
M6	7.3	2hr	15	2hr	20.4	2hr	23	1hr	27	1hr	69	30min
M7	2.5	2hr	5	2hr	7.3	2hr	8	1.5hr	10	1.5hr	24	15min
M8	11.7	2hr	25	2hr	33.5	2hr	38	2hr	43	1hr	113	30min
M9	1.5	1.5hr	3	1.5hr	4.2	1.5hr	5	1.5hr	5	1.5hr	13	15min
M10	3.6	2hr	8	2hr	10.6	2hr	12	2hr	14	2hr	35	30min
M14	1.6	2hr	4	2hr	5.5	2hr	6	1.5hr	7	1.5hr	18	30min
Dum9	15.1	2hr	32	2hr	41.8	2hr	47	1hr	55	1hr	139	45min
M15	16.2	2hr	34	2hr	44.1	2hr	50	1hr	58	1hr	148	45min
M17	2.7	2hr	6	2hr	8.7	2hr	10	2hr	12	2hr	30	30min
Dum13	18.6	2hr	39	2hr	50.8	1hr	58	1hr	67	1hr	174	45min
M18	37.1	2hr	76	2hr	100.7	2hr	113	2hr	130	1hr	338	1hr
U5	0.7	1.5hr	1	1.5hr	1.7	1.5hr	2	1.5hr	2	1.5hr	6	15min
OUT-E	45.4	2hr	92	2hr	121.1	2hr	135	2hr	154	2hr	438	1hr
C1	0.6	2hr	1	2hr	2.0	2hr	2	2hr	3	2hr	8	30min
C2	2.0	2hr	5	2hr	6.6	2hr	8	2hr	9	1.5hr	24	30min
C3	3.1	2hr	7	2hr	9.5	2hr	11	2hr	13	1hr	35	45min
C4	5.4	2hr	12	2hr	16.3	2hr	19	2hr	22	2hr	58	1hr
C5	1.8	2hr	4	2hr	5.6	2hr	6	2hr	7	1.5hr	19	30min
C6	2.6	2hr	6	2hr	7.8	1.5hr	9	1.5hr	10	1.5hr	26	15min
Dum3	8.1	2hr	18	2hr	23.8	2hr	27	2hr	31	2hr	84	1hr
C8	1.6	2hr	3	2hr	4.6	2hr	5	1.5hr	6	1.5hr	16	15min
C7	2.3	2hr	5	2hr	6.8	1.5hr	8	1.5hr	9	1.5hr	23	15min
C10	2.2	2hr	5	2hr	6.5	1.5hr	7	1.5hr	9	1.5hr	22	15min
Dum4	11.7	2hr	24	2hr	32.4	1.5hr	37	1.5hr	43	1.5hr	115	1hr

Node	2yr		20yr		100yr		200yr		500yr		PMF	
	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur	Flow	Crit.dur
C11	12.8	2hr	27	2hr	36.0	1.5hr	41	1.5hr	47	1.5hr	125	1hr
C9	3.4	2hr	7	2hr	9.5	1.5hr	11	1.5hr	12	1.5hr	33	15min
C12	3.5	2hr	7	1.5hr	9.1	1.5hr	10	1.5hr	12	1hr	32	15min
Dum12	16.1	2hr	34	2hr	45.0	2hr	51	2hr	59	2hr	153	1hr
OUT-N	92.1	2hr	186	2hr	248.0	2hr	278	2hr	318	2hr	907	1hr

A.4 Previous Modelling Approach

A.4.1 Narrabeen Lagoon Flood Study (BMT-WBM, 2013)

Hydrologic modelling was conducted using XP-RAFTS to model 101 sub-catchments with an average catchment of area of 54.5 ha. Representative vectored slopes, impervious percentages and PERN (roughness) values have been assigned to each sub-catchment based on available LiDAR data (from March 2007) and aerial photography (from 2007). Delineation has presumably been conducted either manually or using delineation software such as CatchSIM.

A.4.2 Pittwater Overland Flow Flood Study (Cardno, 2013)

Hydrology has been conducted using the direct rainfall method as part of the two dimensional Sobek model, with rainfall applied directly to the topographical grid and flows routed automatically by the model.

A.4.3 Mona Vale - Bayview Flood Study (DHI, 2002)

Hydrologic modelling was conducted using RDII (MOUSENAM) to model 56 sub-catchments with an average catchment of area of 9.3 ha. Representative vectored slopes, impervious percentages and PERN (roughness) values have been assigned to each sub-catchment based on available 2m contour data and land-uses confirmed with aerial photography. Delineation has been conducted manually.

A.4.4 Warriewood Valley Flood Study (Cardno Lawson Treloar, 2005)

Hydrologic modelling was conducted using XP-RAFTS to model 56 sub-catchments with an average catchment of area of 9.0 ha. Representative vectored slopes, impervious percentages and PERN (roughness) values have been assigned to each sub-catchment based on available 2m interval contour information and aerial photography (from July 2003). Delineation has been conducted manually.

A.4.5 Warriewood Valley Water Management Specification (Lawson & Treloar, 2001)

Hydrologic modelling was conducted using XP-RAFTS to model 15 sub-catchments or Sectors with an average catchment of area of 9.5 ha. Representative vectored slopes, impervious percentages and PERN (roughness) values have been assigned to each sub-catchment based on available information and aerial photography. Delineation was conducted manually.

A.4.6 Previous Model Parameters

A.4.6.1 Narrabeen Lagoon Flood Study (BMT-WBM, 2013)

Table A-14: Initial and Continuing Loss

Land Zone	Initial Loss (mm)	Continuing Loss (mm/hr)	Roughness
Calibration Event Parameters			
Impervious Area	5	0	0.015
Pervious Area	30	2.5	0.1
Design Event Parameters			
Impervious Area	1.5	0	0.015
Pervious Area	10	2.5	0.035

Bx – 1

Note – Design Event parameters were adopted following sensitivity testing of loss parameters in the hydraulic model. It should be noted that the flood levels for Mullet Creek were generally estimated to be higher than those recorded for historical events.

A.4.7 Pittwater Overland Flow Flood Study (Cardno, 2013)

Hydrology has been conducted using the direct rainfall method as part of the two dimensional Sobek model, with rainfall applied directly to the topographical grid and flows routed automatically by the model.

A consistent rainfall loss was applied to the entire LGA; initial loss of 5mm and 2.5mm continuing loss. These values were determined to be intermediate values between losses associated to pervious and impervious surfaces through pilot testing with local XP_RAFTS models.

A.4.8 Warriewood Valley Flood Study (Cardno Lawson Treloar, 2005)

Table A-15: Initial and Continuing Loss

Land Zone	Initial Loss (mm)	Continuing Loss (Proportional)	Roughness
Impervious Area	1.5	0	
Forest	10	0.35	0.1
Rural	10	0.05	0.07
Urban	10	0.02	0.015

Bx = 3

Note - The composition of the model did not use the split catchment approach, which is now uncommon. The parameters adopted in this study may not be applicable to a split catchment approach.

A.4.9 Warriewood Valley Water Management Specification (Lawson & Treloar, 2001)

Table A-16: Initial and Continuing Loss

Land Zone	Initial Loss (mm)	Continuing Loss (mm/hr)
Forest	50	2

Rural	30	2
Urban-pervious	10	1.5
Urban-impervious	1.5	0

Note - The XP_RAFTS modelling approach was calibrated using time series water level data from the fern and Mullet Creek gauges operated by MHL. It was discussed in the report that the length of data for calibration was short and further validation was recommended.

A.4.10 Design Rainfall

A comparison of the peak design rainfall intensities is included in **Table A-17**.

Table A-17: Peak design rainfall intensities

Study	20yr ARI 2hr	100yr ARI 2hr	PMF 1hr
Warriewood	47	62	333
Narrabeen	36.4	64	280
Mona Vale	45.3	59.7	480
Ingleside	46.6	61.6	320

A.5 XP_RAFTS Model under Developed Conditions

The existing XP_RAFTS model was modified for the development conditions to represent the land uses proposed in the Ingleside Concept Plan (Dated August 2014).

The catchment was divided into 72 subcatchments by considering the proposed design layout, land uses and the existing subcatchment layout. The XP_RAFTS subcatchment layout for the development scenario is shown in **Figure A-3**.

The impervious percentage for each land use under the development conditions is listed in **Table A-18**.

Table A-18 Impervious Percentage Adopted for the Proposed Land Uses

Land Use	Impervious Percentage
Medium Density Residential	95%
Low Density Residential	80%
Environmental Living Area/Bahai Temple	20%
Neighbourhood Centre	60%
Community Centre	60%
School	70%
Open Space	5%
Bushland	0%

The details of these subcatchments are provided in **Table A-19**. The estimated total peak flows for 100 year and 2 year ARI at each node location are presented in **Table A-20**.

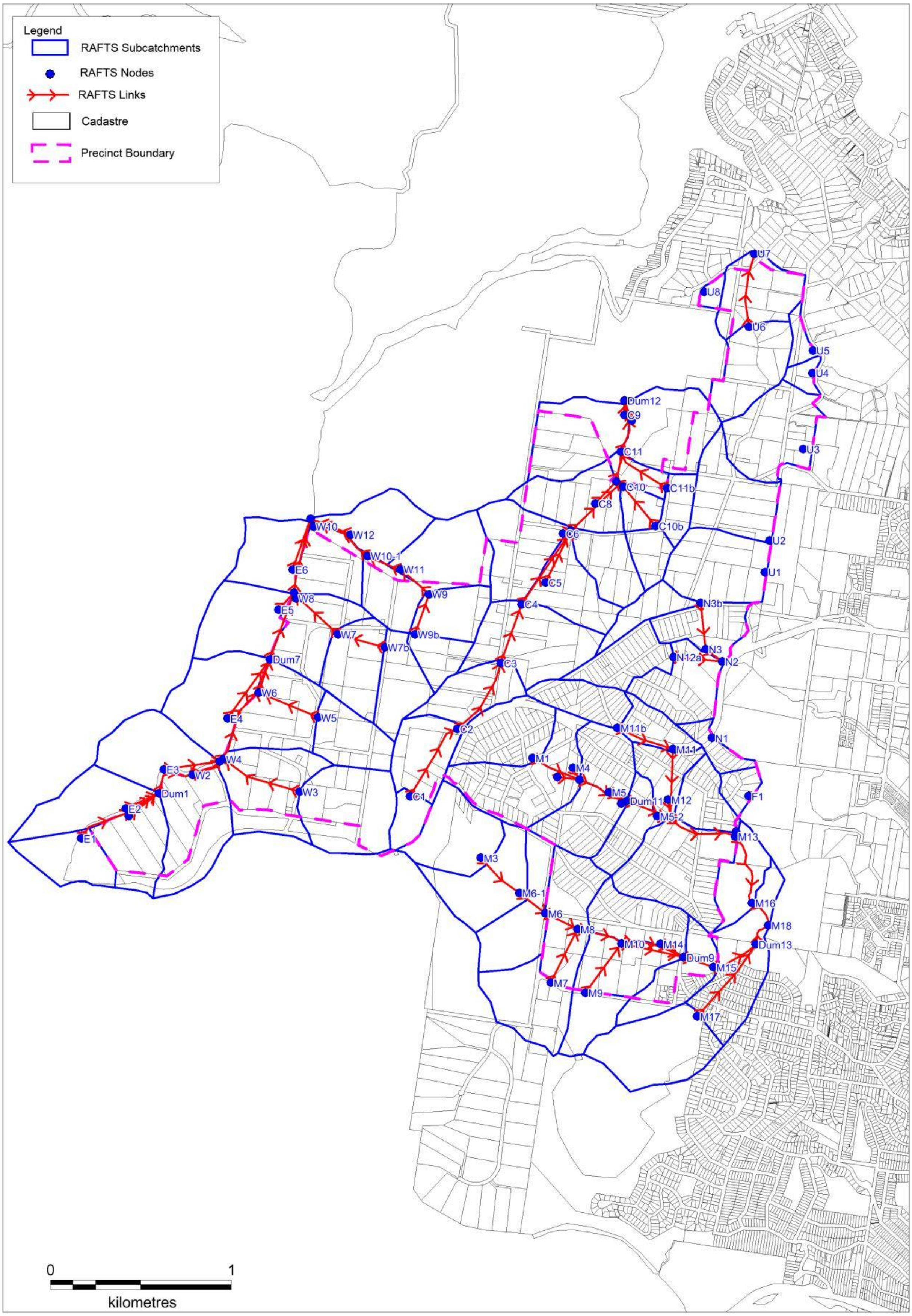


Figure A-3 Sub-Catchment Boundaries and Node Locations under Developed Conditions

Table A-19 XP-Rafts Subcatchment Properties under Developed Conditions

Id	Area (ha)	Impervious Area (%)	Slope (%)
C1	5.03	21.8	2.05
C10	4.73	1	8.2
C10b	5.99	46.8	10.32
C11	4.65	1	9.94
C11b	5.71	64.9	5.85
C12	19.90	1	16.52
C2	13.40	58.5	2.67
C3	12.47	34.1	4.03
C4	22.92	70.3	4.93
C5	13.43	73	5.25
C6	17.31	42.3	7.8
C7	10.97	79.8	7.3
C8	15.59	2	7.62
C9	19.42	2	11.96
E1	11.90	1	14.38
E2	15.64	1	10
E3	17.61	1	8.01
E4	20.10	1	13.14
E5	16.82	1	13.06
E6	13.30	1	15.1
F1	3.95	8.6	15.85
M1	16.16	81.9	5.96
M10	13.48	79.1	5.96
M11	7.28	17.2	5.85
M11b	9.63	70.4	6.7
M12	8.43	33.4	6.87

Id	Area (ha)	Impervious Area (%)	Slope (%)
M13	24.94	51.3	3.66
M13b	9.35	47.3	7.9
M14	13.55	38	4.51
M15	13.11	40.8	6.06
M16	10.20	10	11.39
M17	22.28	2	5.51
M18	21.20	40	9.42
M2	18.12	71.4	7.24
M3	17.17	20.5	10.64
M4	5.90	59.7	7.81
M5	10.41	38	9.96
M5-1	12.19	70.6	5.23
M5-2	9.26	50.5	4.67
M6	15.94	3	5.86
M6-1	17.09	2	7.94
M7	16.57	2	7.27
M8	17.36	49.8	4.67
M9	8.11	20.9	6.99
N1	4.56	11.1	14.94
N12a	11.44	79.8	6.55
N2	14.72	8.9	7.88
N3	11.28	64.7	6.01
N3b	6.80	49.3	2.62
U1	19.75	68.3	7.59
U2	18.04	62.8	7.39
U3	20.41	5	9.25
U4	2.60	1	13.58

Id	Area (ha)	Impervious Area (%)	Slope (%)
U5	2.89	1	13.58
U6	16.10	5	4.32
U7	15.25	5	8.14
U8	1.76	5	15.08
W1	14.64	2	9.67
W10	12.36	2	6.78
W10-1	9.80	2	7.53
W11	17.12	1	10.94
W12	13.75	1	15.69
W2	21.51	2	6.54
W3	22.47	2	9.6
W4	21.30	2	6.49
W5	12.38	2	7.34
W6	17.65	2	9.34
W7	14.43	2	10.4
W7b	11.57	2	8.67
W8	14.47	1	7.94
W9	10.46	2	8.83
W9b	6.61	2	9.35

Table A-20 Estimated Peak Flows for 100 yr and 2yr ARI under Developed Conditions

Id	100yr Peak Flow (m^3/s)	2yr Peak Flow (m^3/s)
E2	7.46	2.67
E1	6.10	2.45
W1	7.09	2.74
Dum1	17.75	6.81
E3	7.93	2.69
W2	9.46	3.19

Id	100yr Peak Flow (m^3/s)	2yr Peak Flow (m^3/s)
W3	11.18	4.16
W4	18.78	6.92
Dum8	49.68	17.68
E4	9.85	3.62
W5	6.49	2.48
W6	14.92	5.65
Dum7	59.17	21.62
W7b	7.56	3.28
W7	14.30	5.84
E5	8.34	3.13
W8	6.68	2.30
Dum6	69.25	25.78
E6	6.81	2.72
W10	5.55	1.87
W9b	4.47	2.02
W9	9.37	3.77
W11	17.21	6.69
W10-1	20.97	8.07
W12	7.06	2.83
Dum5	92.29	35.00
U8	1.01	0.43
U6	6.05	1.85
U7	10.93	3.59
F1	2.16	0.93
N1	2.47	1.06
N3b	3.36	1.30
N3	8.86	3.61

Id	100yr Peak Flow (m^3/s)	2yr Peak Flow (m^3/s)
N12a	7.61	3.29
N2	22.69	9.13
U3	9.41	3.17
M1	10.66	4.62
M2	11.20	4.79
M4	3.52	1.49
Dum10	22.26	9.71
M5-1	7.43	3.15
M5	5.51	2.15
Dum11	29.30	12.71
M11b	6.00	2.57
M11	9.27	3.73
M5-2	4.94	1.91
M12	4.20	1.59
Dum2	42.81	18.16
M13b	5.19	2.04
M13	49.71	20.98
M16	51.35	21.69
M3	8.34	3.18
M6-1	15.65	5.79
M6	22.06	7.89
M7	7.32	2.47
M8	33.68	11.91
M9	3.89	1.45
M10	10.33	4.12
M14	6.24	2.26
Dum9	40.54	14.78

Id	100yr Peak Flow (m^3/s)	2yr Peak Flow (m^3/s)
M15	42.90	15.76
M17	8.70	2.69
Dum13	49.51	18.20
M18	104.04	41.15
U5	1.58	0.68
U4	1.43	0.61
Dum_U4_U5	3.01	1.29
U2	10.57	4.41
U1	11.95	5.08
Dum_U1_U2	22.53	9.48
OUT-E	124.11	50.00

A.6 Detention Basin Assessment

This study undertook a hydrological assessment of detention basin options. The aim of the assessment was to meet the following water management targets:

- For the 2 and 100 year ARI events (2 hr durations):
  - Peak flow is +/-5% of predevelopment condition;
  - Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration; and
  - The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs

Seven off-line and three on-line basins were sited and their locations are shown in **Figure A-4**.

The hydrographs for each flow measurement lines are provided in **Figure A-5** to **Figure A-17**.

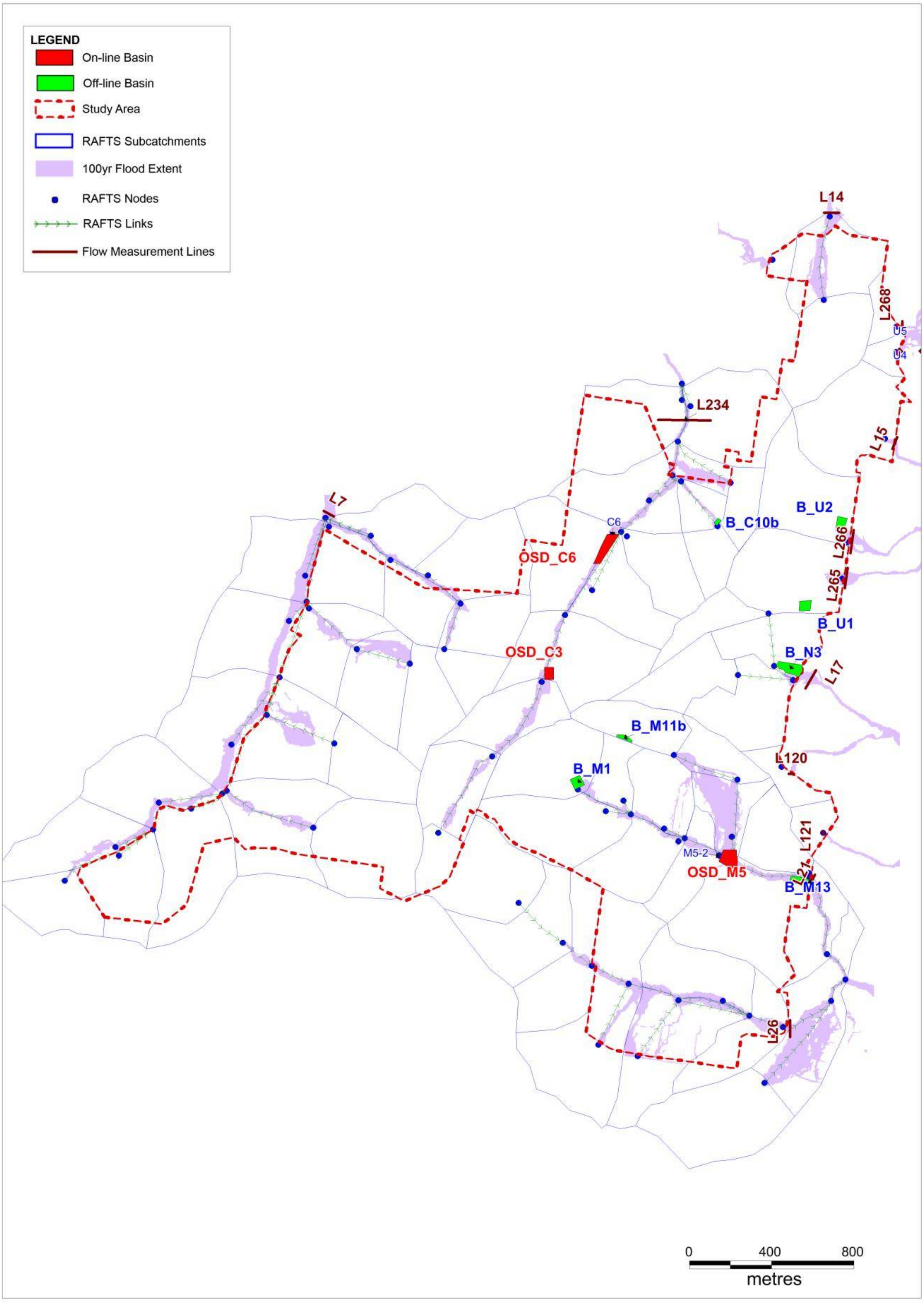
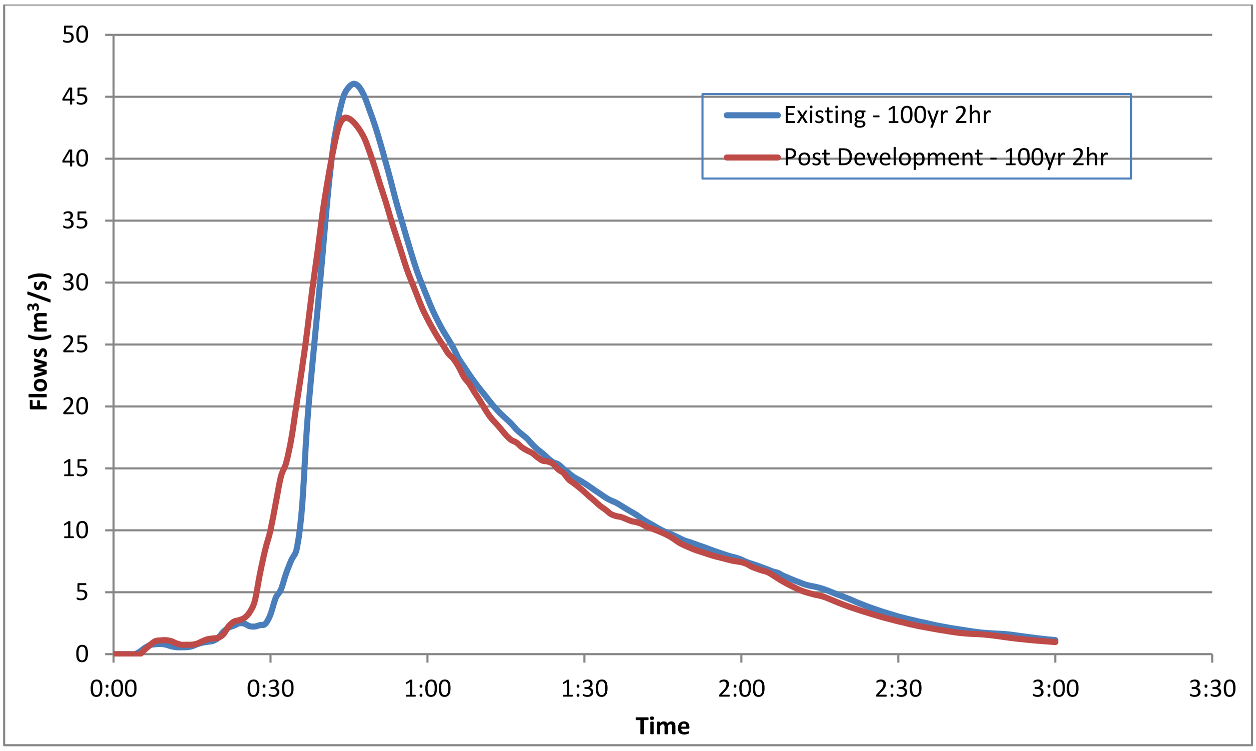


Figure A-4 Detention Basin Locations



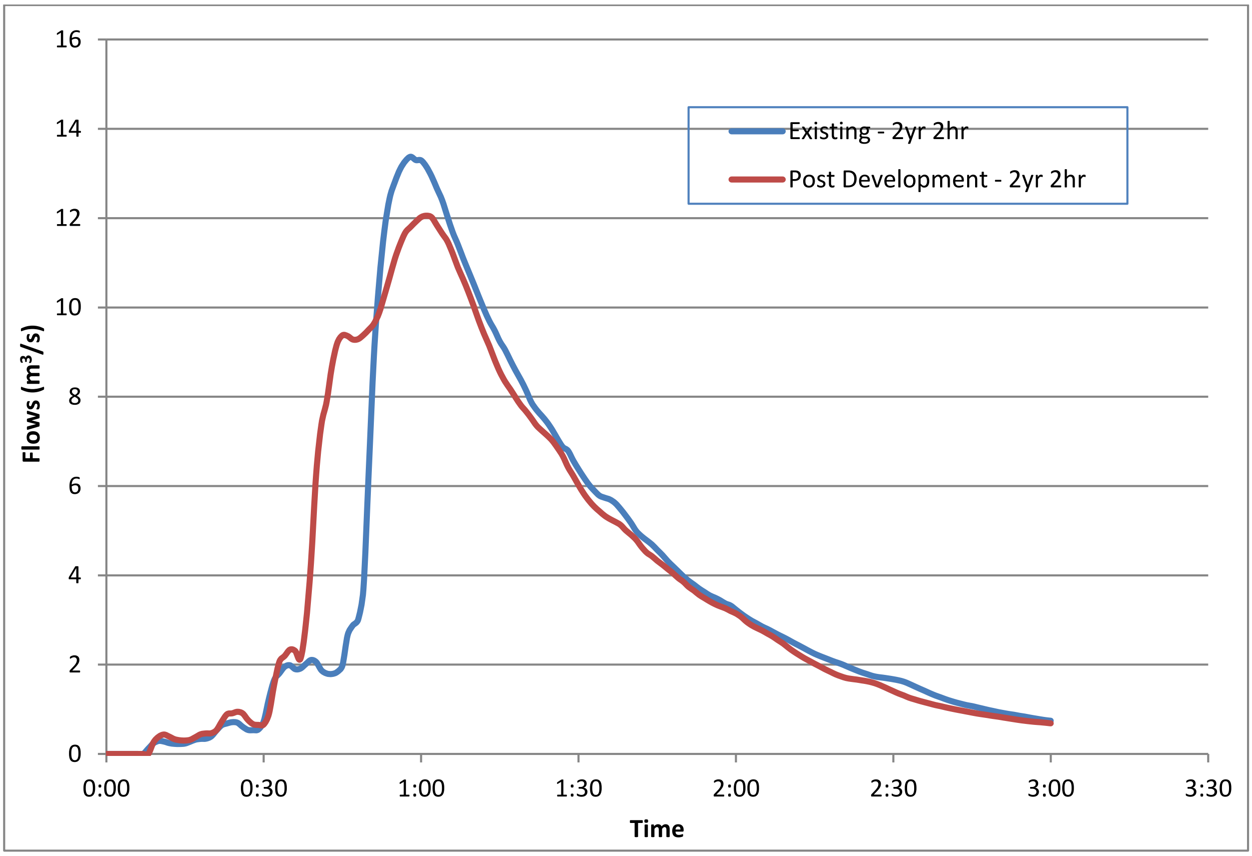
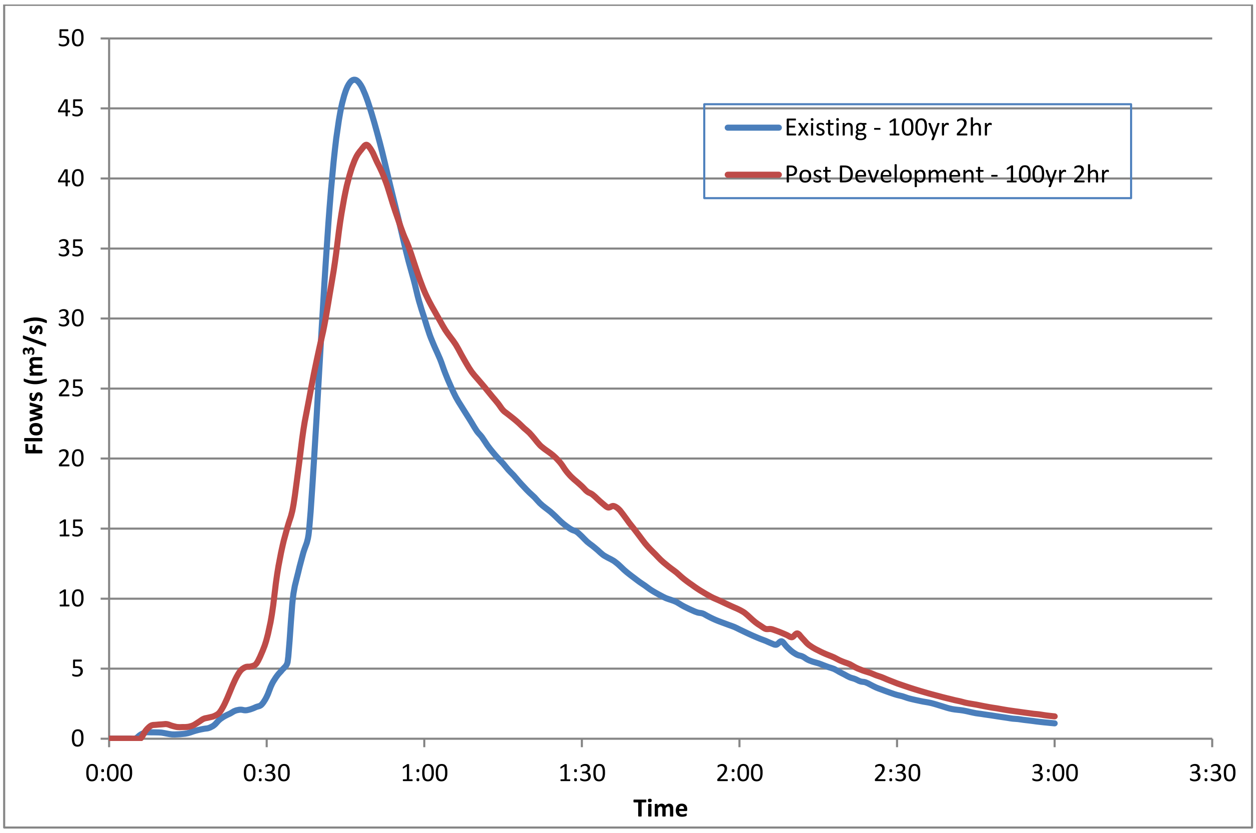


Figure A-5 Hydrograph Comparison at Flow Measurement Line L26



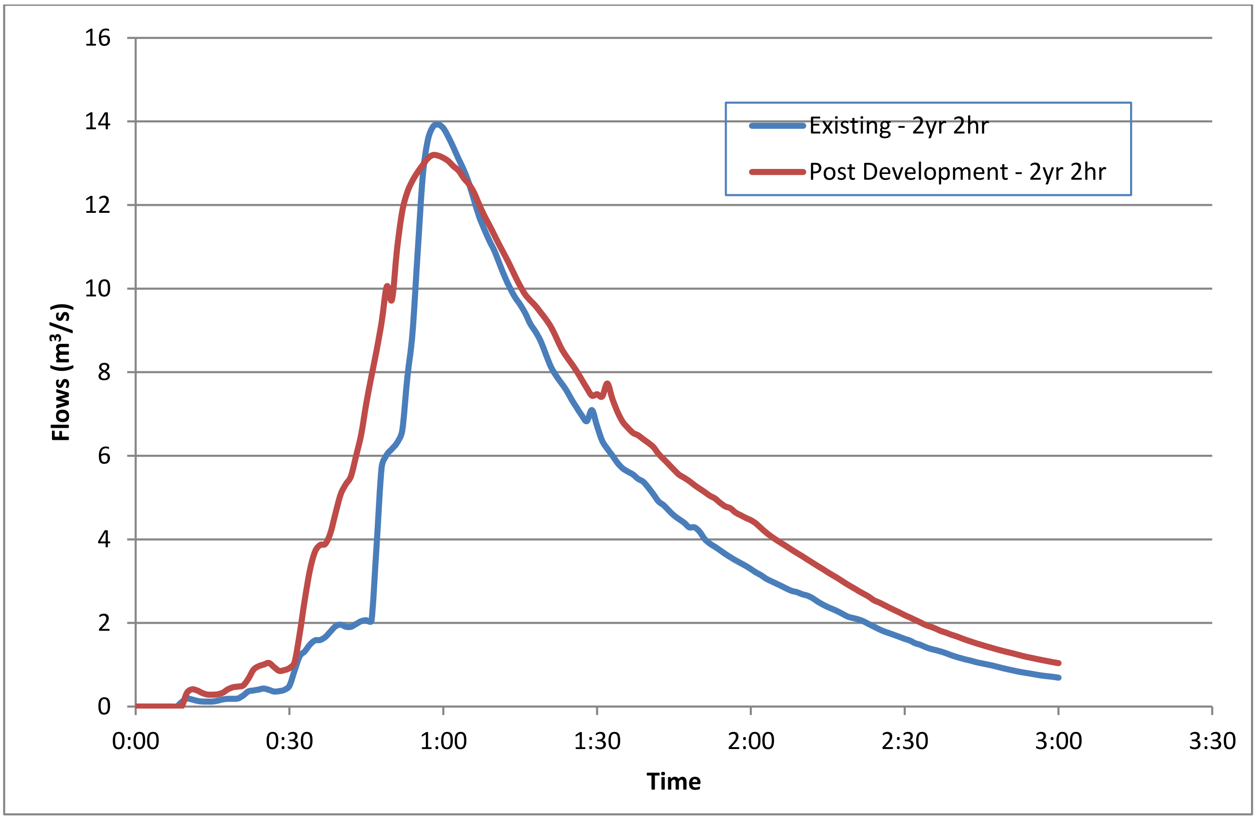
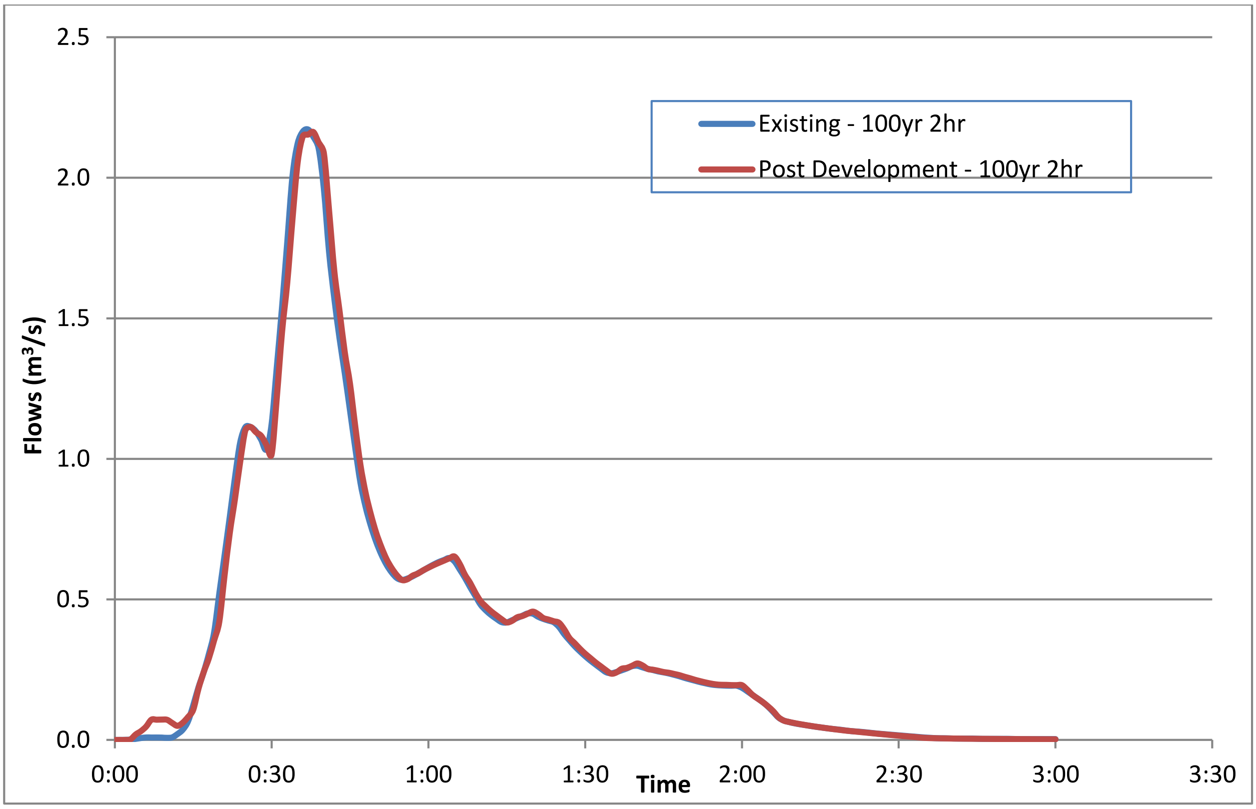


Figure A-6 Hydrograph Comparison at Flow Measurement Line L21



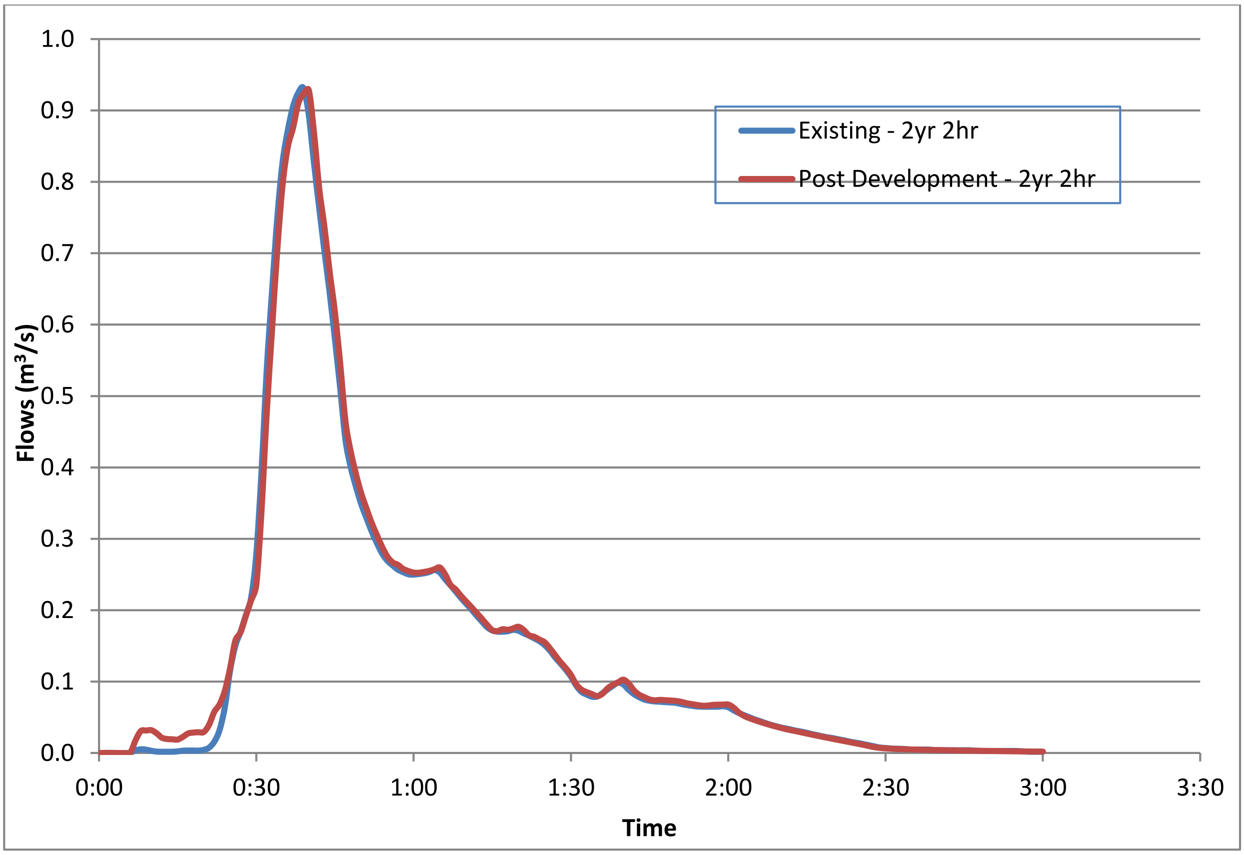
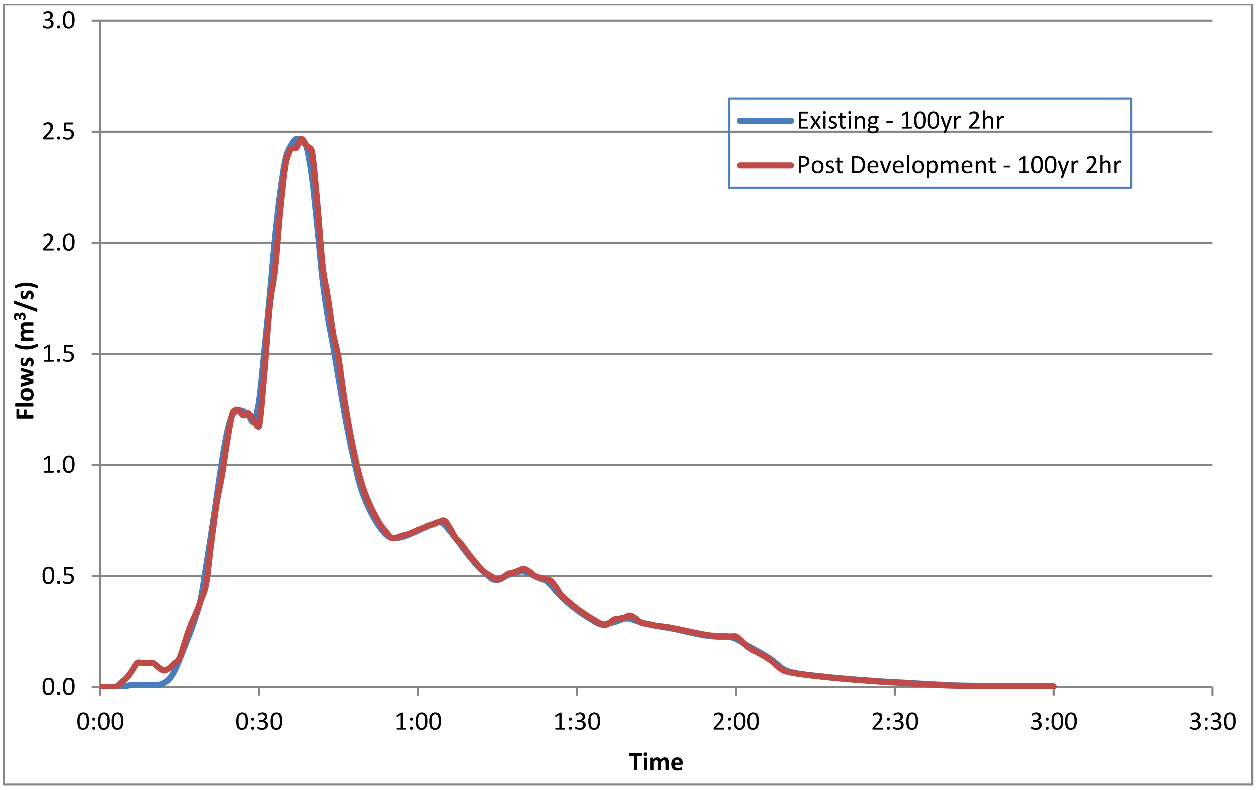


Figure A-7 Hydrograph Comparison at Flow Measurement Line L121



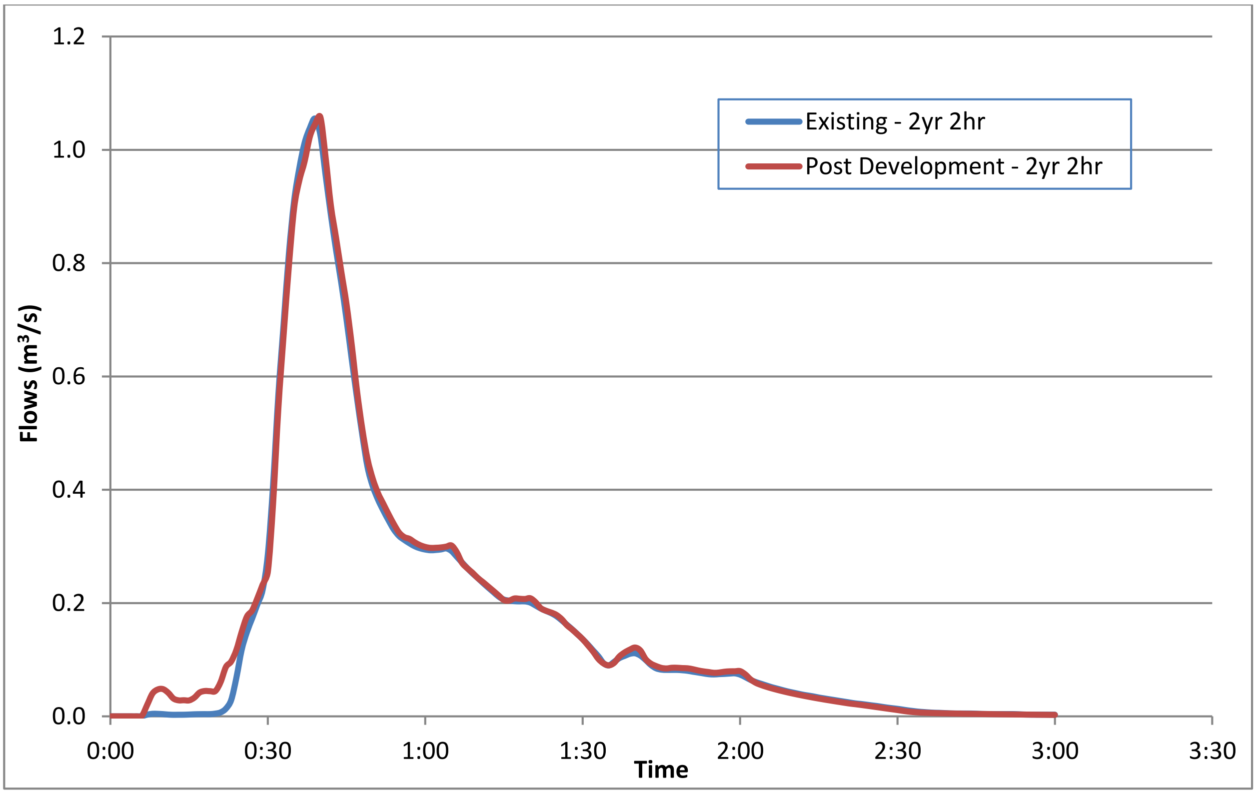
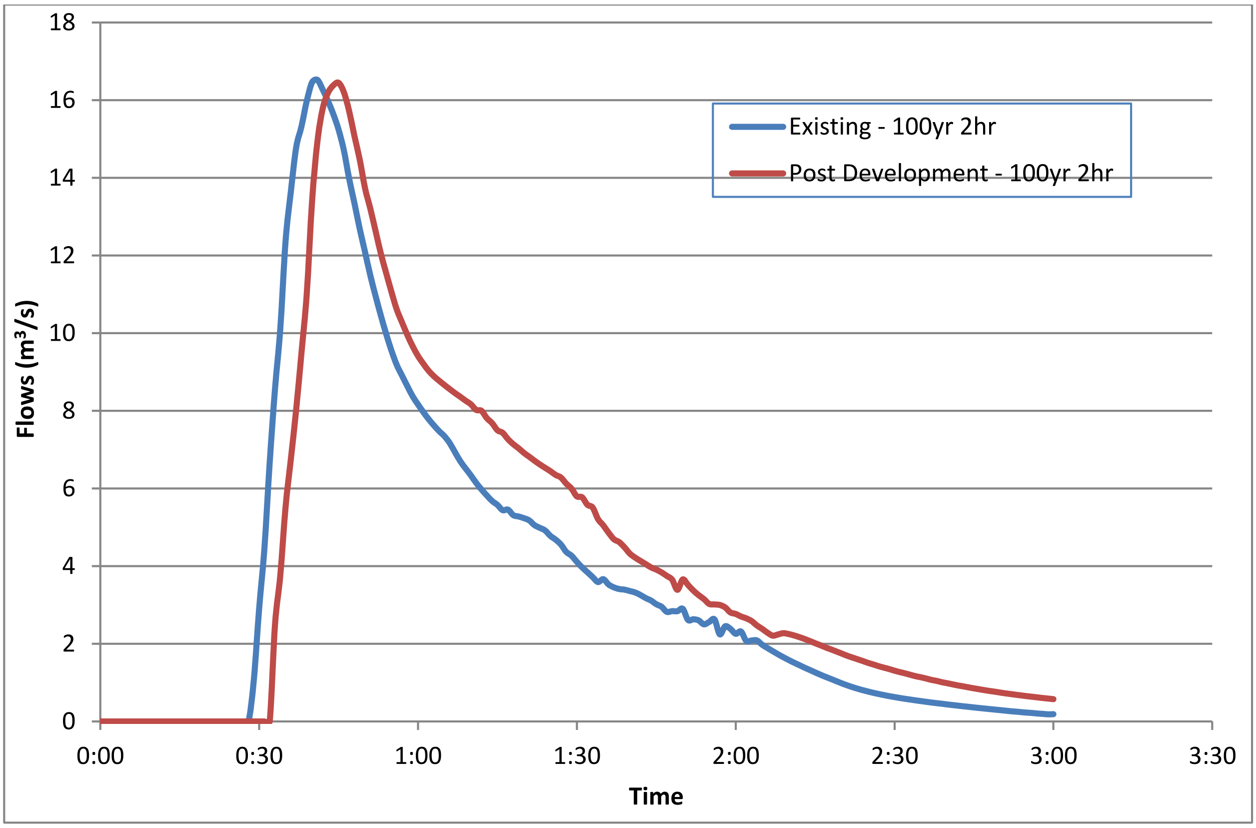


Figure A-8 Hydrograph Comparison at Flow Measurement Line L120



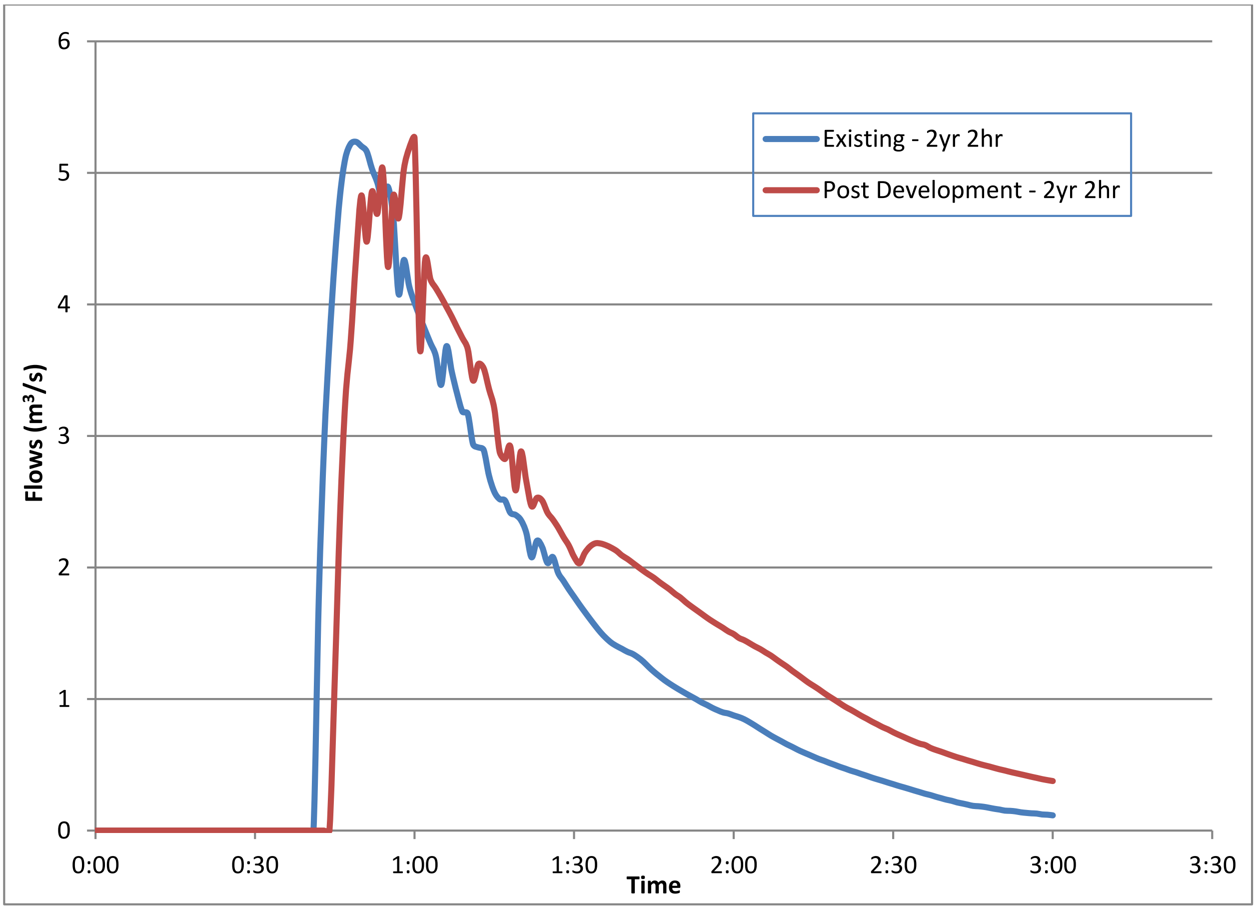
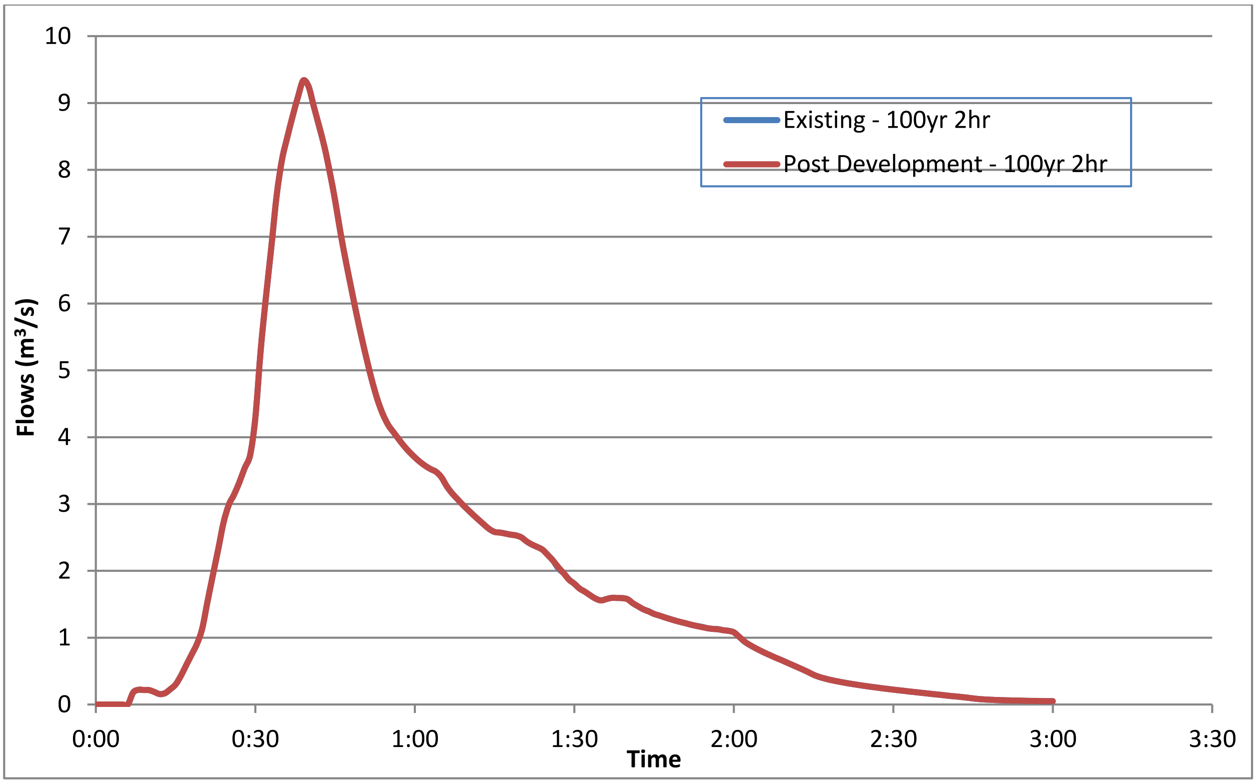


Figure A-9 Hydrograph Comparison at Flow Measurement Line L17



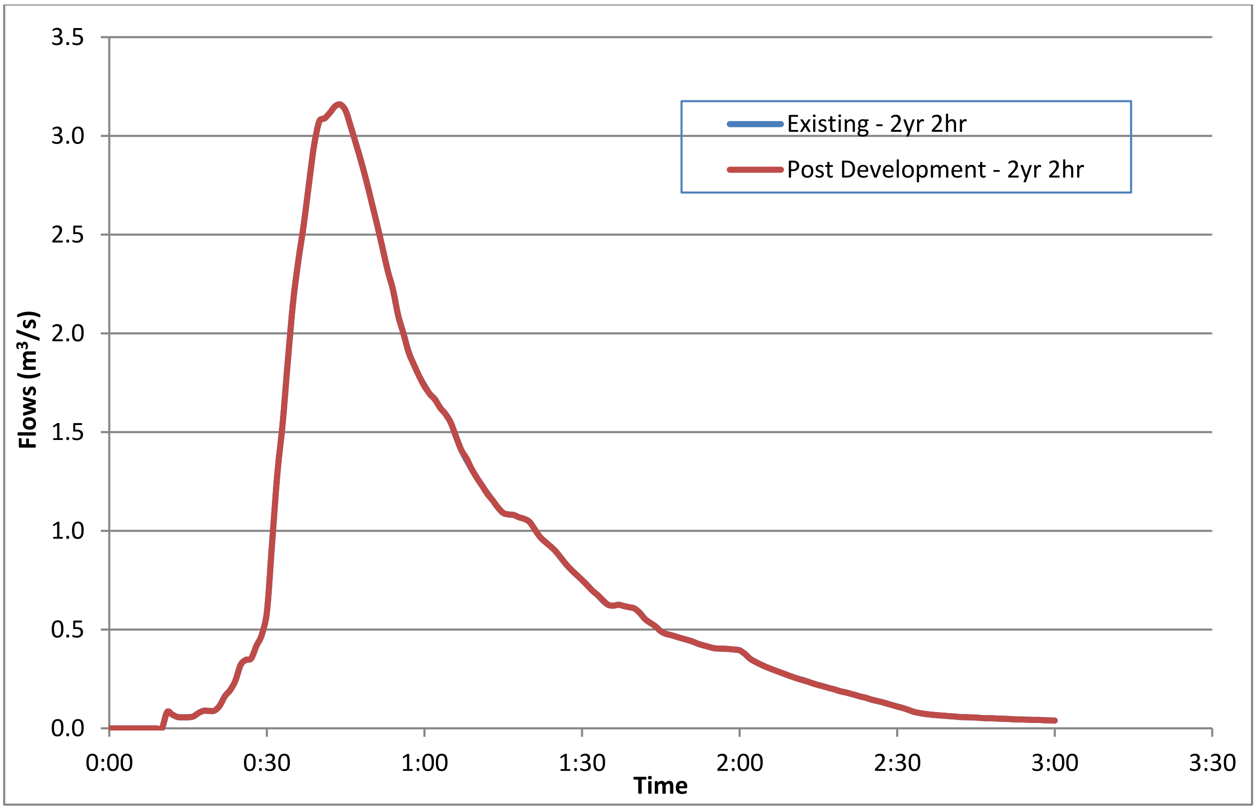
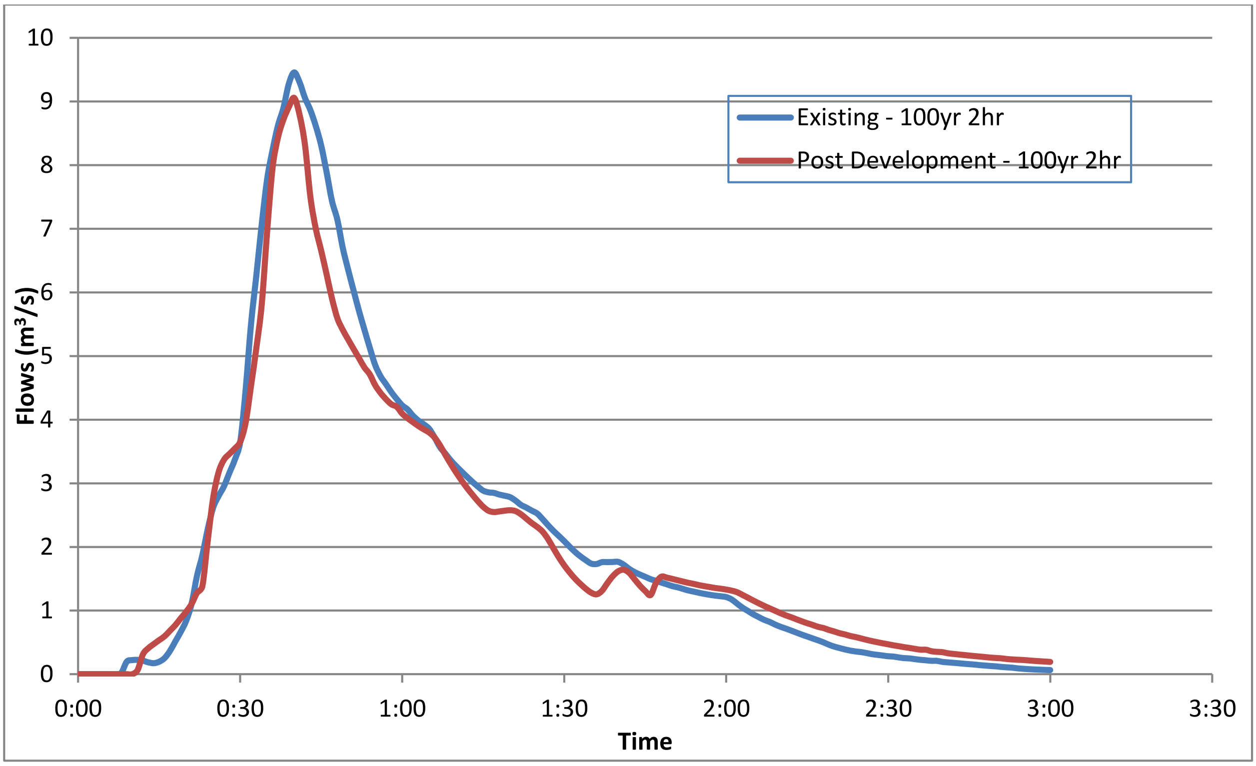


Figure A-10 Hydrograph Comparison at Flow Measurement Line L15



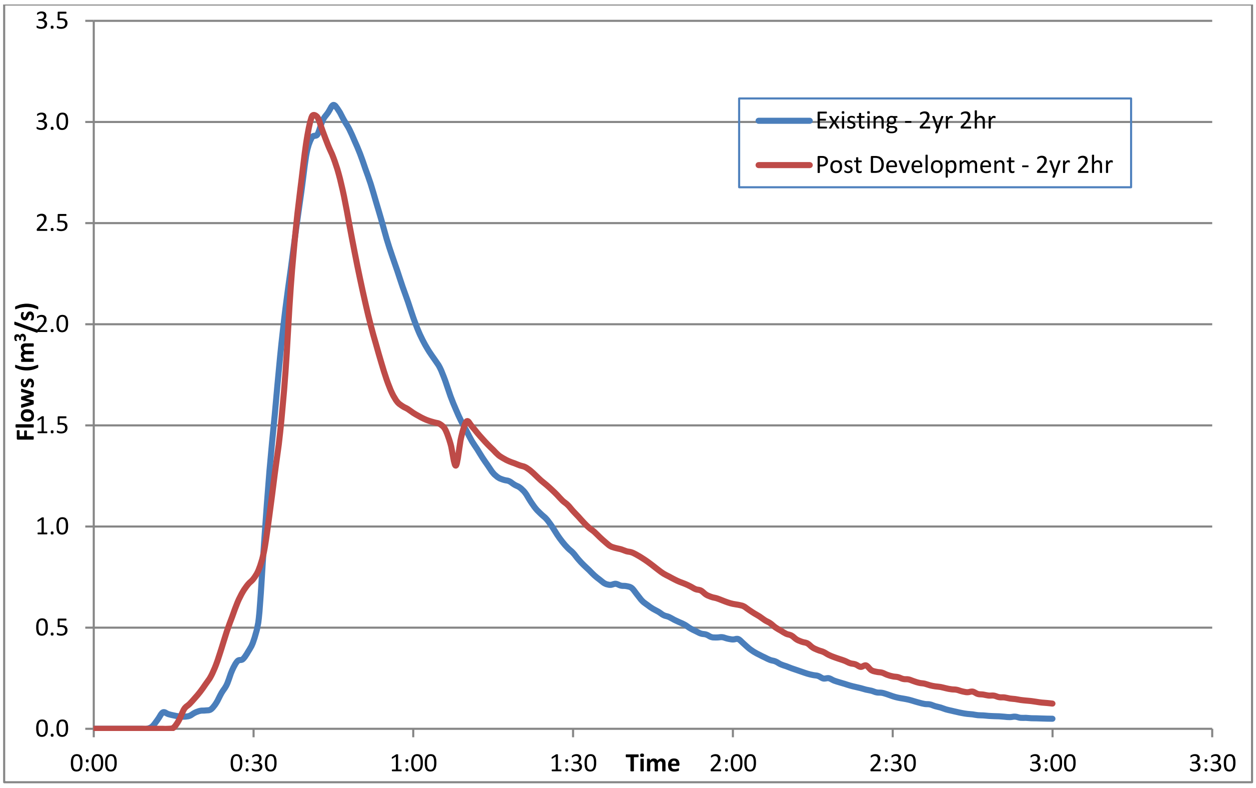
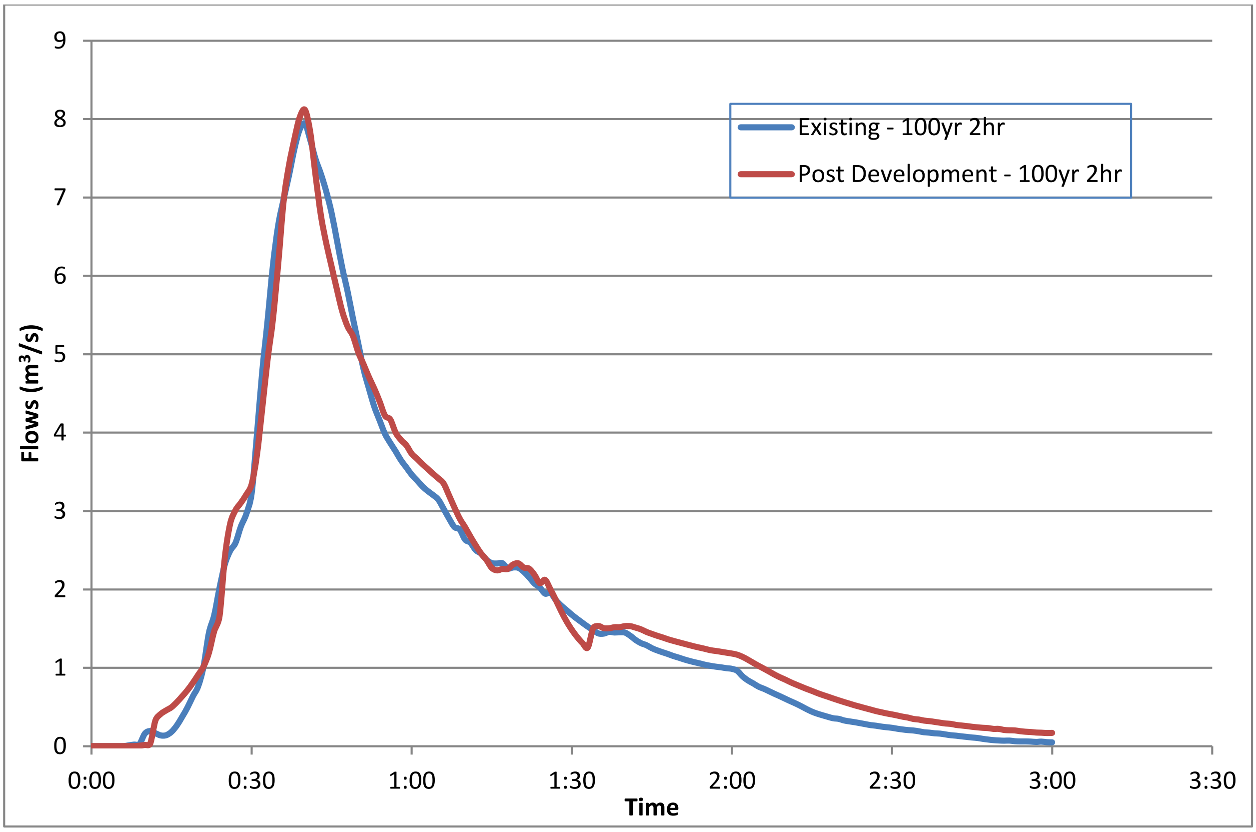


Figure A-11 Hydrograph Comparison at Flow Measurement Line L265



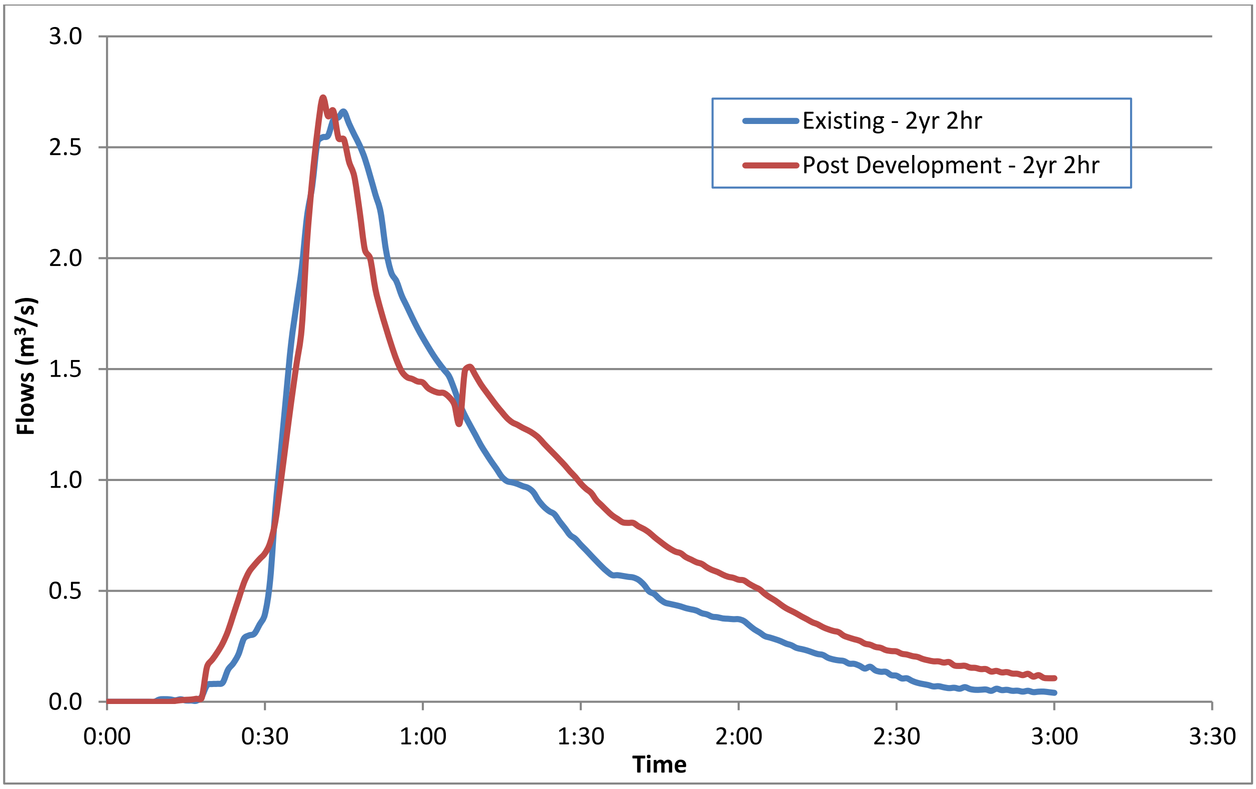
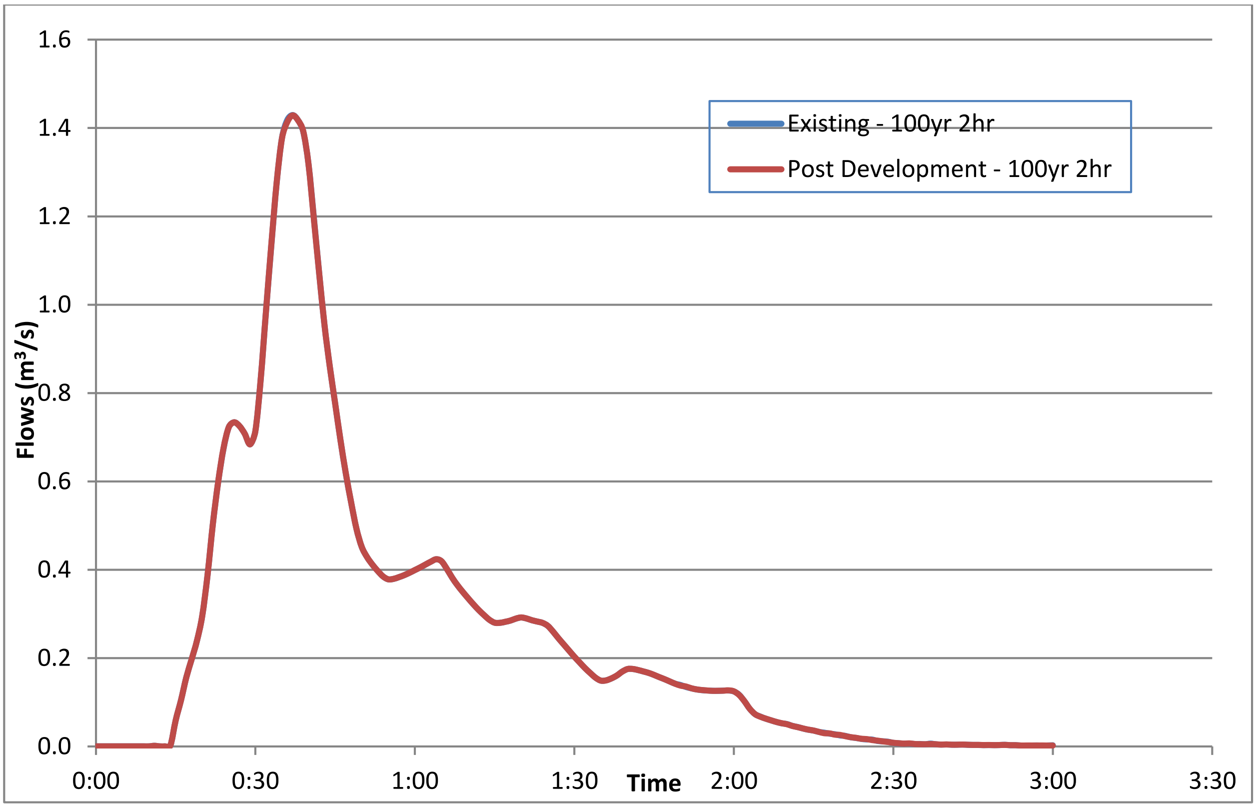


Figure A-12 Hydrograph Comparison at Flow Measurement Line L266



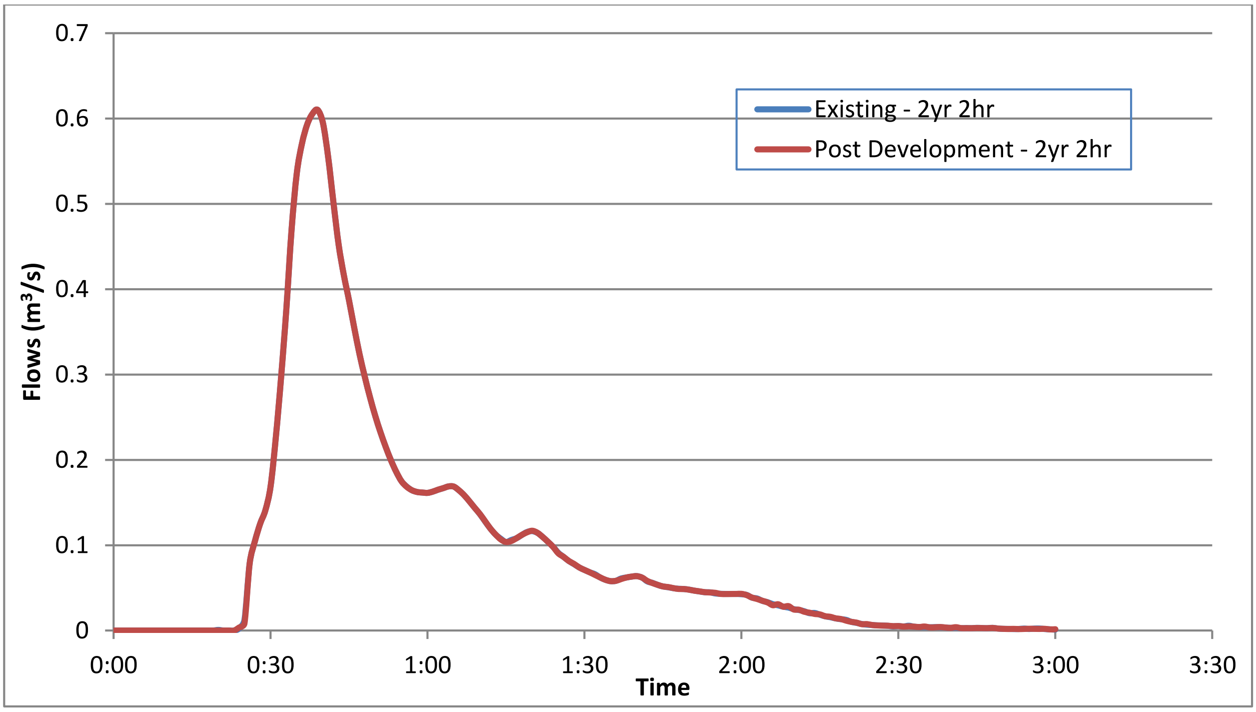
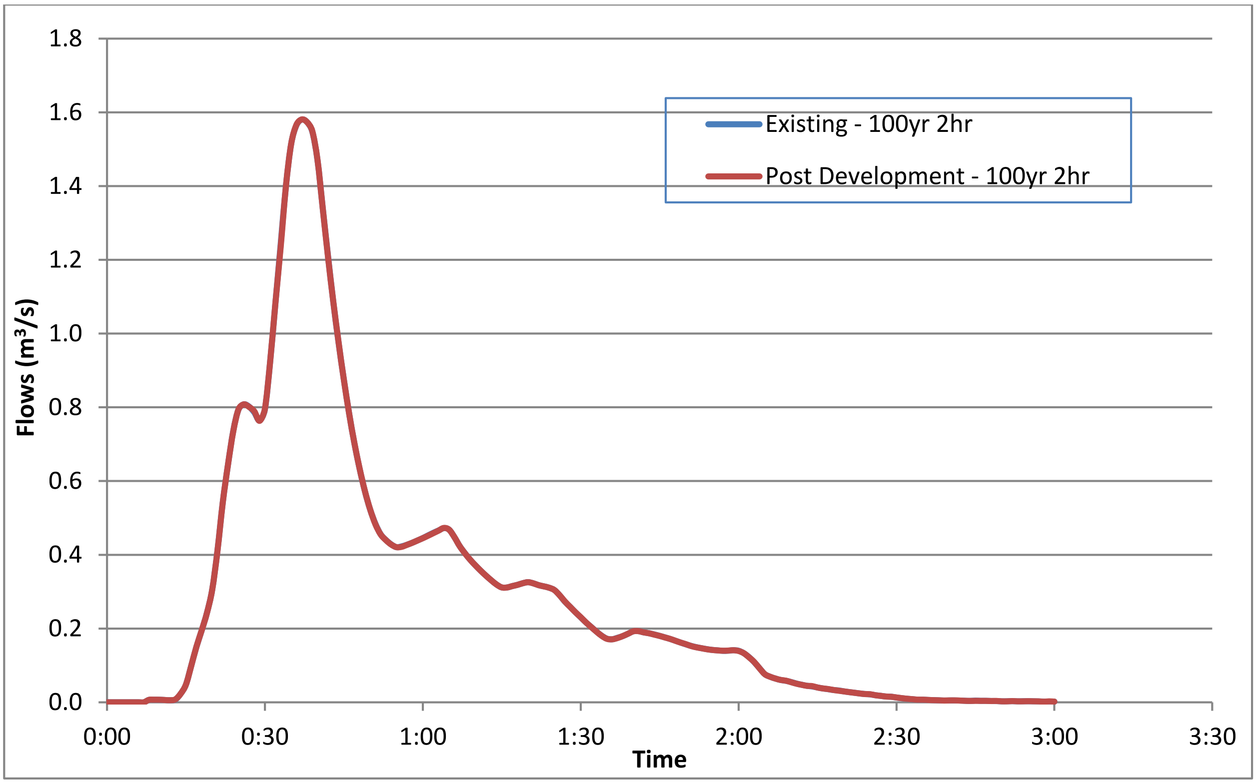


Figure A-13 Hydrograph Comparison at Flow Measurement Line L267



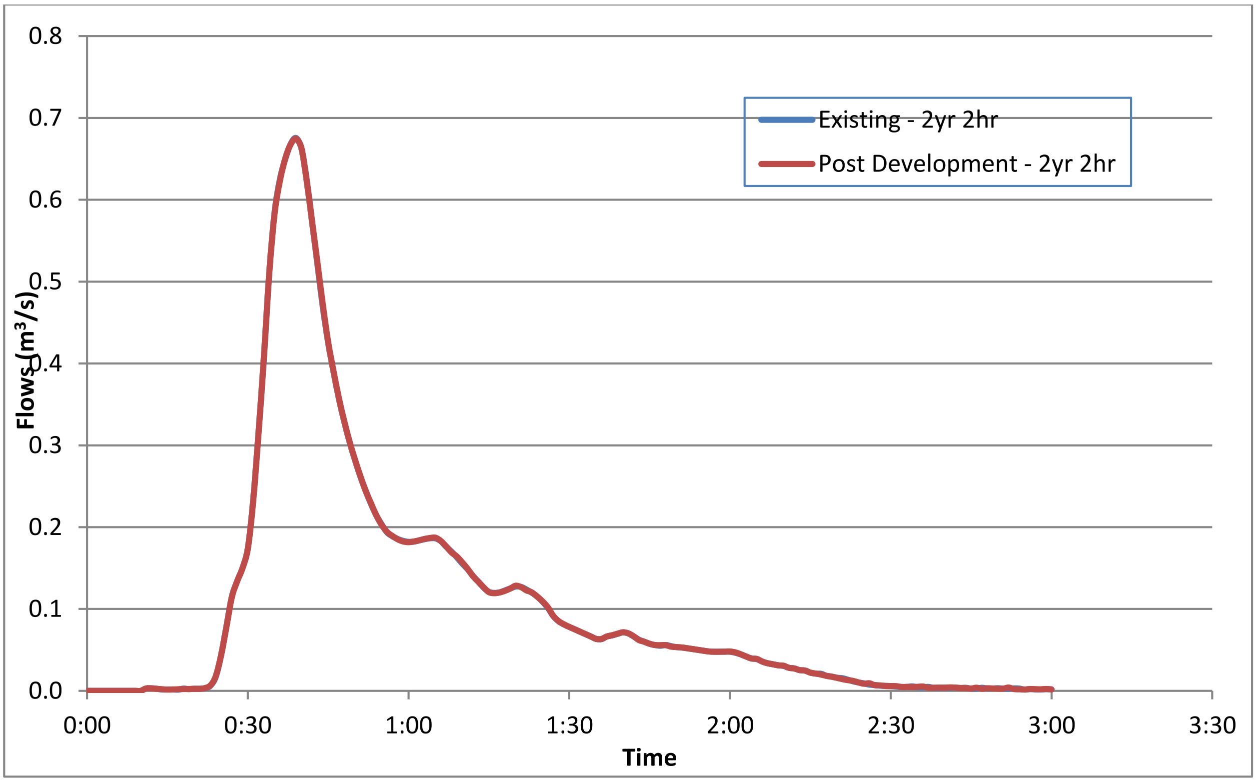
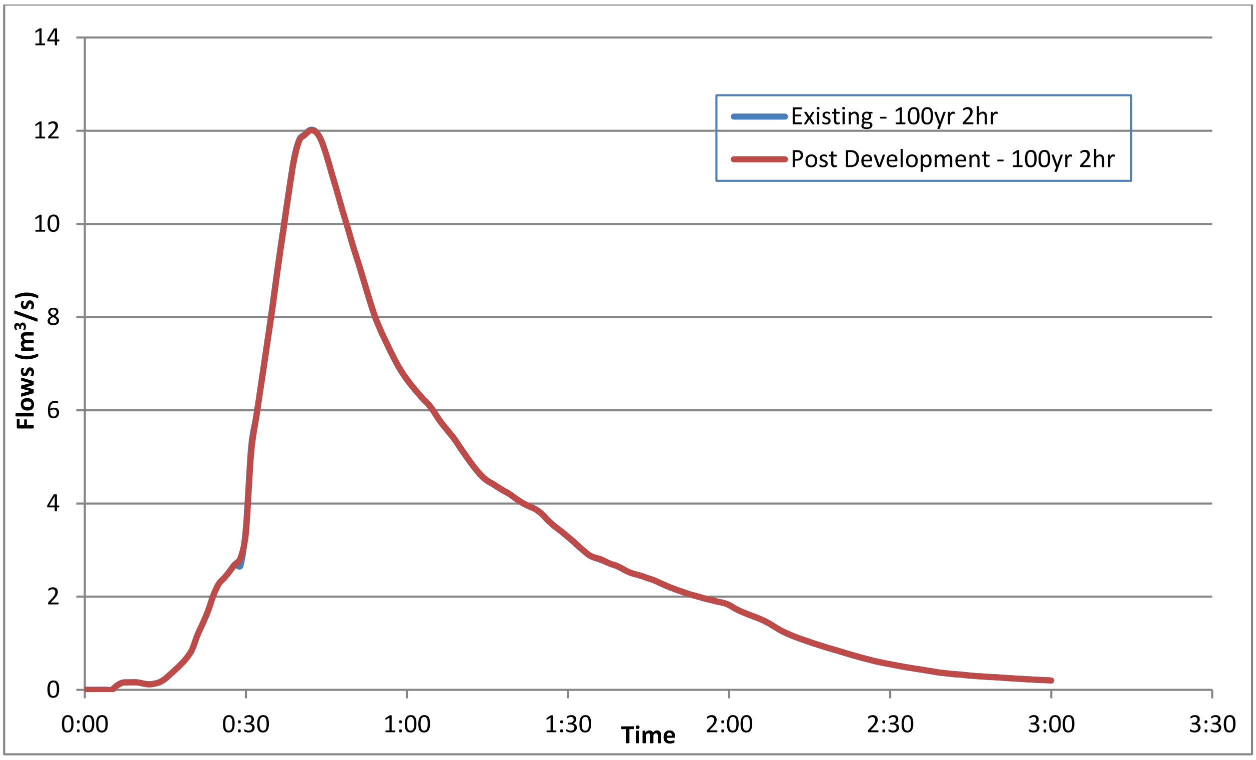


Figure A-14 Hydrograph Comparison at Flow Measurement Line L268



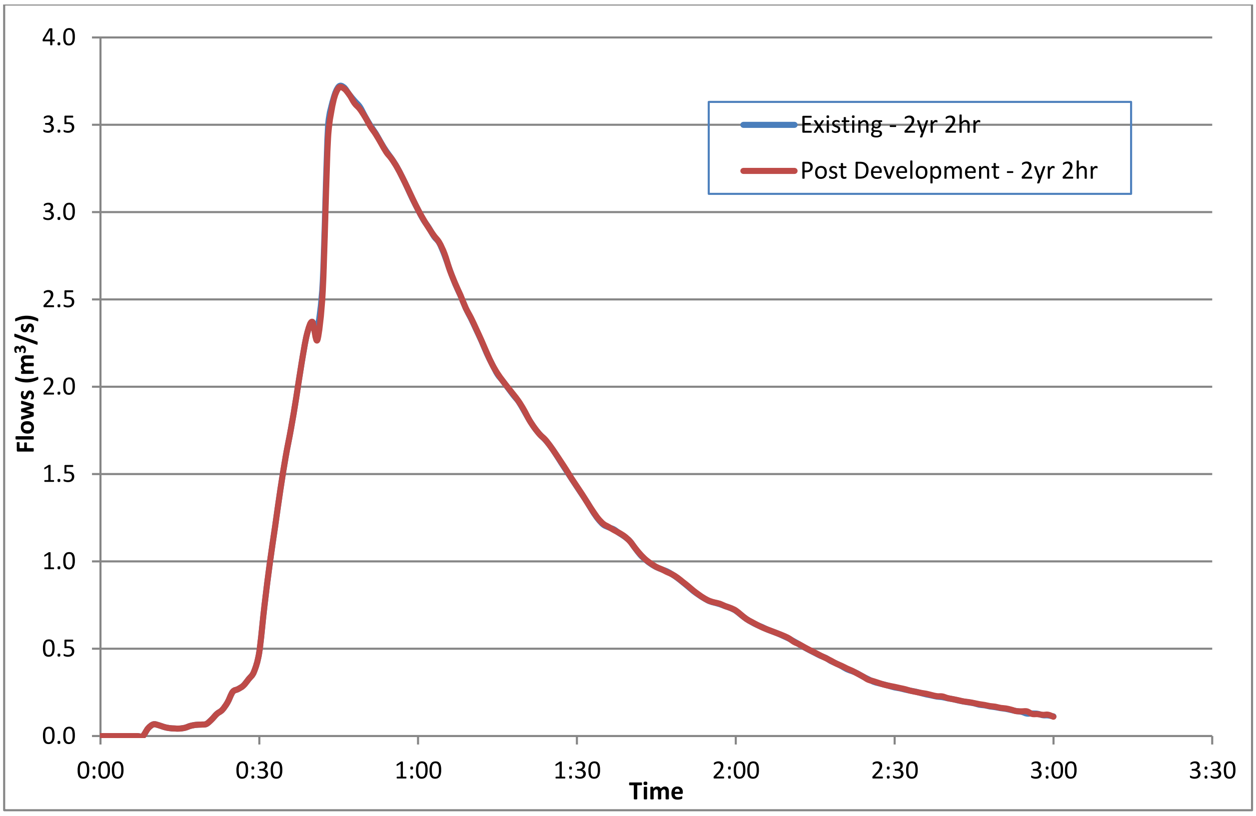


Figure A-15 Hydrograph Comparison at Flow Measurement Line L14

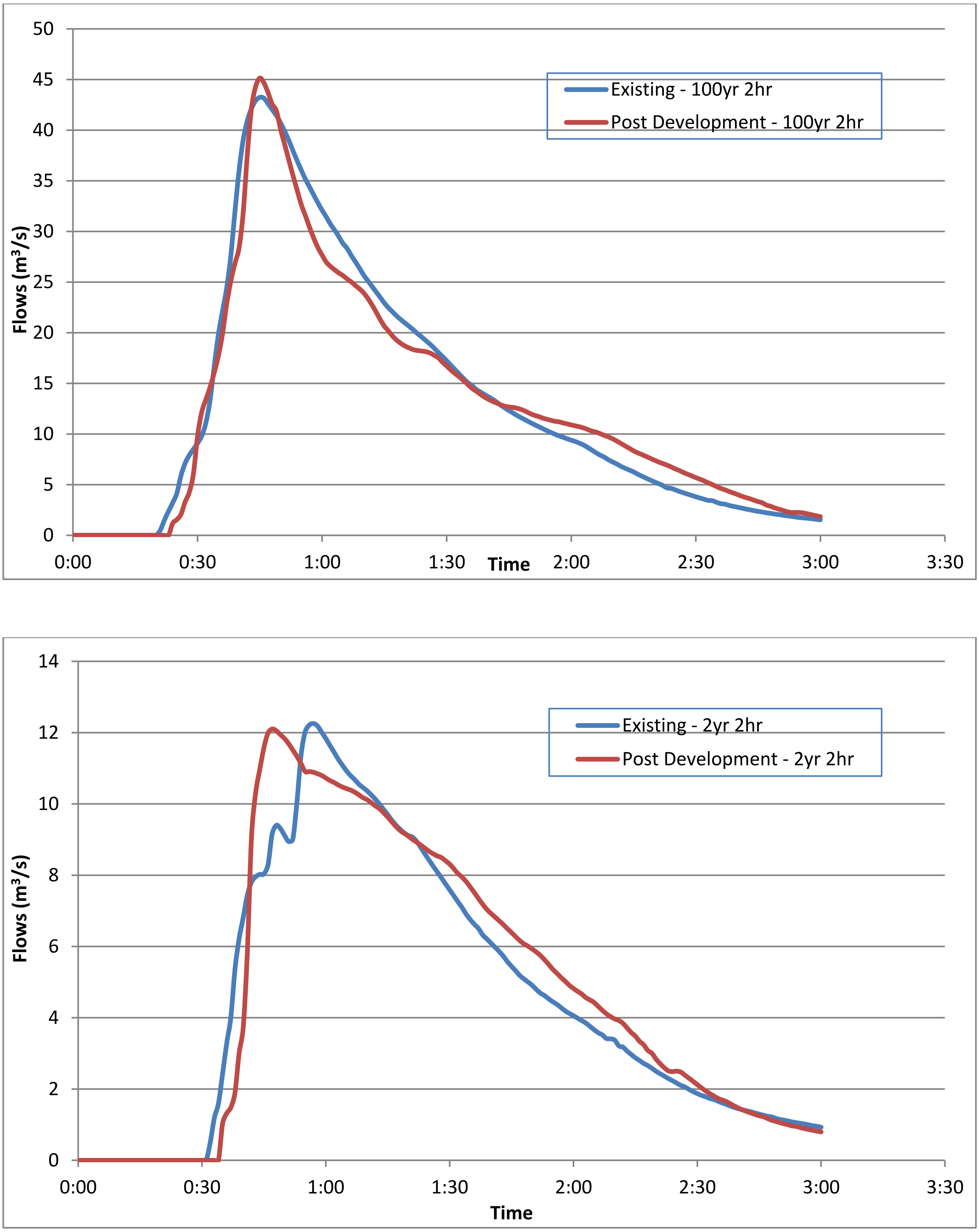


Figure A-16 Hydrograph Comparison at Flow Measurement Line L234

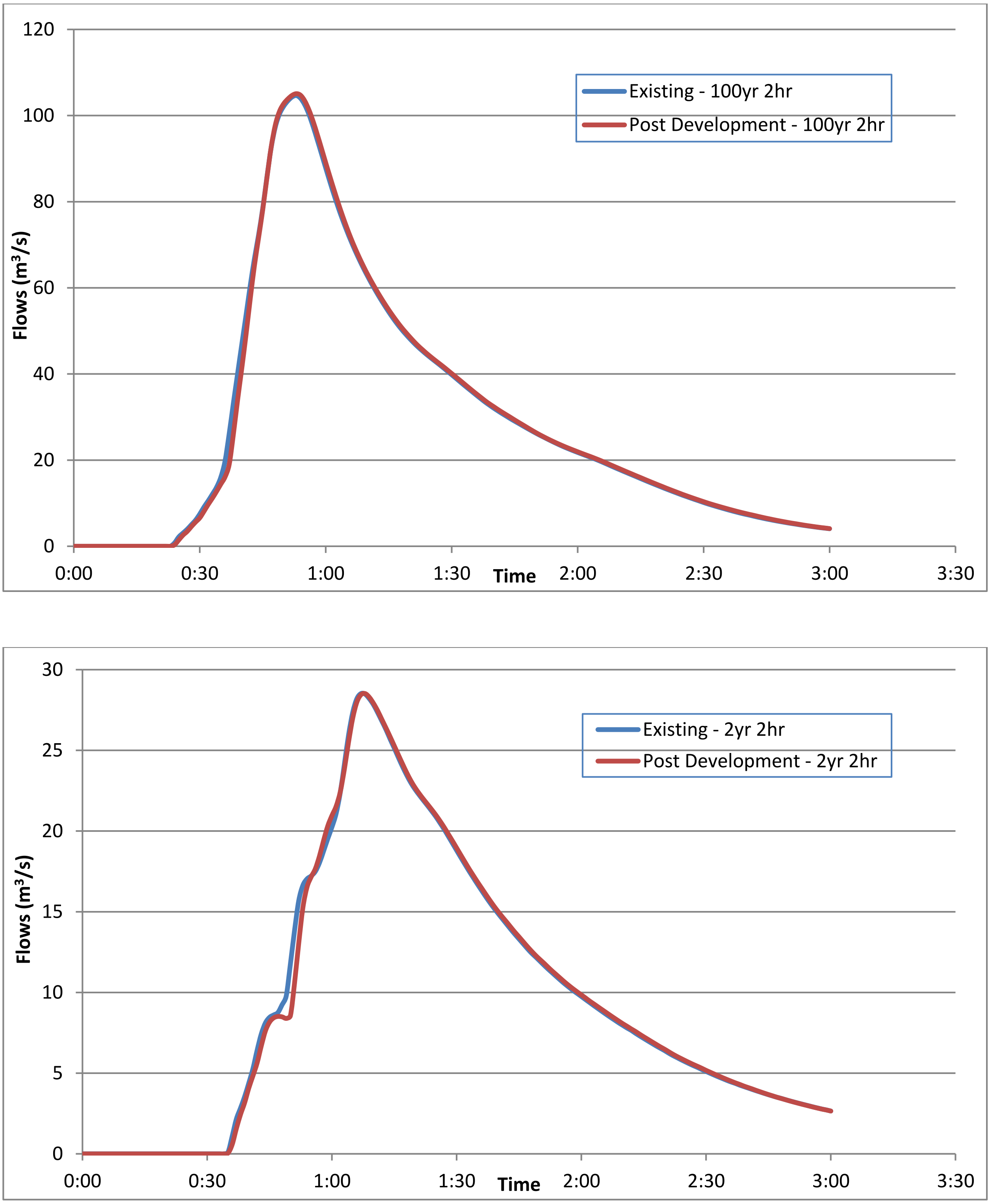


Figure A-17 Hydrograph Comparison at Flow Measurement Line L7

Ingleside Precinct
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APPENDIX B

APPENDIX

B

HYDRAULICS

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B. Hydraulics

B.1 Previous Modelling Approach

B.1.1 Narrabeen Lagoon Flood Study (BMT-WBM, 2013)

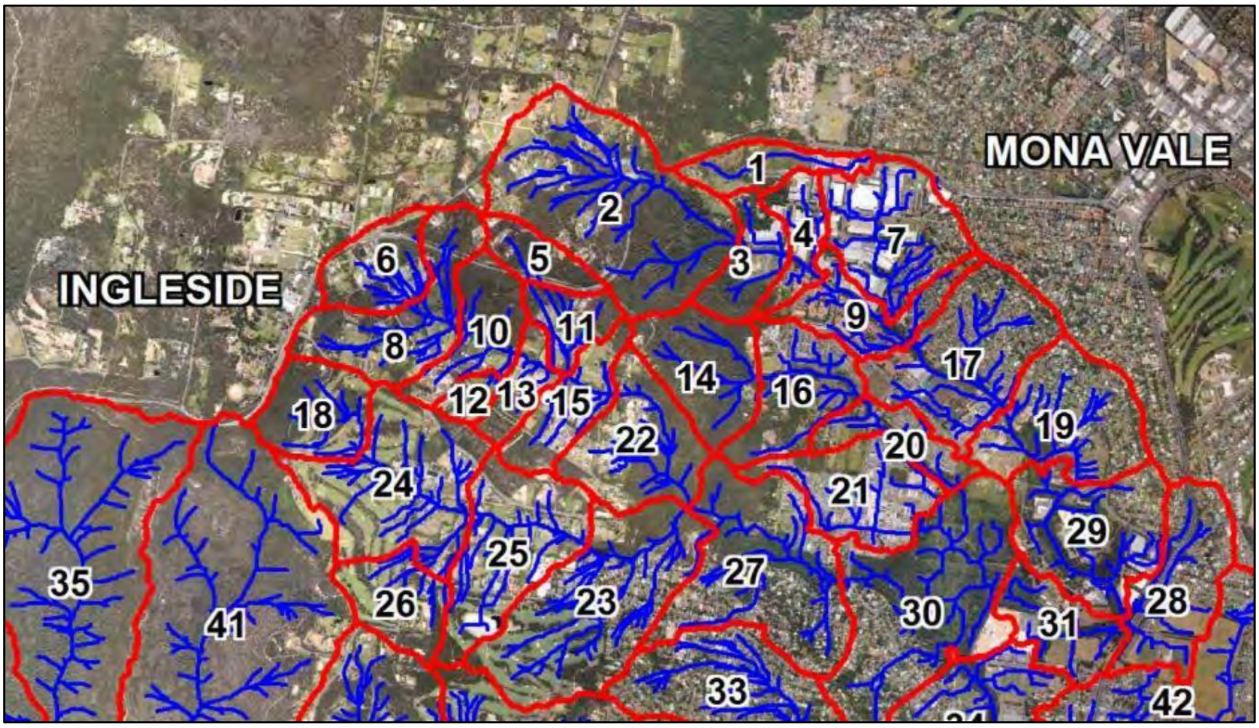

Figure B-1 Narrabeen Lagoon Flood Study Model Layout

- The extent of the model layout shown in **Figure B-1**;
- The hydraulic model was run using Tuflow 2D, with flood extents extending into part of the Ingleside development precinct in Mullet and Fern Creeks.
- A 6m grid cell was applied with sample points at 3m centres
- This flood study supersedes any outcomes of the Pittwater overland flow flood study within the flood study area because it undertook more detailed analysis of flood behaviour over the Study Area.
- It was found through sensitivity testing that the adjustment in rainfall losses had little effect on the flood levels estimated using historical events. This was reported for the Mullet Creek water level gauge at Mullet Creek, being approximately 1km downstream of the Ingleside precinct.
- Peak flood level estimates for the Mullet Creek gauge were reported to be approximately 0.5m higher than the Warriewood Flood Study.

B.1.2 Pittwater Overland Flow Flood Study (Cardno, 2013)

- The hydraulic modelling was done using a two-dimensional Sobek model, divided into seven models based on catchments within the Pittwater LGA, with the Ingleside development precinct covering three of these models:
  - Model C – Mona Vale;
  - Model D – Warriewood & North Narrabeen; and
  - Model E – Ingleside (more specifically the McCarrs Creek catchment).
- The model was set-up as such:
  - A 3m x 3m grid cell size was adopted;

- At the time of modelling, sufficient pits and pipe data was not available for the entire precinct. Due to this and given the size of the task to apply 1D to the entire LGA, no pit and pipes were accounted for in the model;
- ALS data was adopted across the entire LGA;
- To account for the loss of conveyance associated with no inclusion of 1D elements in the model for drainage networks and open channels, the 20 year ARI rainfall event was adopted to represent to the equivalent 100 year ARI event. This approach was justified by sensitivity testing of a pilot catchment; and
- No buildings were raised in the model. High roughness was adopted for building.

- The outcome of the study was mapping of the following two overland flow categories for the entire Pittwater LGA:
  - Minor: Overland flow affected land with a depth of flow between 0.15m and 0.3m for the 100 year ARI design event (20 year ARI with no pipes); and
  - Major: Overland flow affected land with a depth of flow greater than 0.3m for the 100 year ARI design event (20 year ARI with no pipes).
- The major overland flow planning extents had a 5m horizontal buffer applied as opposed to a 0.5m vertical freeboard as it was found that applying a vertical freeboard over-estimated potential flood affected land in locations were side slopes were particularly flat.

B.1.3 Mona Vale - Bayview Flood Study (DHI, 2002)

A 1D Mike 11 model was prepared using ground survey of open channels, major structure and available data for drainage networks. Inflows were applied to Mike 11 from a MOUSE hydrological model. No model parameters or design rainfall depths were reported.

B.1.4 Warriewood Valley Flood Study (Cardno Lawson Treloar, 2005)

A SOBEK model was prepared using the 1D domain for open channels and trunk drainage networks detailed through ground survey. The 2D domain used a 10m grid sampling points from an aerial survey undertaken by QASCO providing surface elevations at 5m spacing and 0.5m contours. Flows were inserted to the model in the 1D creek lines from the XP_RAFTS model.

B.2 Model roughness

B.2.1 Narrabeen Lagoon Flood Study (BMT-WBM, 2013)

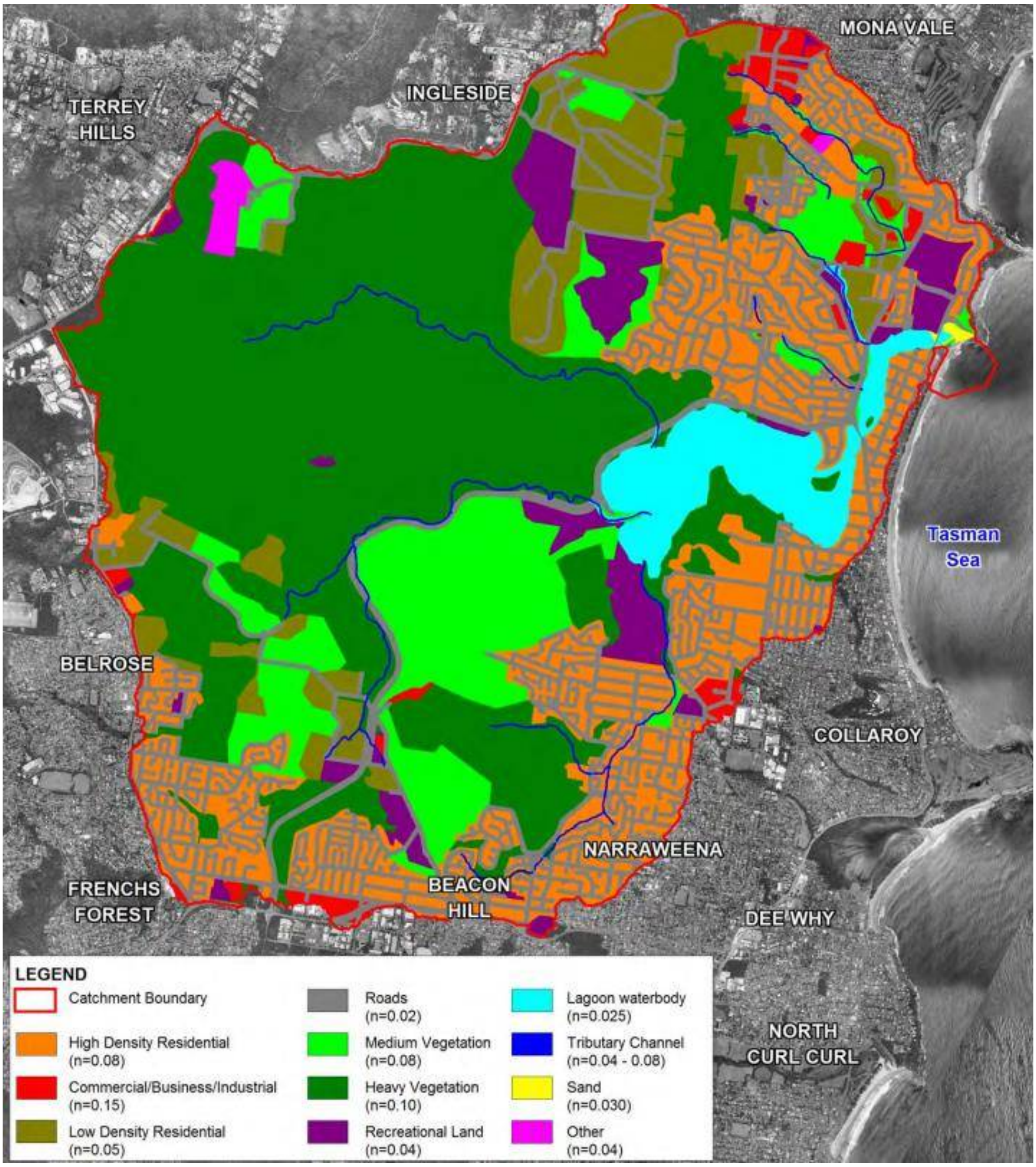

Figure B-2 Narrabeen Lagoon Flood Study Manning's n Values (BMT WBM 2013)

B.2.2 Mona Vale - Bayview Flood Study (DHI, 2002)

Table B-1 Hydraulic Roughness in Mike 11 model

Channel Type	Manning's 'n'
Creek channels	0.025 – 0.04
Overbank areas	0.050 – 0.10

B.2.3 Warriewood Valley Flood Study (Cardno Lawson Treloar, 2005)

Table B-2 One Dimensional Creek Roughness

Creek Description	Manning's 'n'
Rehabilitated Creek Bed	0.04
Rehabilitated Creek Banks	0.16
N0n-rehabiliated Creek Bed	0.16
Non-rehabilitated Creek Banks	0.16
Creek Lower Reaches (always containing water)	0.03

Table B-3 Two Dimensional Surface Roughness

Land Description	Manning's 'n'
Forest/ Heavy Scrub	0.160
Urban	0.200
Roads	0.015
Open Spaces/ Paddocks	0.020
Open Water	0.010

B.3 Results

See attached flood maps for the existing 2, 20, 100, 200 and 500 year ARI and PMF events and developed 2 and 100 year ARI events.

Ingleside Precinct Water Cycle Management and Flooding Assessment

APPENDIX C

APPENDIX C

WATER QUALITY

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C. Water Quality and Quantity

C.1 Climate Data

C.1.1 Rainfall Data

Pluvio rainfall data was purchased from the Bureau of Meteorology for the nearest daily rainfall station 566051 Warriewood STP. Details are summarized in **Table C-1**. Pluvio rainfall data between 11/11/1981 and 01/03/212 (31 calendar years) was used for the purposes of the analysis in this study.

Table C-1: Rainfall Details

	Station 566051
Location	Warriewood STP
Data Period	11/11/1981 - 01/03/2012
Data period used	11/11/1981 - 01/03/2012
Data Type	Pluvio
No of Years	31
Total for Period (mm)	38424
Average Annual (mm)	1139

C.1.2 Evapo-transpiration

Evapo-transpiration data was included as monthly average values from Observatory Hill in Sydney and is listed in **Table C-2**.

Table C-2: Average Daily Evapo-transpiration by Month (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
5.81	4.82	4.13	2.83	1.87	1.43	1.39	1.87	2.93	4.1	5.07	5.26

C.2 Modelling Parameters

C.2.1 Existing Scenario

C.2.1.1 Land Use Categories

The catchments were separated into three main components based on the current land uses in the Precinct for the purposes of the MUSIC model. These included:

- Bushland;
- Rural residential; and
- Urban.

C.2.1.2 Catchment Impervious

Land use impervious percentages were assigned based on current conditions within each of these catchments. The existing characteristics of the catchments are summarised in **Table C-3**.

Table C-3: Catchment Conditions - Existing Scenario

Waterway Catchment	Land Use Type	Area (ha)	Impervious Percentage
WIRREANDA CREEK (McCARRS CREEK)	Bushland	156.3	2%
	Rural Residential	50.5	5%
CICADA GLEN CREEK CAHILL CREEK (PITTWATER)	Bushland	34.7	1%
	Rural Residential	240.0	11%
MULLET CREEK & NARRABEEN CREEK (WARRIEWOOD VALLEY)	Bushland	65.4	6%
	Rural Residential	264.4	11%
	Urban	34.3	48%

C.2.1.3 Rainfall Runoff Parameters

The adopted rainfall-runoff parameters for the existing scenario is provided in **Table C-4**. This is based on the CMA (now LLS) and SCA MUSIC Modelling Guidelines.

Table C-4: Adopted MUSIC Parameters - Existing Scenario

Parameter	Bushland	Rural Residential	Residential
Impervious Area Properties			
Rainfall Threshold (mm/day)	1	1	1
Pervious Area Properties			
Soil Storage Capacity (mm)	195	98	98
Soil Initial Storage (% of Capacity)	25%	25%	25%
Field Capacity (mm)	135	70	70
Infiltration Capacity coefficient - a	250	250	250
Infiltration Capacity exponent - b	1.3	1.3	1.3
Groundwater Properties			
Initial Depth (mm)	10	10	10
Daily Recharge Rate (%)	60%	60%	60%
Daily Baseflow Rate (%)	45%	45%	45%
Daily Deep Seepage Rate (%)	0%	0%	0%

C.2.1.4 *Pollutant Generation*

In MUSIC stormwater quality is characterised by event mean concentrations (EMC) for storm flow and base flow conditions. In this study, the EMC were adopted from the CMA (now LLS) and SCA MUSIC modelling guidelines. Base flow parameters are given in **Table C-5** and storm flow parameters are given in **Table C-6**.

Table C-5: Base Flow Pollutant Concentration Parameters by Land Use

Land Use	Concentration (mg/L-$\log_{10}$)					
	Total Suspended Solids (TSS)		Total Phosphorus (TP)		Total Nitrogen (TN)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Bushland	0.9	0.13	-1.5	0.13	-0.14	0.13
Rural Residential	1.4	0.13	-0.88	0.13	0.074	0.13
Residential	1.1	0.17	-0.82	0.19	0.32	0.12

Table C-6: Storm Flow Pollutant Concentration Parameters by Land Use

Land Use	Concentration (mg/L-$\log_{10}$)					
	Total Suspended Solids (TSS)		Total Phosphorus (TP)		Total Nitrogen (TN)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Bushland	1.9	0.2	-1.1	.22	-0.075	0.24
Rural Residential	2.3	0.31	0.27	0.3	0.59	0.26
Residential	2.2	0.32	-0.45	0.25	0.42	1.9

C.2.1.5 *Existing Scenario Model Results*

The MUSIC model results are provided in **Table C-7**.

Table C-7: MUSIC Results - Existing Scenario

Parameter	Source Loads			
	Wirreanda Creek	Cicada Glen Creek	Narrabeen/ Mullet Creek	TOTAL
TSS (kg/yr)	42,400	123,000	175,000	340,400
TP (kg/yr)	107	517	638	1,262
TN (kg/yr)	9bb	2,830	3,720	7,538
Gross Pollutants (kg/yr)	1,440	13,000	22,000	36,440
Groundwater flows (ML/yr)	482	555	709	1,746

Parameter	Source Loads			
	Wirreanda Creek	Cicada Glen Creek	Narrabeen/ Mullet Creek	TOTAL
Environmental Flows (ML/yr)	211	632	942	1,785

C.2.2 Developed Scenario

C.2.2.1 Land use categories

Precinct land use type and area breakdown within each catchment was provided by Cox Richardson for the developed scenario. These were combined with the remaining land uses of the catchment. The proposed land uses in the Precinct for the purposes of the MUSIC model include:

- Bushland;
- Rural Residential;
- Environmental Living;
- Environmental Management ;
- Low Density Residential;
- Medium Density Residential;
- Proposed School;
- Mixed Use;
- Community Centre;
- Infrastructure;
- Passive Open Space;
- Active Open Space;
- Basins/Drainage;
- Major Roads; and
- Mona Vale Road.

C.2.2.2 Catchment impervious

The adopted impervious percentages for each land use category and total area of each land use is summarised in **Table C-8**. The impervious percentages for various land uses were set in consultation with Department of Planning and Environment and Pittwater Council.

Table C-8: Developed scenario catchment conditions

Waterway Catchment	Land Use Type	Area (ha)	Impervious Percentage
WIRREANDA CREEK (McCARRS CREEK)	Bushland	156.3	2%
	Rural Residential	46.8	5%
	Low density	3.4	70%
	Infrastructure	0.1	70%

Waterway Catchment	Land Use Type	Area (ha)	Impervious Percentage
	Active Open Space	0.2	5%
CICADA GLEN CREEK CAHILL CREEK (PITTWATER)	Bushland	68.2	0%
	Rural Residential	56.0	10%
	Environmental Living	19.2	20%
	Environmental Management	2.5	10%
	Low density	65.8	70%
	Medium density	17.9	85%
	Proposed Schools	4.0	70%
	Mixed Use	1.6	70%
	Community Centre	0.2	70&
	Infrastructure	1.4	70%
	Passive Open Space	2.1	5%
	Active Open Space	5.8	5%
	Basins/Drainage	10.2	10%
	Major Roads	17.4	70%
	Mona Vale Road[1]	2.4	30%
MULLET CREEK & NARRABEEN CREEK (WARRIEWOOD VALLEY)	Bushland	65.1	2%
	Rural Residential	91.3	5%
	Urban	26.2	44%
	Environmental Living	5.8	20%
	Environmental Management	1.7	15%
	Low density	70.9	70%
	Medium density	44.1	85%
	Proposed Schools	2.9	70%
	Mixed Use	0.2	70%

[1] Based on advice from DP&E, Mona Vale Road Upgrade has been excluded from this assessment. The impervious percentage for Mona Vale Road has been calculated based on the existing conditions.

Waterway Catchment	Land Use Type	Area (ha)	Impervious Percentage
	Community Centre	0.2	70%
	Infrastructure	1	70%
	Passive Open Space	0.8	5%
	Active Open Space	4	5%
	Basins/Drainage	17.6	5%
	Major Roads	24	70%
	Mona Vale Road[2]	8.2	20%

C.2.2.3 *Urban Area Breakdown*

The environmental living, low density, medium density, mixed use, school and community centre land uses were further categorised into the following area types:

- Roof – the following assumptions were made with regards to roof area breakdown:
    - For environmental living the roof area is 50% of the total impervious area;
    - For low density the roof area is 80% of the total impervious area;
    - For medium the roof area is 50% of the total impervious area;
    - For school the roof area is 50% of the total impervious area;
    - For mixed use the roof area is 80% of the total impervious area; and
    - For community centre the roof area is 75% of the total impervious area;
- Other Impervious – this is the remained of the impervious area; and
- Pervious – this is remained of the land use type area.

C.2.2.4 *Rainfall Runoff Parameters*

The existing scenario rainfall runoff parameters have been adopted for the developed scenario. The parameters for residential land use has been adopted for remainder land use types in the developed scenario.

C.2.2.5 *Pollutant Generation*

The existing scenario pollution generation rates have been adopted for the developed scenario. The parameters for residential land use has been adopted for remainder land use types in the developed scenario.

C.2.2.6 *Developed Scenario Model Results*

The MUSIC model results are provided in **Table C-9.**

[2] Based on advice from DP&E, Mona Vale Road Upgrade has been excluded from this assessment. The impervious percentage for Mona Vale Road has been calculated based on the existing conditions.

Table C-9: MUSIC Results - Developed Scenario

Parameter	Source Loads			
	Wirreanda Creek	Cicada Glen Creek	Narrabeen/ Mullet Creek	TOTAL
TSS (kg/yr)	44,700	212,000	302,000	558,700
TP (kg/yr)	110	434	610	1,154
TN (kg/yr)	1,010	3,160	4,390	8,560
Gross Pollutants (kg/yr)	2,010	24,800	35,400	62,210
Groundwater Flows (ML/yr)	477	424	535	1,436
Environmental Flows (ML/yr)	228	1,148	1,626	3,002

C.2.3 <u>Mitigated Scenario</u>

The water quality treatment proposed for Ingleside Precinct consist of:

- Rainwater harvesting and re-use of residential, mixed use, community centre and school roof runoff by utilising rainwater tanks;
- Gross Pollutant Traps (GPT) to pre-treat runoff prior to discharge into basins;
- Bioretention basins which will receive flows from the GPTs;
- Detention basins as water retention ponds; and
- Stormwater harvesting for re-use in irrigation of sports field.

C.2.3.1 Rainwater Harvesting

Rainwater tanks were modelled for the low density, medium density, environmental living, mixed use, community centre and school land uses based on the following design assumptions:

- Minimum connected roof area – It has been assumed that 80% of all the roof areas will be directly connected to rainwater tanks. The remaining 20% of the roof area is assumed to by-pass the rainwater tanks and discharge directly to the drainage system.
- Average rainwater tank size – A 6kL, 10kL and 12kL nominal rainwater tank size was adopted for medium density/mixed use, low density and environmental living development respectively. A 150kL/ha rainwater tank size was adopted for school and community centre.
- Average reuse – The average reuse amount adopted for residential and mixed use areas was 349kL/year/dwelling for toilet flushing, laundry, hot water, and outdoor use. The average reuse amount adopted for community centre and school was 0.1kL/day/1000m^2 of roof area for internal use and 20kL/year/1000m^2 site area for external use.

These assumptions have been based on the CMA (now LLS) Draft Music Modelling Guidelines.

C.2.3.2 Gross Pollutants Traps (GPTs)

GPTs have been provided to filter stormwater prior to discharge into the drainage system, bioretention basins, detention basins/ponds and stormwater harvesting system. The expected pollutant removal rates adopted within the model is provided in **Table C-10**. For the purposes of MUSIC modelling it was assumed that the GPTs will be located upstream of bioretention basins, detention basins/retention ponds and stormwater harvesting system. Additionally, it was assumed that GPTS will be located at all other outflows into the waterways.

Table C-10: GPT Input Parameters

Pollutant	Input	Output
TSS (mg/L)	0	0
	75	75
	1000	350
TP (mg/L)	0	0
	0.5	0.5
	1	0.85
TN (mg/L)	0	0
	0.5	0.5
	5	4.3
GP (mg/L)	0	0
	15	1.5

C.2.3.3 Bioretention Basins

The design parameters adopted for the bioretention systems is shown in **Table C-11**. The approximate location of bioretention basins is provided in the attached figure. Basins are either online or offline depending on their location in relation to the riparian zones and location of the detention basins.

Table C-11: Bioretention Basin Input Parameters

Parameters	Wirreanda Creek	Cicada Glen Creek	Narrabeen/ Mullet Creek
Area (m^2)	200	14,000	25,000
Saturated Hydraulic Conductivity (mm/hr)	120	120	120
Filter Depth (m)	0.6	0.6	0.6
Extended Detention (m)	0.3	0.3	0.3
TN Content (mg/kg)	500	500	500
Orthophosphate Content (mg/kg)	40	40	40
Exfiltration Rate (mm/hr)	30	40	31
Based Lined	No	No	No

C.2.3.4 Retention Basins

Retention basins provided for flood mitigation will include a permanent water storage component. The design parameters adopted for the basins is shown is **Table C-12**.

Table C-12: Retention Basin Input Parameters

Parameters	Cicada Glen Creek	Narrabeen/ Mullet Creek
Surface Area (m^2)	11,535	8,050
Extended Detention Depth (m)	2	2
Permanent Pool Volume (m^3)	11,535	8,050

C.2.3.5 Stormwater Harvesting[3]

Based on information provided by Council, approximately 0.64ML/week of water can be reused for irrigation of one sports field. Within the Narrabeen and Mullet Creek area there are two proposed sports field with approximately 66ML/year of reuse opportunities.

Stormwater harvesting was modelled for sports field in the Narrabeen and Mullet Creek area with the following design assumptions:

- All the runoff generated from the catchment will be harvested at the bottom of Mullet Creek and Narrabeen Creek and pumped up for reuse at the sports field; and
- A 6ML storage volume was adopted for reuse.

The adopted stormwater harvesting system provided 59ML/year of harvested water available for reuse.

C.2.3.6 MUSIC Results - Mitigated Scenario

Results from the MUSIC analysis are presented in **Table C-13**. The adopted WCM measures approach has helped achieve the water quality, groundwater flow and environmental flow targets set out in the WCM strategy.

Table C-13: Mitigated Scenario MUSIC Results

Parameter	Source Loads			
	Wirreanda Creek	Cicada Glen Creek	Narrabeen/ Mullet Creek	TOTAL
TSS (kg/yr)	39,700	46,500	83,300	169,500
TP (kg/yr)	102	183	276	561
TN (kg/yr)	973	1,450	2,130	4,553
Gross Pollutants (kg/yr)	1,370	2,720	6,380	10,470

[3] Stormwater harvesting for irrigation of sports field is not proposed for Cicada Glen Creek catchment due to site constraints. The sports fields are located at the top of the catchment. In future a combination reuse option could be considered which allows stormwater harvesting in the upper reaches of the catchment for irrigation of sports field and stormwater harvesting in the lower reaches of the catchment for irrigation of other potential areas. This could reduce the lot size rainwater tanks requirement in the catchment.

Parameter	Source Loads			
	Wirreanda Creek	Cicada Glen Creek	Narrabeen/ Mullet Creek	TOTAL
Groundwater Flows (ML/yr)	479	606	782	1,867
Environmental Flows (ML/yr)	220	660	989	1,869

Ingleside Precinct Water Cycle Management and Flooding Assessment

APPENDIX C

APPENDIX D

AQUATIC MONITORING

D. Ingleside Precinct Aquatic Macroinvertebrate Monitoring

Ingleside Precinct Aquatic Ecology Survey

Spring 2014 Data Report

59914096

Prepared for
NSW Dept. of Planning & Environment

23 November 2015

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1 Introduction

Cardno was engaged by NSW Department of Planning & Environment (DP&E) to prepare a Water Cycle Management and Flooding Assessment for the Ingleside Precinct Planning Project (the Project). The Project investigates the development potential of a possible land release within the Ingleside area, and considers developmental needs associated with the environment, economic viability, housing types, the local community and local infrastructure. The Project is managed by the DP&E in partnership with UrbanGrowth NSW and Pittwater Council.

As part of the Project, DP&E requested that an aquatic habitat and macroinvertebrate survey be undertaken to provide information on the ecological status of the various freshwater creeks and drainages present within the study area. Aquatic macroinvertebrates are important indicators of creek health, as they respond to changes in water quality and aquatic and riparian habitat that may occur as a result of anthropogenic disturbances. Examination of macroinvertebrates can provide an indication of the duration and magnitude of potential impacts to creek health and inform management decisions aimed at preventing, ameliorating and / or minimising such impacts.

This data report presents the methodology and results of the aquatic habitat macroinvertebrate sampling event undertaken in Spring 2014. The specific aims of this survey were to:

- Characterise the aquatic macroinvertebrate assemblages, aquatic habitat and water quality within a number of creeks within the McCarrs Creek catchment that may be affected by the development of the Project; and
- Provide information that will help assess the effect of the Project on aquatic ecology.

It is noted that detailed spatial and temporal interpretation of the data was not been undertaken. Also, this study provides a 'snapshot' only of the condition of aquatic ecology at the time of the survey and does not provide any measure of temporal variability in the indicators of aquatic ecology considered.

2 Methodology

2.1 Sampling Sites and Dates

The suburb of Ingleside is situated in Sydney's northern beaches area, approximately 30 km north of the CBD. The Ingleside Precinct covers an area of around 700 ha and encompasses a number of surface drainages and creeks, including Wirreanda Creek and Cicada Glen Creek, which are the subject of this study.

A total of six sites (**Figure 2.1**) were sampled on 29 and 30 September 2014. Each site was approximately 100 m in length. Two sites were located on each of Wirreanda Creek and Cicada Glen Creek and were designated as 'Impact' sites. These sites are situated either within, or downstream of, the Ingleside Precinct area and could be affected by any potential impacts associated with the Project. Two sites were also situated within the McCarrs Creek catchment upstream of the confluence with Wirreanda Creek. These are designated as 'reference' sites and would not be affected by any potential impact associated with the Project. Data from the reference creeks provides a measure of background natural variability against which the data collected from the impact sites could be compared to determine the occurrence of any potential impact on aquatic ecology. GPS coordinates of the centre of each site are shown in **Table 2.1**.

Table 2-1 GPS coordinates of the centre point of each 100 m long site (all coordinates in WGS84)

Treatment	Location	Site	Easting (UTM 56H)	Northing (UTM 56H)
Impact	Wirreanda Creek	WC1	337651	6271926
		WC2	338187	6273705
	Cicada Glen Creek	CGC1	339525	6273040
		CGC2	339838	6274174
Reference	McCarrs Creek	MC1	336842	6274139
		MC2	337761	6273846

2.2 Rainfall

Rainfall data collected at the Terrey Hill Automatic Weather Station (AWS) (Station ID: 066059) during August and September 2014 was used to examine the amount of rain that had fallen prior to the Spring 2014 macroinvertebrate survey. This information, coupled with average rainfall data for the region collected from the Pennant Hills (Yarrara Rd) Weather Station (Station ID: 066047) were used to determine if any rain that had fallen prior to the survey may explain patterns observed in the macroinvertebrate data. For example, high flows occurring prior to sampling could affect the results of the AUSRIVAS analysis.

Data for both weather stations were accessed via the Bureau of Meteorology website (http://www.bom.gov.au/).

2.3 Aquatic Habitat Assessment

The condition of the aquatic habitat at each site was assessed using a modified version of the Riparian, Channel and Environmental (RCE) inventory method (Chessman et al. 1997). This assessment involves evaluation and scoring of the characteristics of the adjacent land, the condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site (**Appendix A**). The maximum score (52) indicates a stream with little or no obvious physical disruption and the lowest score (13) indicates a heavily channelled stream without any riparian vegetation. This methodology was developed by Peterson (1992) and modified for Australian conditions by Chessman *et al*. (1997) by combining some of the descriptors, modifying some of the associated categories and simplifying the classifications from 1 to 4.

The RCE scoring system provides a simplified description of aquatic and riparian habitat. While it may not fully represent the complex habitat occurring at a site, it does provide an objective and repeatable measure of the condition of aquatic habitat and any disturbance it may experience. The inventory also has equal weightings for each of the indices and therefore, certain elements and differences in the habitat of each site may be masked. The scores, therefore, should be used as a generalised assessment only and are supplemented by other observations of important habitat features and signs of disturbance made in the field.

The in-stream and emergent aquatic macrophytes present within the riparian zone were surveyed to provide an indication of the species present and their indicative cover at each site. Species were identified in the field by an experienced aquatic ecologist.

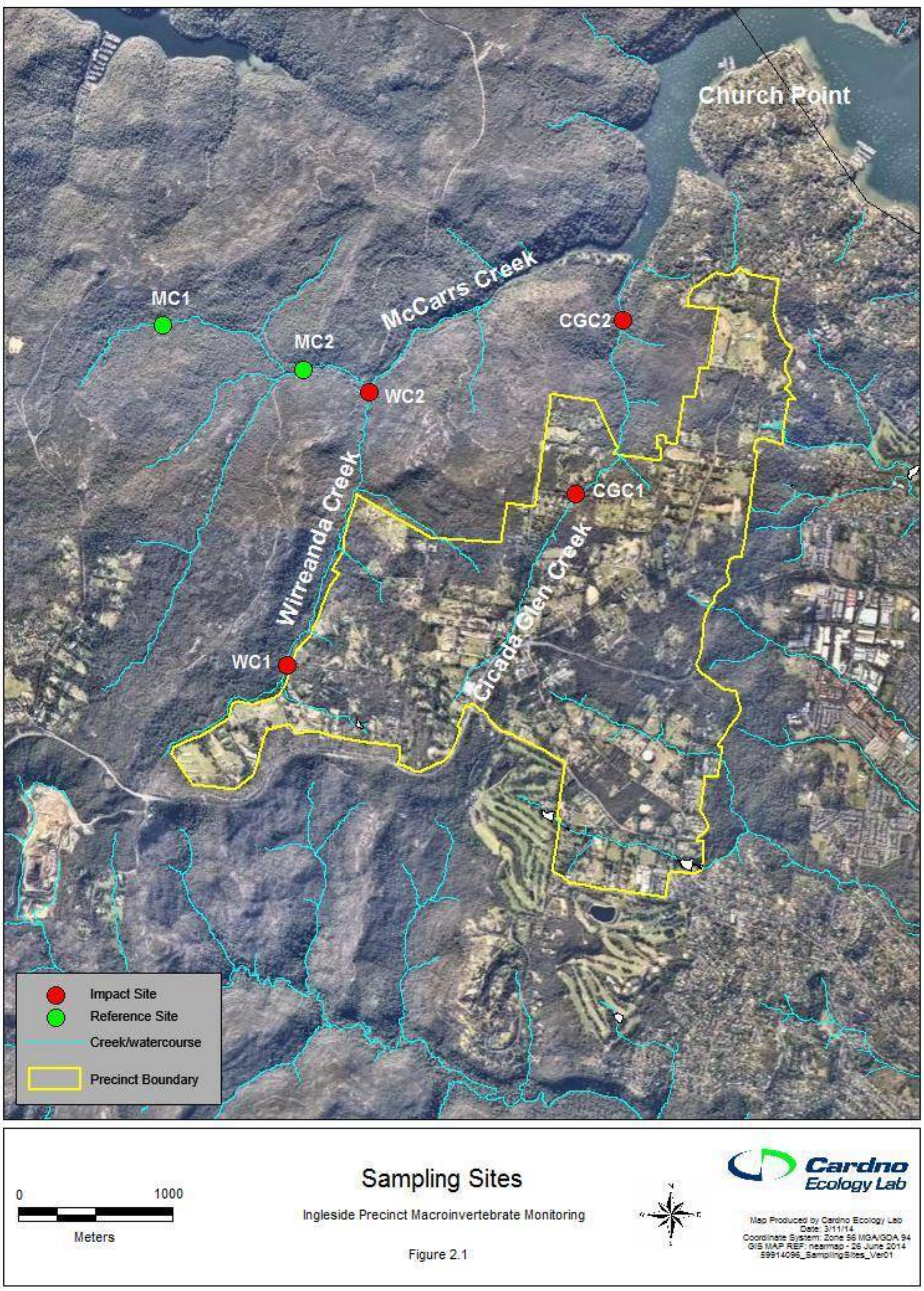

Figure 2-1 Map of the six sampling sites used during the Spring 2014 macroinvertebrate monitoring survey.

2.4 Water Quality

Water quality was measured *in situ* using a YSI 6920 Datasonde water quality multi-parameter probe coupled with a 650MDS handheld display unit. The Probe was calibrated for all parameters before deployment, with the exception of temperature and Oxidation Reduction Potential (ORP), which are factory calibrated. Two replicate readings of each variable were taken in accordance with Australian Guidelines (ANZECC/ARMCANZ 2000).

The following variables were recorded at each site:

- Temperature (°C);
- Electrical Conductivity (EC) (µs/cm);
- pH (pH units);
- Dissolved Oxygen (DO) (mg/L and % saturation);
- Oxidation Reduction Potential (ORP) (mV); and,
- Turbidity (NTU).

Water quality data were compared with the ANZECC/ARMCANZ (2000) default trigger values (DTVs) for south-east Australian lowland rivers (**Table 2.2**). These values provide a point of reference for aquatic ecosystem protection and are derived from ecotoxicology investigations. It should be noted that these DTVs are general and are applicable wherever site specific water quality trigger values have not been developed.

Table 2-2 ANZECC/ARMCANZ (2000) default trigger values for south east Australian lowland rivers

Parameter	Default Trigger Value	Comments
Dissolved Oxygen (% saturation)	85 – 110%	Daytime measurements
pH	6.5 – 8.5	NSW lowland river
Electrical conductivity	125 – 2200 µS/cm	NSW coastal rivers typically in the range of 200 – 300 µS/cm
Turbidity	6 – 50 NTU	Depends on flow at time of measurement

2.5 Aquatic Macroinvertebrates

2.5.1 Field Sampling and Laboratory Methods

Samples of aquatic macroinvertebrates were collected at each site using the NSW AUSRIVAS Rapid Biological Assessment (RBA) method (Turak et al. 2004). Only 'edge' habitat was sampled at each site as no suitable riffle sections (as defined by the AUSRIVAS manual) were available for assessment at the time of sampling. Samples were collected with dip nets (250 µm mesh) over a period of 3-5 minutes from a 10 m length of edge habitat at each site. Each sample was rinsed from the net onto a white sorting tray from which animals were picked using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten minute intervals for a total of one hour or until no new taxa had been found. Care was taken to collect cryptic and fast moving animals in addition to those that were conspicuous or slow. The animals collected at each site were placed into a labelled jar containing 70% ethanol.

In the laboratory, each sample was sorted under a binocular microscope (at 40 X magnification), macroinvertebrates were extracted and identified to family level, with the exception of Oligochaeta and Polychaeta (to class), Ostracoda (to subclass), Nematoda and Nemertea (to phylum), Acarina (to order) and Chironomidae (to subfamily). Up to ten animals of each family were counted in accordance with the latest NSW AUSRIVAS protocol (Turak et al. 2004). Identifications were confirmed using standard references.

After confirmation of sample identifications, samples were stored in 70% ethanol in containers appropriate for long-term archiving.

2.5.2 Data Analyses

2.5.2.1 AUSRIVAS Modelling

Macroinvertebrate data were analysed using the AUSRIVAS predictive models for the NSW spring season (15 September – 15 December) (Coysh et. al. 2000). The AUSRIVAS model generates the following key indices:

- OE50Taxa Score - This is the ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed at a site (i.e. collected) to the number of macroinvertebrate families expected with a greater than 50% probability of occurrence. OE50 taxa values range from 0 to >1 and provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage; values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams within the model; and values exceeding 1 indicating a richer condition than the reference streams within the model.
- Overall Bands - These indicate the level of impairment of the assemblage and are derived from OE50 Taxa scores. The bands for spring edge samples are graded as shown in **Table 2.3**.

Table 2-3 AUSRIVAS OE50 band boundaries for the Spring 'Edge' habitat model.

Band	Description	OE50 Taxa Score for Edge Habitat Sampled in Spring
X	Richer than Reference	Greater than 1.16
A	Reference condition	0.84 to 1.16
B	Significantly impaired	0.52 to 0.83
C	Severely impaired	0.2 to 0.51
D	Extremely impaired	Equal to or below 0.19

2.5.2.2 SIGNAL2

The revised SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (2003) was used to determine the "environmental quality" of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers to each macroinvertebrate family or taxa found, based on their responses to chemical pollutants. Grade values range from 1 to 10, with a value of 1 indicating a family tolerant to chemical pollution and a value of 10 indicating a sensitive family.

The sum of all grade numbers for that habitat/site was divided by the total number of families recorded in each habitat/site to calculate the SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to provide an indication of potential water pollution. SIGNAL2 indices > 6 are indicative of an unpolluted site, whereas indices of 5-6, 4-5 and <4 indicate mild, moderate and severe pollution, respectively.

It should be noted not all macroinvertebrate taxa have been assigned a SIGNAL2 index by Chessman (2003). Therefore, there are sometimes discrepancies between the total number of taxa collected during a field survey and the number of taxa used during the SIGNAL2 Index analysis.

3 Results

3.1 Rainfall

There was substantial rainfall within the Northern Sydney region during August and September, with a total of 307 mm recorded at the Terrey Hills AWS (Station ID: 066059) 2014 (**Figure 3.1**). Average rainfall for the region during August and September is typically around 120 mm (calculated from summary statistics collected from the Pennant Hills (Yarrara Rd) Weather Station (Station ID: 066047)).

Despite this, there was relatively little rainfall in the week prior to the survey (29 and 30 September 2014). Approximately 9 mm of rain on 25 and 26 September 2014 immediately prior to the macroinvertebrate survey on.

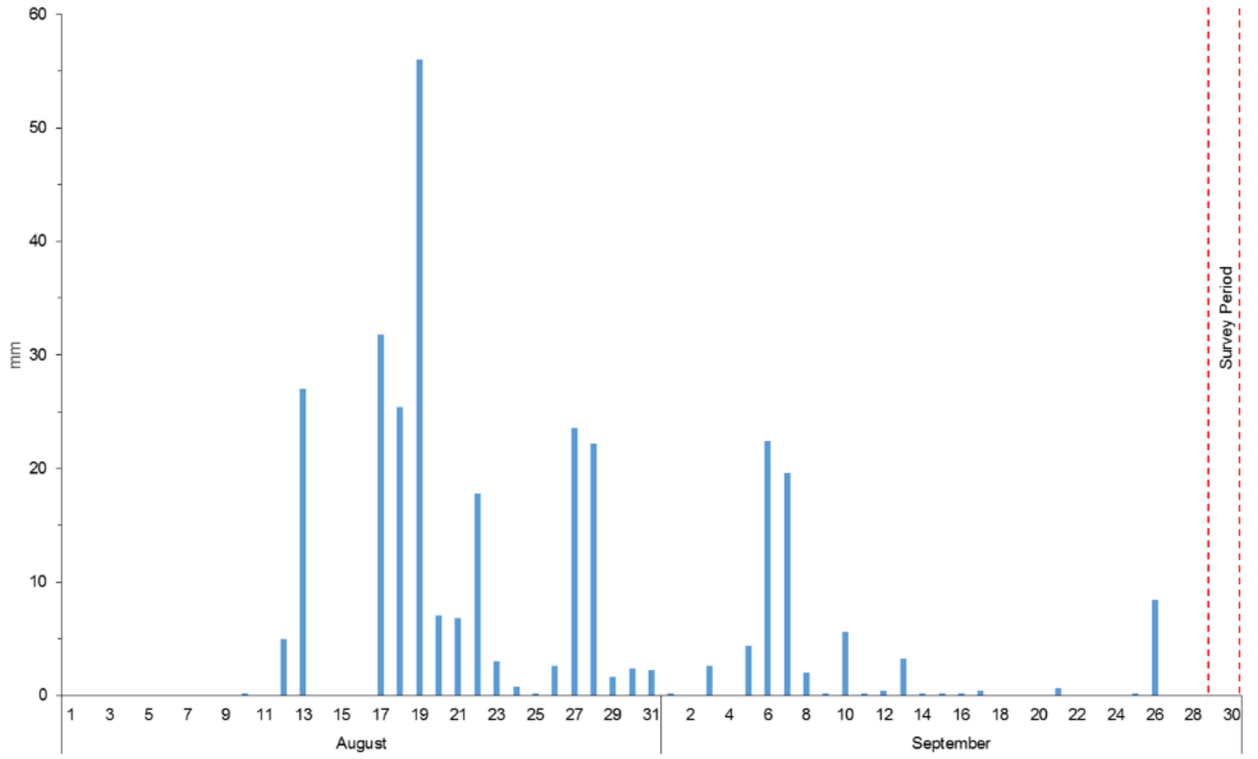

Figure 3-1 Daily rainfall (mm) recorded at the Terrey Hills Automatic Weather Station (Station I.D. 066059) during August and September 2014.

3.2 Description of Habitats

3.2.1 WC1 – Wirreanda Creek (Upstream)

Site WC1 was located on Wirreanda Creek approximately 1.9 km upstream from the confluence with McCarrs Creek on the western boundary of the Precinct. The surrounding land use was primarily native forest and rural-residential, although a local nursery was situated nearby to the east of the site. The section of creek within the site consisted mostly of a long continuous pool, approximately 3 m wide and 0.3 m deep. The riparian zone comprised mostly large eucalypts and smaller shrubs of other native vegetation which stabilised the bank. Some small patches of weeds and exotic grasses were also present. The creek bed consisted mostly of bedrock with accumulations of some sand and silt. At the time of the survey, the flow within the creek was low.

Water clarity was fair, with no visible signs of water pollution i.e. foaming or algal proliferation. The site was classified as relatively undisturbed with an RCE score of 39 (**Table 3.1**). Very little in-stream macrophytes were observed and moss and some filamentous green algae were common throughout much of the site. A number of large woody snags were present within the site.

(a) (b)

Figure 3-2 (a) WC1 looking downstream (b) WC1 looking upstream.

3.2.2 WC2 – Wirreanda Creek (Downstream)

Site WC2 was located on Wirreanda Creek, just upstream of the confluence with McCarrs Creek. The surrounding land use was native forest. The water course at this site consisted mostly of a long continuous pool with a maximum width of 7 m and depth of 0.5 m. The riparian zone consisted mostly of tall eucalypts and other native vegetation. Some areas of bank, mostly in the upstream portion of the site, consisted of loose, unvegetated sand deposits, and bank overhang was present. The composition of the creek bed was mostly sand and silt with small areas of bed rock.

A visual assessment of water quality indicated little evidence of disturbance due to water pollution. The site was classified as undisturbed with a RCE score of 46 (**Table 3.1**). The upstream portion of the site supported the emergent macrophyte *Sagittaria graminea* whilst the downstream portion of the site had little instream macrophytes. Green filamentous algae was present on some of the exposed hard structures along the bank.

(a) (b)

Figure 3-3 (a) WC2 looking downstream (b) WC2 looking upstream.

3.2.3 CGC1 – Cicada Glen Creek (Upstream)

Site CGC1 was situated within the Precinct on Cicada Glen Creek approximately 1.7 km upstream of the confluence with McCarrs Creek. The surrounding land use was predominantly rural residential. The water course within this section of creek consisted of a series of shallow pools interconnected via large areas of bedrock. The creek itself was approximately 3 m wide and 0.2 m deep. The riparian zone was a mixture of tall eucalypts and small native and exotic shrubs and grasses which cover the majority of each bank. Bank overhang occurred in approximately 10% of the site.

Water clarity throughout much of the site was clear, with little evidence of any disturbance or water pollution. The site was relatively undisturbed with a RCE score of 42 (**Table 3.1**). No in-stream macrophytes were observed. Some of the exposed hard structures were covered in moss and green filamentous algae.

(a)

(b)

Figure 3-4 (a) CGC1 looking downstream (b) CGC1 looking upstream.

3.2.4 CGC2 – Cicada Glen Creek (Downstream)

CGC2 was situated on Cicada Glen Creek within the freshwater section of the watercourse approximately 400 m upstream from the confluence with McCarrs Creek. The surrounding land use was native forest. The creek consisted of a large continuous pool at the more downstream section of the site, with smaller fragmented pools and boulder habitat within the more upstream section of the site. The wetted width of the creek averaged approximately 3 m, and was up to 10 m in some sections. The water was approximately 0.5 m deep. The riparian zone of the creek consisted mainly of tall eucalypts and other native vegetation, mixed with some vines, native shrubs and ferns. There was minimal bank overhang at this site.

Water clarity was good, with little evidence of water pollution or disturbance. The site was classified as undisturbed, with a RCE score of 47 (**Table 3.1**). No in-stream macrophytes were observed throughout the site during the survey. Some of the exposed hard structures were covered in moss and green filamentous algae, especially within the upstream section of the site.

(a)

(b)

Figure 3-5 (a) CGC2 looking downstream (b) CGC2 looking upstream.

3.2.5 MC1 – McCarrs Creek (Upstream)

Site MC1 was located on a small un-named watercourse approximately 900 m upstream from the confluence with McCarrs Creek. This watercourse forms part of the McCarrs Creek catchment and is referred to as McCarrs Creek in this study. The surrounding land use was native forest. The creek consisted of a series of pools connected by areas of flow over flat bedrock. The maximum wetted width of the creek at the site was 5 m, although the majority of the creek was around 3 m in width. The average water depth was approximately 0.4 m. The riparian zone of the creek consisted mainly of tall eucalypts and other native vegetation. Some bank overhang was present. The creek bed consisted mostly of bedrock with accumulations of some sand and silt.

Water clarity was clear, with little evidence of water pollution or other. The site was largely undisturbed with an RCE score of 47 (**Table 3.1**). Little in-stream vegetation was present, with only minimal amounts of green filamentous algae occurring within the littoral zone of the creek (i.e. along the edge).

(a)

(b)

Figure 3-6 (a) MC1 looking downstream (b) MC1 looking upstream.

3.2.6 MC2 – McCarrs Creek (Downstream)

Site MC2 was situated on McCarrs Creek, approximately 4.2 km upstream of the creek mouth near Church Point. The surrounding land use was predominantly native forest. The section of creek within the site consisted of a number of long continuous pools. The width of the creek here was approximately 4 m, and the water depth approximately 0.4 m. The riparian zone consisted mostly of tall eucalypts and *Casuarina* sp., with *Banksia* sp. shrubs also common. Ground cover consisted of native grasses and rushes. Some bank overhang was present. The creek bed consisted mostly of bedrock with some small deposits of sand and silt.

Water clarity was clear, with little evidence of water pollution or other disturbance. The site was largely undisturbed with an RCE score of 47 (**Table 3.1**). Little in-stream vegetation was observed, with minimal amounts of green filamentous algae occurring within the littoral zone of the creek.

(a) (b)

Figure 3-7 (a) MC2 looking downstream (b) MC2 looking upstream.

Table 3-1 Habitat description scores for all sites surveyed in Spring 2014 using the modified RCE inventory. WC = Wirreanda Creek, CGC = Cicada Glen Creek, MC = McCarrs Creek.

		Wirreanda Creek		Cicada Glen Creek		McCarrs Creek	
No.	**Descriptor**	**WC1**	**WC2**	**CGC1**	**CGC2**	**MC1**	**MC2**
#1	Land use pattern beyond the immediate riparian zone	3	4	3	4	4	4
#2	Width of riparian strip of woody vegetation	3	4	3	4	4	4
#3	Completeness of riparian strip of woody vegetation	3	3	3	3	3	3
#4	Vegetation of riparian zone within 10m of channel	3	4	3	4	4	4
#5	Stream bank structure	4	4	4	4	4	4
#6	Bank undercutting	3	3	3	3	3	3
#7	Channel form	3	3	3	3	3	3
#8	Riffle/pool sequence	2	3	3	4	3	3
#9	Retention devices in stream	2	3	4	3	4	4
#10	Channel sediment accumulations	3	4	3	4	4	4
#11	Stream bottom	3	3	3	3	3	3
#12	Stream detritus	3	4	3	4	4	4
#13	Aquatic vegetation	4	4	4	4	4	4
Total		**39**	**46**	**42**	**47**	**47**	**47**

3.3 Water Quality

The majority of conductivity, pH and dissolved oxygen values recorded during the survey were within the ANZECC/ARMCANZ (2000) DTVs (**Table 3.2**), indicating relatively undisturbed water quality. The exception was the pH measured at both sites on McCarrs Creek (MC1 and MC2), which was below the lower DTVs. In addition, both replicate dissolved oxygen readings taken from WC1 (Wirreanda Creek) and one replicate reading from CGC1 (Cicada Glen Creek) were slightly below the lower DTVs. Turbidity values were also below the lower DTVs at each site.

With respect to spatial patterns of water quality, pH and conductivity at sites representing McCarrs Creek were below that recorded at all other sites on different creeks (**Table 3.2**). In addition, sites on Cicada Glen Creek both had pH and conductivity values greater than that recorded at the other sites on the two different creeks.

It should be noted that the water quality data presented here is from a single sampling event and provides only a snapshot of the conditions that may occur within these creeks. Further data collected over a longer period is required to represent the longer term trends in water quality of the study area.

Table 3-2 Water quality measurements from the six sites visited during the Spring 2014 survey and associated ANZECC/ARMCANZ (2000) default trigger values. Values in Red indicate values outside ANZECC/ARMCANZ (2000) DTVs. WC = Wirreanda Creek, CGC = Cicada Glen Creek, MC = McCarrs Creek, Temp. = temperature, EC = electrical conductivity, DO = dissolved oxygen, ORP = oxidation reduction potential.

Site	Replicate	Time	Temp. (°C)	EC (mS/cm)	pH	DO (% sat.)	DO (mg/L)	ORP (mV)	Turbidity (NTU)
WC1	1	10:00	14.90	269	6.81	81.4	8.21	12.6	3.6
	2	10:05	14.91	269	6.81	81.4	8.21	12.6	3.6
WC2	1	13:00	15.94	190	6.81	98.1	9.67	12.5	1.0
	2	13:05	16.01	189	6.74	98.0	9.68	12.7	0.6
CGC1	1	11:00	16.17	340	7.00	85.0	8.35	12.6	3.6
	2	11:05	16.16	340	7.00	84.9	8.34	12.6	3.5
CGC2	1	12:00	14.12	298	7.03	89.5	9.20	12.6	0.1
	2	12:05	14.12	298	7.00	90.0	9.24	12.6	0.1
MC1	1	14:20	16.60	160	5.81	89.3	8.70	12.6	2.0
	2	14:25	16.52	158	5.68	89.0	8.68	12.6	1.3
MC2	1	13:30	16.19	165	6.48	97.1	9.54	12.6	0.3
	2	13:35	16.20	165	6.48	97.1	9.54	12.6	0.3
ANZECC/ARMCANZ (2000) DTV			-	125 - 2200	6.5 - 8.5	85- 110%	-	-	6 - 50

3.4 Aquatic Macroinvertebrates

The number of macroinvertebrate taxa (taxa richness) sampled using AUSRIVAS and the OE50Taxa Scores and AUSRIVAS Bands are shown in **Table 3.3**.

A total of 45 macroinvertebrate taxa were identified from the six sites sampled in Spring 2014, comprising damselflies/dragonflies (Order Odonata: 15.6% of taxa), true flies (Order Diptera; 13.3% of taxa), worms (various Phyla: 11.1% of taxa), crustaceans (Crustacea: 11.1% of taxa), bugs (Order Hemiptera: 11.1% of taxa) and caddisflies (Order Trichoptera: 11.1% of taxa). The greatest number of taxa was sampled at Site MC2 on McCarrs Creek (26 taxa) and the fewest number of taxa were sampled at Site CGC2 on Cicada Glen Creek (13 taxa) (**Table 3.3**). The number of taxa sampled at Wirrenada Creek was less variable than that sampled at Cicada Glen Creek and McCarrs Creek.

OE50 Taxa Scores at sites on Wirreanda Creek and Cicada Glen Creek ranged from 0.38 to 0.77, indicating that the number of taxa observed was less than would be expected relative to the AUSRIVAS reference watercourses. OE50 Taxa Scores at Sites on McCarrs Creek ranged from 0.86 to 0.96, indicating that the number of taxa observed was similar to what would be expected at AUSRIVAS reference watercourses.

AUSRIVAS Bands reflected OE50 Taxa Scores upon which they are based. The condition of the macroinvertebrate fauna at both sites on McCarrs Creek was equivalent to reference condition within the AUSRIVAS model (Band A) (**Table 3.3**). The condition of the macroinvertebrate fauna at Sites WC1 and WC2 on Wirreanda Creek and at Site CGC1 on Cicada Glen Creek was significantly impaired relative to the reference condition (Band B). The macroinvertebrate fauna at Site CGC2 on Cicada Glen Creek were severely impaired relative to reference condition within the model (Band C).

Table 3-3 Taxa richness, AUSRIVAS (OE50Taxa and Band) and SIGNAL2 scores for edge habitat sampled at the six sites in Spring 2014. WC = Wirreanda Creek, CGC = Cicada Glen Creek, MC = McCarrs Creek.

Location	Site	Designation	Taxa Richness	OE50Taxa	Band
Wirreanda Creek	WC1	Impact	20	0.57	B
	WC2	Impact	18	0.77	B
Cicada Glen Creek	CGC1	Impact	19	0.57	B
	CGC2	Impact	13	0.38	C
McCarrs Creek	MC1	Reference	16	0.86	A
	MC2	Reference	26	0.96	A

Signal 2 Indices ranged from 3.00 at Site CGC1 (indicative of severe pollution) to 5.46 at (Site CGC2 (indicative of moderate pollution) (**Table 3.4**). The taxa from each of the sites during the Spring 2014 survey and their respective SIGNAL2 grades are shown in **Table 3.4**. No pollutant sensitive taxa (i.e. SIGNAL2 Grade > 6) were collected from Site CGC1 on Cicada Glen Creek, whilst five pollutant sensitive taxa (Calamoceratidae, Leptophlebiidae, Tasimiidae, Helicopsychidae and Telephlebiidae) were sampled from Site CGC2, which was the most pollutant sensitive taxa collected at any of the sites during the survey. With respect to more pollutant tolerant macroinvertebrate taxa (SIGNAL2 < 4), MC2 on McCarrs Creek had 11 taxa collected during the Spring 2014 survey. Likewise, CGC1 had 10 taxa that are considered to be pollutant tolerant. In comparison, CGC2 only had two pollutant tolerant taxa collected during the survey (**Table 3.4**).

Table 3-4 Signal 2 scores and presence (✓) of macroinvertebrate taxa sampled at the six sites during the Spring 2014 survey. Note: taxa with a higher SIGNAL2 score are generally more sensitive to water pollution. WC = Wirreanda Creek, CGC = Cicada Glen Creek, MC = McCarrs Creek.

		Wirreanda Creek		Cicada Glen Creek		McCarrs Creek	
Taxa SIGNAL2 Score	Order or Family	WC1	WC2	CGC1	CGC2	MC1	MC2
Site SIGNAL2 Score		4.11	4.53	3.00	5.46	4.59	3.79
1	Physidae	✓		✓			✓
1	Glossiphoniidae			✓	✓		
1	Notonectidae		✓	✓		✓	✓
2	Hydridae			✓			
2	Dugesiidae	✓					✓
2	Oligochaeta	✓		✓			✓
2	Coenagrionidae			✓			✓
2	Corixidae		✓	✓		✓	✓
2	Dytiscidae	✓		✓			✓
2	Hydrophilidae					✓	✓
2	Stratiomyidae	✓					
3	Nematoda		✓	✓			
3	Atyidae	✓	✓		✓	✓	✓
3	Hydrometridae					✓	
3	Veliidae	✓	✓				✓
3	Chironomidae/Chironominae	✓	✓	✓		✓	✓
4	Hydrobiidae	✓		✓	✓		
4	Parastacidae		✓				✓
4	Aeshnidae		✓	✓			
4	Gerridae					✓	
4	Chironomidae/Orthocladiinae						✓
4	Chironomidae/Tanypodinae	✓		✓	✓	✓	✓
4	Ceratopogonidae	✓	✓	✓	✓	✓	
4	Hydroptilidae				✓		✓
5	Temnocephalidae		✓				
5	Corbiculidae/Sphaeriidae			✓			✓
5	Baetidae		✓				✓
5	Megapodagrionidae	✓	✓			✓	✓
5	Gomphidae	✓				✓	✓
5	Hemicorduliidae	✓		✓			✓
5	Tipulidae				✓	✓	
6	Hydracarina	✓	✓			✓	✓
6	Leptoceridae		✓	✓	✓	✓	✓
7	Synlestidae		✓				✓
7	Elmidae	✓					
7	Calamoceratidae	✓			✓		
8	Leptophlebiidae		✓		✓	✓	✓
8	Gripopterygiidae		✓			✓	
8	Tasimiidae				✓		
8	Helicopsychidae				✓		
9	Telephlebiidae	✓			✓	✓	

4 Results and Discussion

The findings of the spring 2014 aquatic ecology survey are outlined below:

- A substantial amount of rainfall (> 300 mm) occurred in the region in the two months prior to sampling. On average, 120 mm of rainfall occurs in this period. However, as the majority of rainfall fell during August (one month before the survey), and there was little rainfall in the weeks prior to sampling it is likely that the macroinvertebrate assemblages present at the time of sampling were representative of those present during normal flow conditions (Turak *et al*, 2004),. Therefore, the data collected during this survey are considered representative of normal flow conditions.
- Total RCE scores were 39 or greater at each site, indicating that the aquatic habitat was generally unimpaired. Sites on McCarrs Creek and downstream Site CGC2 on Cicada Glen Creek (CGC2) had the greatest RCE scores with 47 (out of a possible 52). The upstream site on Wirreanda Creek (WC1) had the lowest RCE score (39) compared with the other sites, mostly due to the smaller width and completeness of the riparian strip and its shallower channel form.
- The majority of conductivity, pH and dissolved oxygen measures fell within the relevant ANZECC/ARMCANZ (2000) DTVs. Exceptions were a low pH at McCarrs Creek (both sites MC1 and MC2), slightly lower dissolved oxygen values for the upper sites on Wirreanda Creek (WC1) and Cicada Glen Creek (CGC1), and lower Turbidity values were below the lower DTV on each occasion. These area-wide low turbidity values could be a result of the underlying geological attributes within the catchments of each creek (e.g. composition of surrounding soils) and the lack of physical disturbance to the riparian vegetation and bank integrity at each site. Low turbidity values are also often related to periods of low/stable flow.
- Aquatic macroinvertebrate taxa richness ranged from 13 (CGC2) to 26 (MC2). AUSRIVAS Bands at sites on McCarrs Creek were Band A, which indicates macroinvertebrate assemblages similar to those at undisturbed reference creeks selected by the AUSRIVAS model. Other sites on Wirreanda Creek and Cicada Glen Creek were somewhat impaired relative to AUSRIVAS reference creeks (Band B – significantly impaired (WC1, WC2, CGC1) and Band C – severely impaired (CGC2)).
- SIGNAL2 Indices ranged from 3.00 (CGC1) to 5.46 (CGC2), which suggests that all sites currently experience some degree of impact due to water pollution. The SIGNAL2 Index was also more variable on Cicada Glen Creek than on the other two creeks, suggesting this creek experiences more variable water quality than that experienced by the other two creeks.

5 Conclusion

The results of the RCE and habitat assessment suggest that the sites selected are relatively undisturbed. They also share many common characteristics, in particular the condition and completeness of the riparian strip and the absence of any major physical disturbances to the banks and channel. Most measures of water quality were within relevant guidelines. When measures were outside of guidelines, they were only marginally so. The results of the AUSRIVAS assessment suggested that the health of the macroinvertebrate fauna in Wirreanda Creek and Cicada Glen Creek is below that which would be expected at creeks with similar physical and chemical attributes. The health of the macroinvertebrate fauna in McCarrs Creek is similar to what would be expected at AUSRIVAS reference (i.e. undisturbed) creeks. The SIGNAL2 Indices suggest that each creek experiences some degree of stress due to poor water quality.

As noted in **Section 1**, the aim of this study was to characterise the current condition of aquatic habitat and macroinvertebrates in the study area to aid in the assessment of the potential effect of the Project on aquatic ecology. The findings provide a ‘snapshot’ only of the condition of aquatic ecology at the time of the survey and do not provide any measure of natural temporal variability in the indicators of aquatic ecology considered.

6 References

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Appendix A – River Channel and Environment (RCE) Score Sheet

Descriptor and category	Value	Descriptor and category	Value
1 Land use pattern beyond the immediate riparian zone		8 Riffle / pool sequence	
Undisturbed native vegetation	4	Frequent alternation of riffles and pools	4
Mixed native vegetation and pasture/exotics	3	Long pools with infrequent short riffles	3
Mainly pasture, crops or pine plantation	2	Natural channel without riffle / pool sequence	2
Urban	1	Artificial channel; no riffle / pool sequence	1
2 Width of riparian strip of woody vegetation		9 Retention devices in stream	
More than 30 m	4	Many large boulders and/or debris dams	4
Between 5 and 30 m	3	Rocks / logs present; limited damming effect	3
Less than 5 m	2	Rocks / logs present, but unstable, no damming	2
No woody vegetation	1	Stream with few or no rocks / logs	1
3 Completeness of riparian strip of woody vegetation		10 Channel sediment accumulations	
Riparian strip without breaks in vegetation	4	Little or no accumulation of loose sediments	4
Breaks at intervals of more than 50 m	3	Some gravel bars but little sand or silt	3
Breaks at intervals of 10 - 50 m	2	Bars of sand and silt common	2
Breaks at intervals of less than 10 m	1	Braiding by loose sediment	1
4 Vegetation of riparian zone within 10 m of channel		11 Stream bottom	
Native tree and shrub species	4	Mainly clean stones with obvious interstices	4
Mixed native and exotic trees and shrubs	3	Mainly stones with some cover of algae / silt	3
Exotic trees and shrubs	2	Bottom heavily silted but stable	2
Exotic grasses / weeds only	1	Bottom mainly loose and mobile sediment	1
5 Stream bank structure		12 Stream detritus	
Banks fully stabilised by trees, shrubs etc	4	Mainly unsilted wood, bark, leaves	4
Banks firm but held mainly by grass and herbs	3	Some wood, leaves etc. with much fine detritus	3
Banks loose, partly held by sparse grass etc	2	Mainly fine detritus mixed with sediment	2
Banks unstable, mainly loose sand or soil	1	Little or no organic detritus	1
6 Bank undercutting		13 Aquatic vegetation	
None, or restricted by tree roots	4	Little or no macrophyte or algal growth	4
Only on curves and at constrictions	3	Substantial algal growth; few macrophytes	3
Frequent along all parts of stream	2	Substantial macrophyte growth; little algae	2
Severe, bank collapses common	1	Substantial macrophyte and algal growth	1
7 Channel form		**TOTAL**	
Deep: width / depth ratio less than 7:1	4		
Medium: width / depth ratio 8:1 to 15:1	3		
Shallow: width / depth ratio greater than 15:1	2		
Artificial: concrete or excavated channel	1		

Appendix B – Raw Macroinvertebrate Data and Summary Statistics

a) Spring 2014

Date collected	30/09/2014	30/09/2014	30/09/2014	30/09/2014	30/09/2014	29/09/2014
Creek Name	Wirreanda Creek	Wirreanda Creek	Cicada Glen	Cicada Glen	McCarrs Creek	McCarrs Creek
Creek Position	Upper	Lower	Upper	Lower	Upper	Lower
Habitat	Edge	Edge	Edge	Edge	Edge	Edge
Order or Family	WC1	WC2	CGC1	CGC2	MC1	MC2
Hydridae			2			
Dugesiidae	2					1
Temnocephalidae		2				
Nematoda		1	2			
Corbiculidae/ Sphaeriidae			2			1
Hydrobiidae	4		1	1		
Physidae	3		5			2
Glossiphoniidae			2	1		
Oligochaeta	4		5			1
Cladocera	3	1	2			2
Copepoda			2			
Ostracoda	3		10			3
Atyidae	4	10		2	3	3
Parastacidae		1				1
Araneae		1				
Hydracarina	1	9			7	2
Baetidae		4				1
Leptophlebiidae		5		9	10	10
Coenagrionidae			7			4
Megapodagrionidae	2	1			1	2
Synlestidae		1				4
Gomphidae	5				1	3
Aeshnidae		2	1			
Telephlebiidae (=Aeshnidae)	4			1	4	
Hemicorduliidae (=Corduliidae)	9		9			3
Gripopterygiidae		1			5	
Hydrometridae					1	
Veliidae	5	2				1
Gerridae					1	
Corixidae						3
Notonectidae		5	1		6	2
Dytiscidae	10		7			2
Hydrophilidae					1	2
Elmidae	5					
Chironomidae/Chironominae	4	1	10		1	2
Chironomidae/Orthocladiinae						1
Chironomidae/Tanypodinae	4		2	1	1	2
Ceratopogonidae	2	1	1	1	4	
Tipulidae				2	2	
Stratiomyidae	1					
Hydroptilidae				1		1
Tasimiidae				1		
Helicopsychidae				1		
Calamoceratidae	1			3		
Leptoceridae		2	1	5	10	5
Number of taxa	20	18	19	13	16	26
SIGNAL2 Grade	4.11	4.53	3.00	5.46	4.59	3.79
OE50Taxa	0.57	0.77	0.57	0.38	0.86	0.96
Band	B	B	B	C	A	A