MOTT MACDONALD

Frenchs Forest Planned Precinct

Flooding & Stormwater Assessment

12 November 2018

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Contents

Executive summary

The following Flooding and Stormwater Assessment has been written on behalf of the NSW Department of Planning and Environment (DPE) to assist with a water quantity, water quality and flooding assessment for the Frenchs Forest Planned Precinct. The Precinct consists of three phases- this report aims to seek Planning Approval of Phase 1, whilst simultaneously addressing stormwater issues arising in Phase 2 and Phase 3.

Phase 1 Summary

The flooding assessment indicates that the Phase 1 development is relatively unaffected by mainstream flooding in the 1% AEP storm event. This is largely due to the site being topographically located at the peak of the catchment. In the Existing Conditions model, the majority of areas identified as flood affected are generally classified as sheet flow (exhibiting flood depths less than 100mm). The main area of interest is the residential properties located north of Frenchs Forest Road, where an overland flow path connects a series of trapped low points – causing minor flooding through these properties. An existing drainage easement runs through the impacted land parcels which will need to be maintained upon future development.

The existing piped network through the trapped low points is insufficiently sized to cater for the existing flows thus resulting in the overland flow. Mitigation measures could consist of pipe upgrades to convey additional stormwater below ground and/or a formal overland flow path could be created. These impacted developments will need to consider managing flows through their site as developments progress. Given the minor nature of flood depths and the low hazard categorisation; a defined channel above the trunk drainage will be sufficient to consolidate the flows. Development within the Phase 1 boundary will be subject to Council's standard flooding controls- including a flood planning level equal to the 1% AEP plus 500mm freeboard. Additional freeboard requirements are recommended for any proposed below-ground entrances (such as basement car parks, supermarkets loading docks). These controls are considered appropriate for the future development and are in line with standard practice and the Flood Plain Development Manual (FDM). An entrance level of the PMF flood level plus an additional 0.3-0.5m is recommended where practically achievable.

The proposed land use changes were modelled to assess the impacts of development on the local and regional catchment to ensure that there were no adverse impacts on neighbouring properties or cumulative impacts as a result of multiple developments. An XP-RAFTS model was prepared to assess proposed runoff from each development parcel. Onsite Detention (OSD) was applied to each development site as a mitigation measure to restrict proposed flows to a "state of nature" condition as per Council's current DCP controls. A test of the cumulative impacts of all development with at source OSD was undertaken to ensure that the proposed works did not adversely impact properties downstream from the study area in accordance with the s117 Directives and the FDM. The results indicate that by adopting Council's current OSD policy of 'state of nature' there are not expected to be any adverse impacts directly downstream of each development parcel and that cumulative impacts of development do not exceed the current condition and the OSD controls are suitable for adoption with no additional mitigation measures proposed to manage runoff quantity. Results from the cumulative impact assessment confirm that the rezoning of Phase 1 will result in positive flood impacts downstream (due to the implementation of detention basins that restrict the peak stormwater flows back to the natural peak flows). Flood modelling and flood affectation maps have been provided to support the Hydrologic modelling. The results of the assessment also indicate that whilst components of the existing trunk pipe network are currently undersized and do no cater for the existing minor storm event, the proposed development is not expected to have an adverse impact on the existing pipe network as a result of at source OSD. It is however recommended that undersized pipes be upgraded to meet current standards where possible.

As development progresses and building layouts/proposed levels become available, those sites that are flood affected will need to undertake modelling to ensure that the proposed works do not adversely impact flood conveyance as per Councils DCP.

The water quality assessment indicates that Council's objectives can be met with the nominated treatment train and confirms that stream forming flows produced from the rezoning are within acceptable limits. Baseline modelling was undertaken to confirm targets could be practically achieved, again similar to the OSD strategy at source treatment is proposed as opposed to regional systems. This will allow development to occur in a piecemeal manner and eliminate the need for temporary works. Additional stretch targets to achieve sustainable best practice have been discussed in this report and objectives outlined in the Sustainability report (by others). The results of the assessment indicate that with the adoption of the above mitigation measures, the impacts of development can be satisfactorily managed and will meet legislative requirements suitable for rezoning.

Phase 2 Summary

A major overland flow path passes through existing residential properties within the Phase 2 boundary. Flood depths of up to 300mm pass through the land parcels, with ponding up to 500mm expected within the roads in the 1%AEP storm event. Existing intermediate to high hazard is precited within the roads and residential properties. Through implementation of OSD, flood affectation can be appropriately managed so that there is no adverse downstream impacts and cumulative impacts.

An assessment on the trunk drainage system found that it is currently undersized, with many pipes operating at maximum capacity and surcharging predicted in several locations. The rezoning of upstream catchments will ease the burden on the trunk drainage system- reducing both the number of pipes operating at maximum capacity and the number of pits surcharging. Surcharge flow rates will also be greatly reduced. Increasing the size of the trunk drainage system can be considered to improve the conveyance of flows and reduce the flood depths and extents on the affected residential properties.

Results from the cumulative impact assessment confirm that the rezoning of Phase 1 and Phase 2 will result in positive flood impacts downstream (due to the implementation of detention basins that restrict the peak stormwater flows back to the natural peak flows).

The water quality assessment indicates that Council's objectives can be met with the nominated treatment train and confirms that stream forming flows produced from the rezoning are within acceptable limits.

Phase 3 Summary

Minimal flood affectation is precited within Phase 3 area, with the exception of a minor overland flow path (with depths less than 200mm) running north to south through some residential properties. The flood depths and extents will reduce upon development in the rezoned Phase 3 area. The flood path through private properties could be managed by constructing a defined channel in a drainage easement to convey the (mostly) sheet flow. No existing trunk drainage runs through Phase 3.

Results from the cumulative impact assessment confirm that the rezoning of Phase 1, Phase 2 and Phase 3 will result in positive flood impacts downstream (due to the implementation of detention basins that restrict the peak stormwater flows back to the natural peak flows).

The water quality assessment indicates that Council's objectives can be met with the nominated treatment train and confirms that stream forming flows produced from the rezoning are within acceptable limits.

1 Introduction

Mott MacDonald has been engaged by the NSW Department of Planning and Environment (DPE) to assist with the preparation of a Stormwater Drainage Study and Hydraulic Assessment to guide the development of the Frenchs Forest Planned Precinct.

1.1 Scope of Works

The DPE is preparing a master plan to guide the future land uses, built form proposals and growth projections of the Frenchs Forest Planned Precinct. Mott MacDonald has been engaged to undertake a flooding and stormwater drainage study to assist in developing the urban design and planning work for the Precinct. The study aims to assess the existing site and identify constraints and risks associated with water quality and quantity infrastructure to support the delivery of the master plan.

To assist in the preparation of the master plan, Mott MacDonald has undertaken the following tasks:

We have separated our Project Plan into the following key Service Activity workstreams.

- Overland Flow Assessment;
  - Hydrologic Assessment;
  - Hydraulic Assessment;
- Water Quality Analysis.

Overland Flow Assessment

Hydrological Assessment

- Review of existing local and regional studies, flood mapping, etc;
- Review available council data and identify gaps requiring additional information;
- Inspect the site to ground truth the data and existing flood studies;
- Develop a trunk existing XP-RAFTS model for the Study Area:
- Provide a plan for the project team identifying overland flow impacted land parcels;
- Develop a trunk proposed XP-RAFTS model for the Study Area based on the preferred scheme;
- Determine percent impervious rates for new land parcels by agreement with Council;
- Manage the surface runoff of each development parcel within their development boundary such there is no adverse impact on council's existing drainage network or private properties.
- Undertake a cumulative impact assessment of the site to ensure that detained post development flows do not coincide with downstream catchment runoff to worsen peak flows. Larger Downstream catchments will be approximated from LiDAR and added to the XP-RAFTS model. The results of this assessment will then either support the appropriateness of current DCP stormwater detention controls or recommend adjustments to ensure that there are no adverse cumulative impacts;
- Provide guidance on DCP controls to be adopted in the precinct and address s117 Directives, and;
- Stormwater and Flooding Report, suitable for Planning Proposal lodgement.

Hydraulic Assessment

- Provide advice on development controls including (if any), Flood planning levels, freeboard allowances, climate change impacts, 1% AEP/PMF events and flood evacuation;
- Provide a plan for the project team identifying overland flow impacted land parcels;
- Based on a preferred layout, provide commentary on flood mitigation options. The detention modelling will address the increase in stormwater runoff from the proposed developments as such it will be the responsibility of the future developers to manage existing flood waters through their site, this will be assessed by Council at the DA stage; and
- Provide a flooding section to the overall Flooding and Drainage Impact Assessment Report suitable for Planning Proposal lodgement.

Water Quality and Waterways

- All future development will be required to provide onsite stormwater runoff treatment in accordance with Council's requirements and objectives. This will be managed through DCP controls; and
- Examine the effects of increased water quantities and altered water quality on downstream environments.

Note. Council has a draft MusicLink model which uses the appropriate local input data and has parameters constrained to Council's requirements.

Section 7.11/SIC Levy

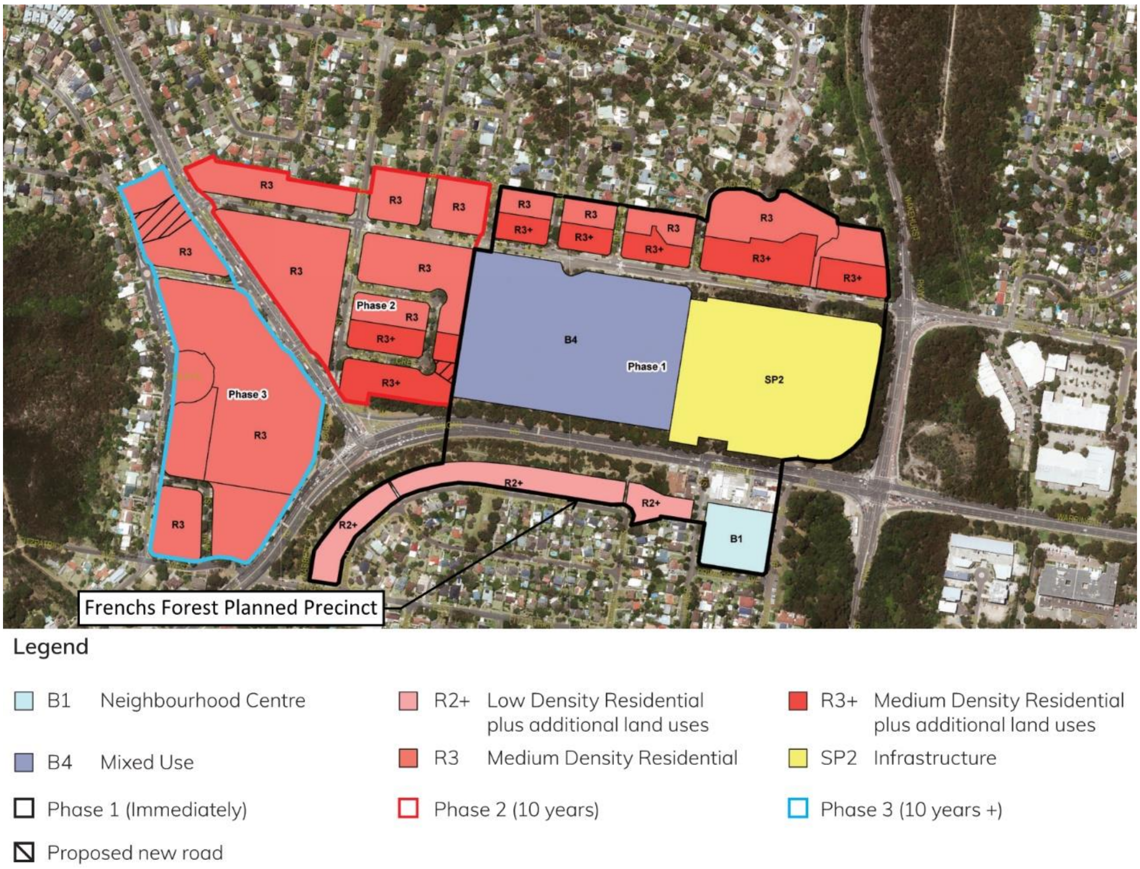
- Identify and cost the trunk drainage works / devices (if any) that will be required to enable all developments in the Structure Plan area to meet the water quantity and quality objectives (note: 'trunk' means the works that will support multiple developments and which are to be transferred to Northern Beaches Council ownership upon completion); and
- Identify the land required for the above works / devices (if any).

1.2 Study Area and Purpose of Report

The Structure Plan is broken into three phases as shown below.

- **Phase 1 (Planned Precinct Rezoning) this study**
- Phase 2 (To be rezoned at a later date)
- Phase 3 (To be rezoned at a later date)

Figure 1: Study Area and Phases



This study is primarily focused around the Phase 1 Planned Precinct rezoning. However, in order to holistically consider the cumulative impacts of the overall Structure Plan, Phases 2 and 3 have been considered in their draft form to allow for wider cumulative impacts to be assessed. The approval sought in this assessment is only related to the Planned Precinct (Phase 1), as such the assessment undertaken aims to address the requirements for rezoning of Phase 1. Further revision may be required to the Phase 2 and 3 areas as development progresses.

The purpose of this report is to address the following:

- Understand the existing stormwater flow conditions for the site and the adjacent catchments discharging to Middle Creek in Jindabyne Reserve;
- Undertake a desktop review of existing stormwater drainage infrastructure and overland flow behaviour within the study area;
- Determine on-site detention requirements for post development flows from regulatory authorities and recommend any change to Council's DCP should there be adverse impacts as a result of the cumulative impact assessment;
- Compare the existing and proposed peak flows for the study area to ensure there are no adverse flood impacts as a result of development, and at the confluence point with downstream catchments at Jindabyne Reserve;
- Identify appropriate treatment measures to satisfy Council's water quality and quantity requirements for each development parcel; and
- Provide support for the Precinct Plan, suitable for Planning Proposal Lodgement.

1.3 Limitations

The nature of rezoning existing urban land such as the Frenchs Forest Planned Precinct means it is currently unclear which blocks will be amalgamated by developers first and developed into the proposed densities. Consequently, staging and rollout of the Planned Precinct is currently uncertain and likely to occur in an irregular piecemeal manner. In the interest of creating a streamlined approach to development rollout the assessment methodology adopted in this report aims to minimise disruption and forward funding of infrastructure.

This study has been prepared based on Council approved and industry standard rates for development potential, impervious fractions, etc. As development progresses and more details become available these assumptions can be refined or modified where appropriate and agreed with Council.

The modelling undertaken in this report is commensurate to its intended purpose and level of information available at the time of preparation. The results and recommendations of this study are provided to support the rezoning of the Precinct and shall not be relied upon by Third Parties. Further detailed investigations will need to be undertaken for individual developments as they occur. This report does not release any third parties of their Environmental and Legal obligations.

1.4 Regional Context

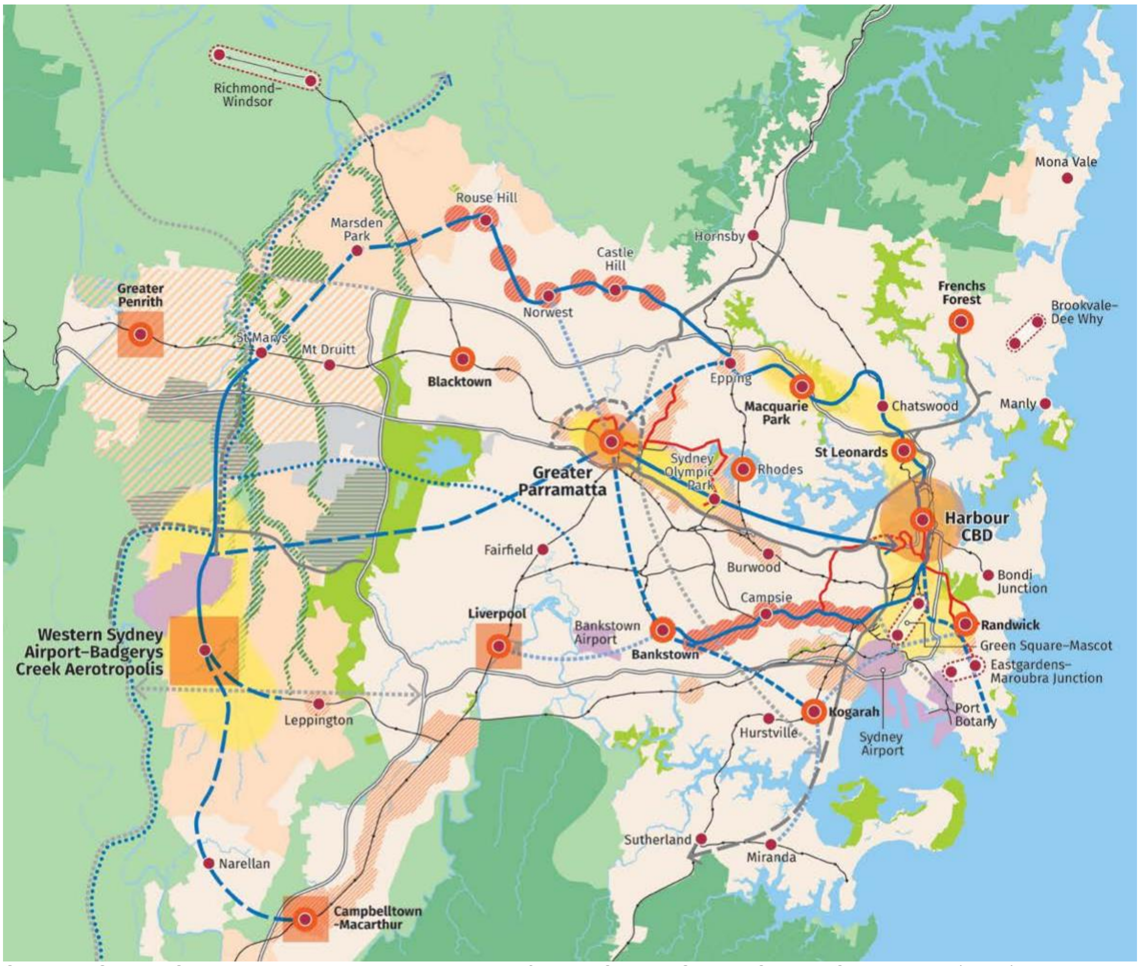
Frenchs Forest is located approximately 18 kilometres north of the Sydney CBD, lies within the local government boundaries of the amalgamated Northern Beaches Council and forms part of the Northern Beaches region. The Northern Beaches region covers approximately 263 km2 which is currently served by Manly and Mona Vale town centres and Brookvale and Dee Why major centres.

In the absence of railway infrastructure, access to the region is reliant upon the regional road network, including Warringah Road, Mona Vale Road, Wakehurst Parkway and Pittwater Road. While there are limited ferry services to Mosman and Manly there is heavy reliance on private vehicle and bus transportation.

In March 2018 the Greater Sydney Commission released the Greater Sydney Region Plan, which identified Frenchs Forest as a Health and Education Precinct. These precincts seek to facilitate place-based outcomes for specific employment and mixed-use centres across Sydney. The Frenchs Forest Precinct will deliver new homes and jobs located close to public transport, shops and services. The Greater Sydney Region Plan is shown on Figure 2.

The Frenchs Forest Precinct also forms part of the North District Plan, which was released in 2017. The Northern Beaches Hospital will form the centre of this Precinct, and will be supported by improved transport links, a new urban core and employment hub. The plan estimates that the Precinct will deliver between 12,000 – 13,000 new jobs by 2036.

Figure 2: Greater Sydney Region Plan



Source: Greater Sydney Region Plan – A Metropolis of Three Cities – Greater Sydney Commission (2018)

1.5 Northern Beaches Hospital Precinct Structure Plan (NBHSP)

To complement the existing local centres and to capitalise on the major Northern Beaches Hospital (NBH) investment, the Northern Beaches Council (NBC) compiled the Northern Beaches Hospital Precinct Structure Plan (NBHPSP) in 2017. This included a new town centre and neighbouring dwellings adjacent the new NBH as illustrated in Figure 3.

The NBHSP covers approximately 49 hectares of rezoned land in Frenchs Forest and proposes the phased delivery of 5,360 new dwellings and 2,300 new jobs over the next 20 years. The NBHSP envisages a transport interchange will be incorporated into the redevelopment of the town centre on the existing Forest High School site. Surrounding the town centre will be apartment buildings with a variety of building heights and forms with a maximum height of 40 metres to correspond with the NBH height.

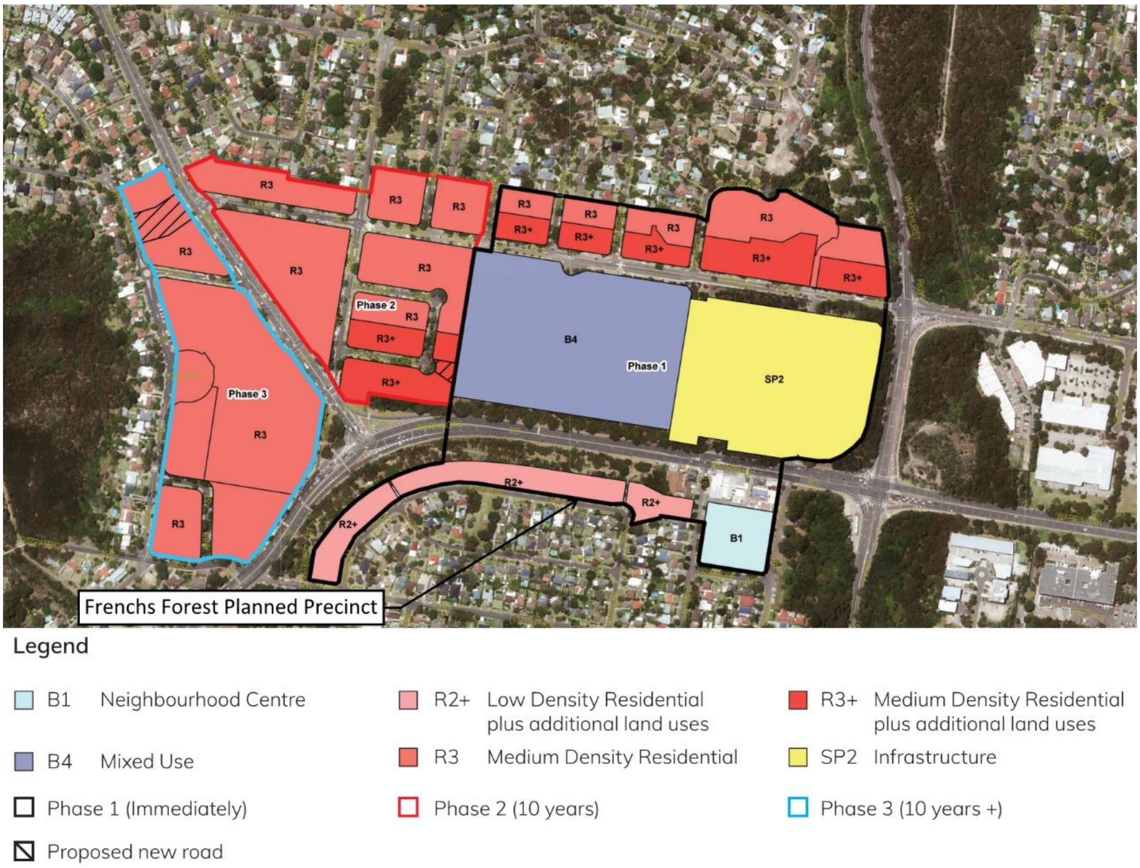
The NBHSP identified that of the 5,360 new dwellings to be delivered in the full NBHPSP area, 3,000 could be supported in the short term without major road infrastructure upgrades. Therefore, the Department of Planning and Environment (DPE) have nominated a Planned Precinct (PP) for the first 3,000 dwellings which fall in the area also illustrated in black in Figure 3.

From the NBHSP, it appears the NBC and its consultants undertook the following supporting activities in developing the NBHPSP:

- A transport and traffic study;
- A detailed community and stakeholder engagement process;
- An affordable housing study;
- A bushfire study;
- A development feasibility study; and
- A retail demand and economic study.

This report aims to support and provide further detail regarding water cycle management in support of both the Structure Plan and Planned Precinct.

Figure 3: Northern Beaches Hospital Precinct Structure Plan



1.6 Frenchs Forest Planned Precinct Area

1.6.1 Location and Topography

The study area is approximately 27 hectares in size and is generally bordered by:

- Karingal Crescent to the south;
- Wakehurst Parkway to the east;
- Sylvia Place to the west; and
- Residential dwellings to the north.

The Precinct Plan area currently does not include any major transport facilities other than bus stops along Frenchs Forest Road and Warringah Road.

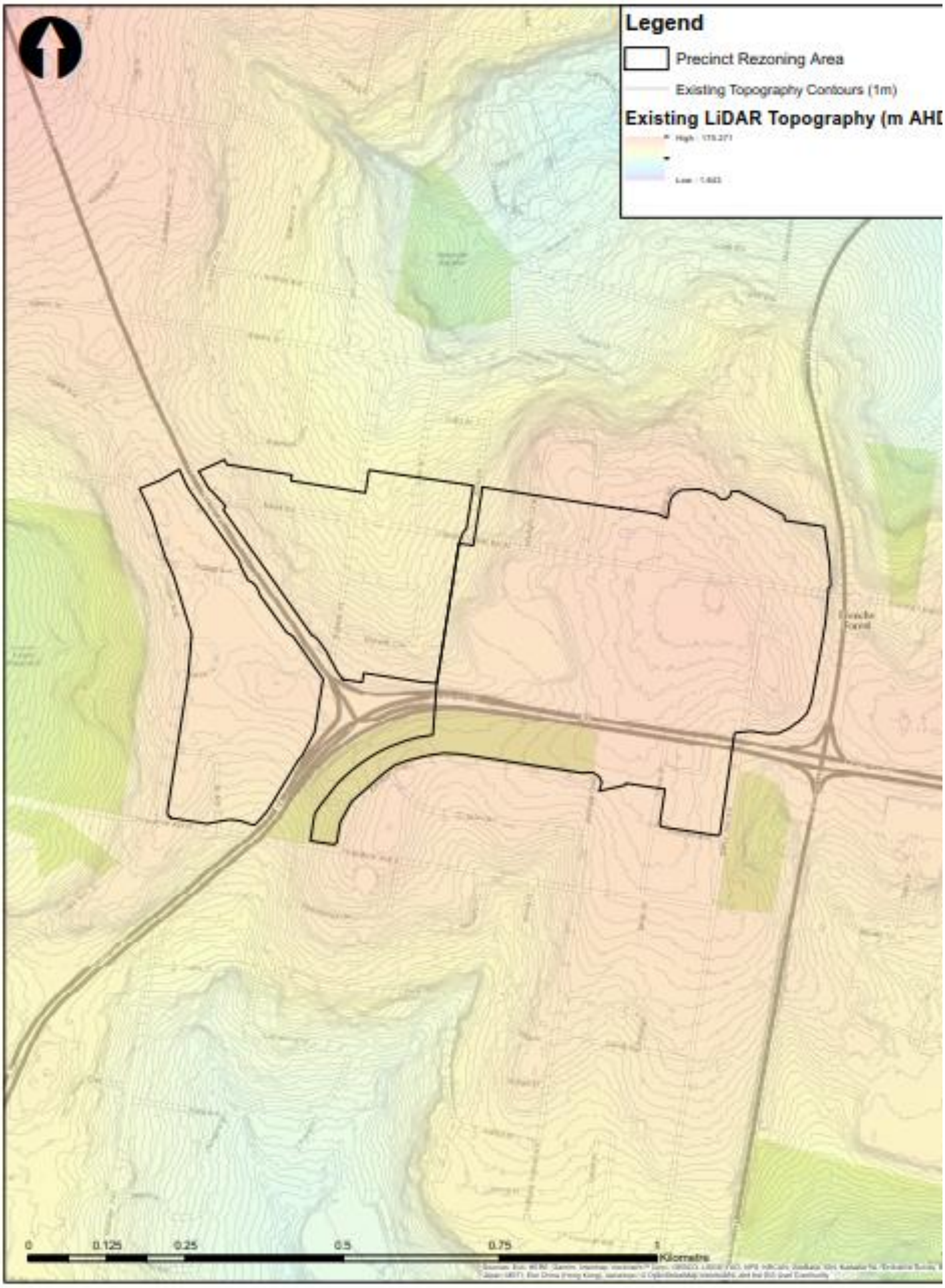
As illustrated in Figure 4, the Planned Precinct area sits approximately at the top of a local hill and grades as follows:

- The north of the Planned Precinct grades towards Jindabyne Reserve and Middle Creek which flows in a north westerly direction from the Precinct;
- To the north east, the study area grades towards Trefoil Creek which flows north until it meets Middle Creek;
- The crest of the hill continues east from the Precinct boundary;
- The south east of the site grades perpendicular from the Precinct until Manly Creek;
- The south and south west grades south into Sydney Harbour via Garigal National Park;
- The west of the Precinct grades perpendicular to the Precinct toward Carroll Creek.

It is noted that the elevation of the:

- Full Structure Plan region varies from a minimum of 125m to a maximum of about 162m;
- Planned Precinct region varies from a minimum of 136m to a maximum of about 162m.

Figure 4: Frenchs Forest Topography



Source: LiDAR (Land & Property Information, 3/6/18)

1.7 Proposed Development

Within the NBHSP area there are 103 existing dwellings:

- 53 of which are south of Warringah Road; and
- The remaining 50 are north of Warringah Road.

The core of the Precinct Plan area includes the NBH and Forest High School (FHS). The NBHSP proposes to move FHS to a site south east of the Precinct and replace it with a new mixed-use town centre.

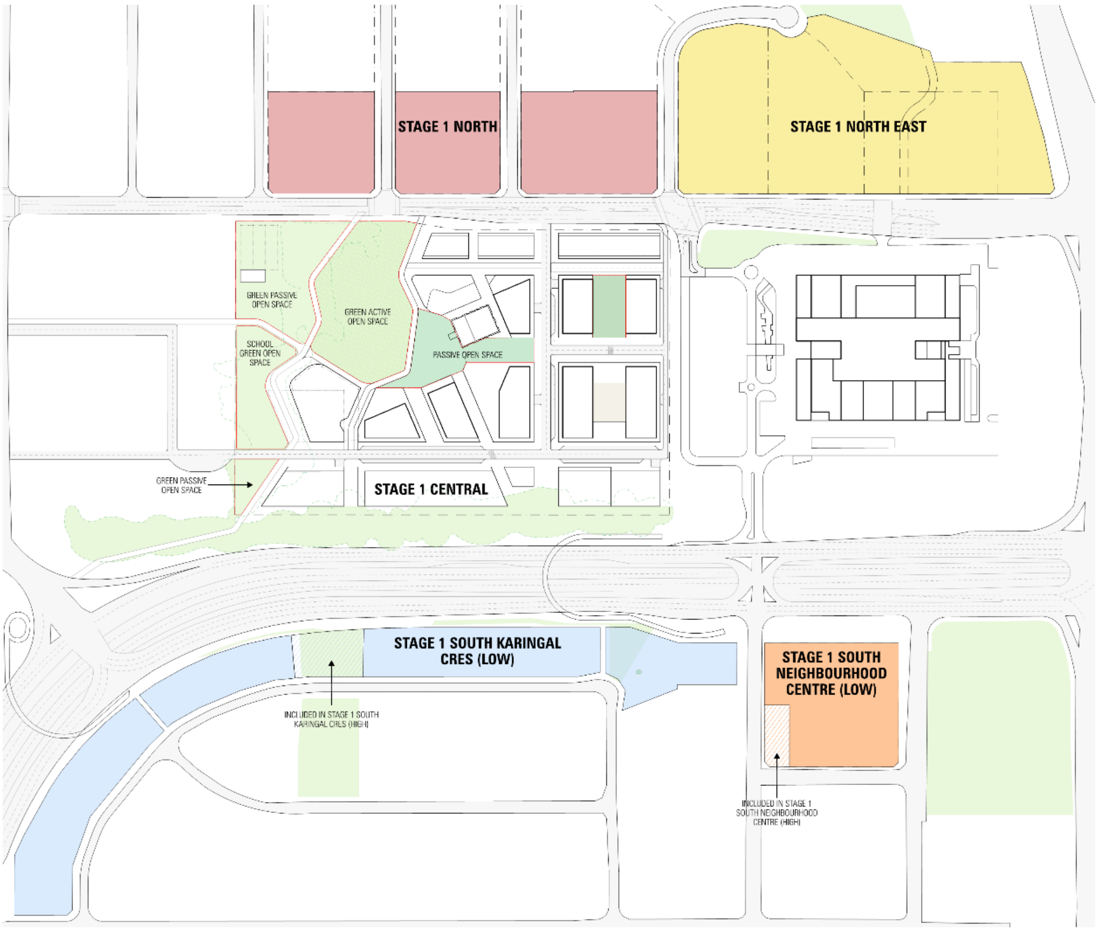
As described in Section 1.5, the NBHSP proposed 5,360 dwellings to be delivered in three Phases over a 20 year period. Through consultation with Council, DPE have now proposed 4,530 dwellings for the NBHSP area. The Frenchs Forest Planned Precinct covers the Phase 1 area and will deliver 2,100 dwellings, with the balance of dwellings to be delivered in Phases 2 and 3. The Planned Precinct will also deliver 82,722m2 GFA of commercial space. The distribution of development is provided in Table 1 below. The Planned Precinct area has been divided into ten blocks as illustrated in Figure 5.

Table 1: Proposed and Existing Yields

Block	Proposed Dwellings	Existing Dwellings	Additional Dwellings	Proposed Retail/ Commercial GFA (sqm)
Stage 1 North	335	24	311	3,292
Stage 1 North East	566	26	540	1,839
Stage 1 South	90	36	54	-
Stage 1 South Neighbourhood Centre	121	17	104	3,196
Stage 1 Central	1,000	1	999	74,395
TOTAL	**2,129**	**103**	**2,008**	**82,722**

Source: Chrofi Frenchs Forest Precinct Key Plan (10/7/18) & NSW DFSI Cadastre

Figure 5: Planned Precinct Key Plan



Source: Chrofi (10/7/18)

1.8 Northern Beaches Hospital Development

The Northern Beaches Hospital development is a major part of, and springboard for the Planned Precinct. The development is largely under construction and has sought its own approvals independent of the Planned Precinct thus far and has therefore been considered as developed in the modelling.

2 Design Controls

2.1 Australian Rainfall and Runoff – Volume 1 (2016)

Prepared by the Institution of Engineers, Australian Rainfall, and Runoff – *A Guide to Flood Estimation* was written to "provide Australian designers with the best available information on design flood estimation". It contains procedures for estimating stormwater runoff for a range of catchments and rainfall events and design methods for urban stormwater drainage systems.

According to the document, good water management master planning should consider:

- Hydrological and hydraulic processes;
- Land capabilities;
- Present and future land-uses;
- Public attitudes and concerns;
- Environmental matters;
- Costs and finances; and
- Legal obligations and other aspects.

2.2 Northern Beaches Council Control Documents

2.2.1 Warringal Council Development Control Plan (2011)

An integral part of the water cycle management study, Development Control Plans (DCP) provide the necessary controls for the assessment of individual sites. The former Warringah Council DCP has been used for the purpose of this study as Northern Beaches Council does not yet have a combined DCP for the LGA.

Specific water management and design requirements include:

- Northern Beaches Council WSUD & MUSIC Modelling Guidelines; and
- Warringah Council On-Site Stormwater Detention Technical Specification.

2.2.2 Northern Beaches Council WSUD & MUSIC Modelling Guidelines

Council's *WSUD & MUSIC Modelling Guidelines* outlines a broad strategy for the implementation of WSUD principles within the LGA including compliance with Council's target water quality pollutant removal rates as summarised below:

Table 2: Water Quality Objectives

Pollutant	Reduction Objective
Total Suspended Solids	85%
Total Phosphorus	65%
Total Nitrogen	45%
Gross Pollutants	90%

Source: Northern Beaches Council *WSUD & MUSIC Modelling Guidelines*

The Guidelines also provide a broad strategy on modelling WSUD elements in the MUSIC software package software including modelling parameters to be used within the Northern Beaches LGA.

2.2.3 Warringah Council On-Site Stormwater Detention Technical Specification

Council's *On-Site Detention Technical Specification* sets out the requirements for the design of stormwater drainage and detention for urban and rural areas. The technical specifications outline a broad strategy for the design and development of land within the LGA including:

- Providing clear guidelines for the requirements of stormwater drainage and civil works;
- Ensuring that developments meet all relevant standards for the disposal of stormwater and that developments do not increase the hazard to persons or property; and
- Catering for minor and major stormwater systems

The policy also provides detailed requirements for the hydrologic and hydraulic design and analysis of the proposed water management system including standard calculation factors.

2.2.4 Northern Beaches Council Flood Risk Management Policy (2017)

The Flood Risk Management Policy (the Policy) establishes the flood risk management approach within the Northern Beaches Council Local Government Area (LGA). Through strategic and operational outcomes, Council aims to reduce the impact of flooding and reduce private and public losses resulting from floods.

The objectives of this Policy are:

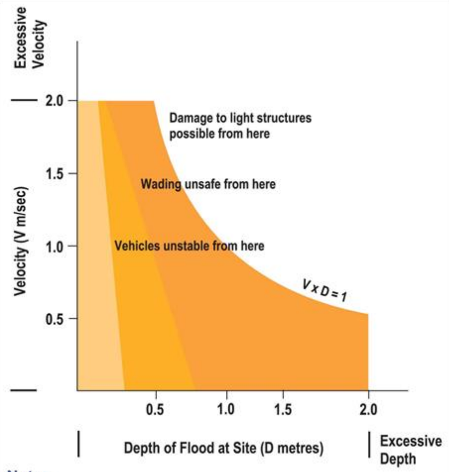
- To ensure a sustainable and holistic catchment wide approach is taken to development, of both private land uses and public facilities, on flood prone land;
- To increase public awareness of the hazard and extent of land affected by all potential floods, including floods greater than the 1% AEP flood;
- To ensure the flood risk associated with development is minimised;
- To manage the risk to life, damage to property and impacts on the natural environment caused by flooding and inundation by controlling development on flood prone land;
- To ensure the development is compatible with the flood risk through the application of risk based controls that take into account social, economic, ecological and design considerations;
- To ensure that proposed development does not expose existing development to increased risks associated with flooding;
- To ensure that effective development controls apply so that development is carried out in accordance with these objectives and the requirements of this policy; and
- To ensure that the preparation of flood related information required to be lodged under this Plan are carried out by suitably qualified professionals with appropriate expertise in the applicable areas of engineering.

2.3 NSW Floodplain Development Manual (2005)

The NSW Government's *Floodplain Development Manual – the Management of Flood Liable Land (2005)* is concerned with the management of the consequences of flooding as they relate to the human occupation of urban and rural developments. The manual outlines the floodplain risk management process and assigns roles and responsibilities for the various stakeholders.

Appendix L – Hydraulic and Hazard Categorisation, of the manual, considers ensuring safe overland flow paths are provided (refer to Figure 6).

Figure 6: Velocity Depth Relationships



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.

Source: *NSW Floodplain Development Manual, 2004 (*Dept. of Infrastructure, Planning & Natural Resources*)*

2.4 NSW Department of Environment and Heritage

The NSW Department of Environment and Heritage and the NSW Environment Protection Authority (EPA) has developed a set of guidelines known as the Managing Urban Stormwater (MUS) series. The set of guidelines includes:

- Managing Urban Stormwater: Council Handbook;
- Environmental targets;
- Managing Urban Stormwater: Source Control;
- Managing Urban Stormwater: Soils & Construction; and
- Managing Urban Stormwater: Harvesting and Reuse.

2.4.1 Managing Urban Stormwater: Environmental Targets

The NSW Department of Environment and Climate Change (DECC) encourages the principle of no net deterioration of water quality. Under its former name, the NSWEPA, the DECC published Managing Urban Stormwater: Environmental Targets, outlining recommended environmental targets for stormwater management in new urban developments. These treatment objectives, along with those outlined in Northern Beaches Council's *WSUD & MUSIC Modelling Guidelines*, have been shown in the below table:

Table 3: Stormwater Treatment Objectives for New Urban Areas

Pollutant	DECC Treatment Objectives	Northern Beaches Council Treatment Objectives
Gross Pollutant	90% retention of the annual average load for particles 0.5mm or less	90% retention of the annual average load for particles 0.5mm or less
Suspended Solids	85% retention of the annual average load	85% retention of the annual average load
Total Phosphorous	65% retention of the annual average load	65% retention of the annual average load
Total Nitrogen	45% retention of the annual average load	45% retention of the annual average load

Source: Managing Urban Stormwater: Environmental Targets; & Council's *WSUD & MUSIC Modelling Guidelines*

2.4.2 Managing Urban Stormwater: Source Control

The DECC guide, Managing Urban Stormwater: Source Control recommends the control of stormwater pollution at the source, rather than more traditional "end of line" systems that are unsightly and require high levels of ongoing maintenance. In this document, Water Sensitive Urban Design (WSUD) is described as "minimising the impacts of development on the total water cycle and maximising the multiple benefits of a stormwater system". It lists the main objectives of WSUD as:

- Preservation of existing topographic and natural features;
- Protection of surface water and groundwater sources;
- Integration of public open space with stormwater drainage corridors, maximising public access; and
- Passive recreational activities and visual amenity.

The broad principles of WSUD are listed as:

- Minimising impervious area;
- Minimising the use of formal drainage systems (e.g. pipes);
- Encouraging infiltration (where appropriate); and
- Encouraging stormwater re-use.

2.4.3 Managing Urban Stormwater: Soils and Construction

Managing Urban Stormwater – Soils and Construction (4th edition, March 2004) are guidelines produced by the NSW Department of Housing to help mitigate the impacts of land disturbance activities on landforms and receiving waters by focusing on the removal of suspended solids in stormwater runoff from construction sites.

According to the guide, effective soil and water management during construction involve the following key principles:

- Assess the soil and water implications of development at the subdivision or site planning stage (including salinity and acid sulphate soils);
- Plan for erosion and sediment control concurrently with engineering design and before the land disturbance begins;
- Minimise the area of soil disturbed;
- Conserve topsoil for subsequent rehabilitation/revegetation;
- Control surface runoff from upstream areas, as well as through the development site;
- Rehabilitate disturbed lands as quickly as possible; and
- Maintain soil and water management measures appropriately during, and after the construction phase until the disturbed land is fully stabilised.

2.5 The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method -Bureau of Meteorology (2003)

The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method (GSDM) offers guidance to those engaged in estimating the probable maximum precipitation for durations up to three or six hours in Australia.

The purpose of this publication is to provide a method that can be used to make consistent and timely estimates of probable maximum precipitation for catchment areas up to 1000 km^2. Estimates are limited to a duration of six hours along the tropical and subtropical coastal areas and three hours in inland and southern Australia. The method allows for two classes of terrain and takes into account the local moisture availability and the mean elevation of the catchment.

3 Hydrology Assessment

The following section addresses the water quantity management for the site. Typically, with large developments, the amount of impervious area (roofs, concrete hardstand etc.) is increased from the existing development scenario. Due to the increase in impervious area, an increase in stormwater runoff from the site will occur. Council and state legislation require that all new developments ensure that the amount of stormwater runoff does not increase as a result of development intensification.

Without On-site Stormwater Detention (OSD) or other compensatory flood storage, the cost of dealing with additional stormwater runoff from a new development is inadvertently passed on to downstream residents in the form of increased flood damage, or onto the local authorities that must upgrade the drainage system or construct additional flood mitigation works. Council does not accept proposed developments to worsen flooding conditions of downstream properties, as their policies require that each developer bears the cost of flood affectation on their own development.

3.1 Objective

The hydrology assessment aims to meet the following objectives for this study:

1. Prepare an XP-RAFTS model under “state of nature” (0% impervious) conditions to determine base case flow discharges;
2. Prepare an XP-RAFTS model under existing conditions to determine existing flow discharges;
3. Prepare an XP-RAFTS model under post-development conditions with the implementation of OSD to restrict proposed flow discharges to existing flow discharges;
4. Determine whether the implementation of OSD will cause a cumulative increase in discharge rates downstream of the subject site; and
5. Assess the impacts of climate change, most notably the increasing rainfall intensity with a warmer climate on flooding in the catchment.

3.2 Modelling Procedure

The assessment of water quantity was completed through hydrological modelling. Computer-based models of the ‘state of nature’, existing and developed catchments were constructed using XP-RAFTS. Design storms were applied to these models to give estimates of the 20%, 5%, 1% Annual Exceedance Percentage (AEP) storm discharges as well as discharge from the probable maximum precipitation (PMP), which are examined in the following sections. For each of the AEP and PMP design storms, a range of storm durations was considered. Modelling the full range of storm durations ensures that the assessment is made on worst case flooding conditions which result from storms of different duration in different locations within the catchment.

The Bureau of Meteorology (BOM) defines AEP as the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. PMP is defined the greatest theoretical depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year.

Assessment of these models allowed for the sizing and configuration of proposed detention basins and an analysis of the time of peak discharges and their cumulative effect downstream.

To account for changes in rainfall intensity and frequency in accordance with latest guidelines and best available information for climate change, the hydrologic assessment includes simulations of climate change scenarios. The approach includes a sensitivity analysis by applying a 20% increase to the IFD coefficients from the Bureau of Meteorology is detailed further in Section 3.11. This approach follows recommendations from the former Department of Environment and Climate Change document titled *Practical Consideration of Climate Change.*

Pipes less than 600mm are assumed to be blocked for the hydrological assessment. Pipes are included in the TUFLOW modelling for the site (Stage 2 Assessment).

3.3 XP-RAFTS Software

An overall catchment is divided into a network of sub-catchments joined by links. The links represent natural watercourses, artificial channels, or pipes. Rainfall is applied to each sub-catchment. Losses (representing infiltration, interception, etc.) are subtracted from the rainfall and the excess is then converted into an instantaneous flow. This instantaneous flow is then routed through the sub-area storages to develop local sub-catchment hydrographs. Total flow hydrographs at various nodes in the drainage network are calculated by combining local hydrographs. Hydrographs are transported through the drainage network by time lagging or channel routing. Hydrographs may also be routed through storage basins such as dams or detention basins.

3.4 Parameters

The user data inputs required by XP-RAFTS include catchment areas, catchment slopes, pervious and impervious areas, Intensity-Frequency-Duration (IFD) rainfall statistics, hydrological losses, and routing times. Guidelines for determining these parameters are provided in the Australian Rainfall and Runoff (I.E Aust, 2001) and are broken up as follows.

3.4.1 Slopes

A three-dimensional (3D) surface was produced from aerial survey (LiDAR) data supplied by NSW Spatial Services using 3D modelling software. A slope analysis was performed on the 3D surface to determine slope profiles across the subject site.

3.4.2 Intensity-Frequency-Duration (IFD)

Rainfall intensities were calculated within the XP-RAFTS model using the automatic storm generator tool. The tool requires the input of nine raw coefficients which were obtained from the Bureau of Meteorology's Intensity-Frequency-Duration (IFD) calculator, as shown in Table 4. The IFD coefficients from the Bureau of Meteorology are consistent with IFD data provided in Appendix 7 of Northern Beaches Council's On-Site Stormwater Detention Technical Specification. Table 4 below provides a summary of the coefficients used.

Table 4: IFD Coefficients from the Bureau of Meteorology

Intensity (mm/hr)	2% AEP 1 hour	86.52
	2% AEP 12 hour	20.02
	2% AEP 72 hour	6.44
	50% AEP 1 hour	41.16
	50% AEP 12 hour	9.23
	50% AEP 72 hour	2.86
Geographic Factors	f50	4.3
	f2	15.87
Location Skew	-	0

Source: Bureau of Meteorology 1987ARR

Storm durations considered for the above AEP design storms include the 20, 25, 30, 45, 60, 90, 120 and 180 minute durations.

3.4.3 Rainfall Losses

The loss model used to estimate rainfall excess in the development of design flow hydrographs was the Initial Loss-Continuing Loss model. Parameters have been assumed from previous works in the area along with best practice approach. The initial and continuing losses for pervious and impervious surfaces for the 1% AEP and PMF are detailed in Table 5.

Table 5: Rainfall losses

		Pervious	Impervious
1% AEP	Initial Loss (mm)	15	2
	Continuing loss (mm/hour)	2	0
PMF	Initial Loss (mm)	0	0
	Continuing loss (mm/hour)	0	0

3.4.4 Hydraulic Roughness Parameters

Hydraulic roughness parameters for the catchments were estimated based upon site inspections. The hydraulic roughness parameters were based on impervious and pervious surfaces and are summarised in Table 6.

Table 6: Hydraulic Roughness Parameters

Land-use	Roughness Coefficient
Pervious Surfaces	0.035
Impervious Surfaces	0.015

3.4.5 B-Multiplier

The B-multiplier (B) used in XP-RAFTS is the coefficient used to calibrate a model to fit observed rainfall and streamflow data/recorded floods. The existing and proposed models both adopted a default ‘b’ value of 1.0. No further calibration was deemed necessary as the model is localised and does not tie into any regional hydrological models completed in the area.

3.4.6 Links

Time-based lag links were used to route flows through the model. To ensure an accurate representation of hydrograph phasing was achieved, TUFLOW was utilised to calibrate the model. The procedure for determining the lag times was based on an iterative process which re-rationalised the links based on actual flow velocities generated by the catchment in the TUFLOW model. The TUFLOW velocity data used was prior to the inclusion of the 1D piped ESTRY network to accurately measure the overland flow paths lag link. The methodology is described below:

- Velocities were initially derived from a preliminary rainfall-on-grid TUFLOW model. As TUFLOW determines stormflow runoff characteristics from the physical topography, overland flow velocities could be accurately measured along each of the major flow paths.
- The adopted flow velocity for each catchment (m/s) was then converted to a lag time (in minutes) based on the known catchment flow path lengths (m).
- Revised XP-RAFTS lag link times were calculated and returned into the model after more detailed TUFLOW models were created using the XP-RAFTS hydrology inputs, opposed to rainfall-on-grid.

3.4.7 Catchment Delineation

The catchment delineation for the Natural Condition, Existing Condition and Developed Condition were consistent to allow for the accurate comparison of flow rates at various discharge outlet points.

The total catchment size modelled is XP-RAFTS was approximately 123 ha. The catchments have been categorised into three catchment types:

- Developable Catchments;
- Downstream and Upstream Catchments; and
- Existing Road Catchments.

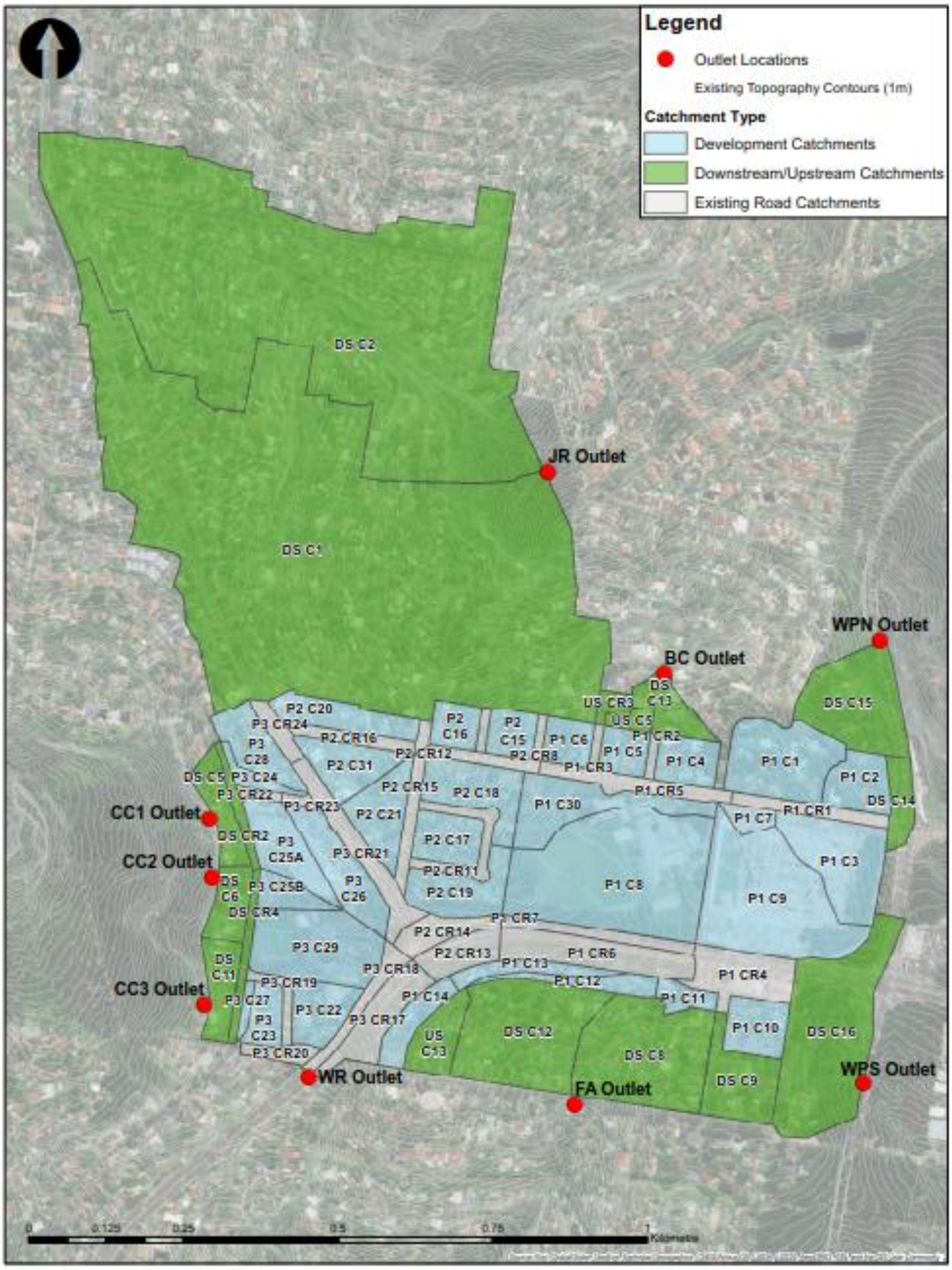
The catchment delineation is shown in Figure 7. Upstream catchments occur in three locations (US C13, US C5 and US CR3) and bypass any detention considered in the analysis discussed later in this report. The impervious percentage of each catchment type has been varied according to the Scenario being modelled.

Key discharge outlet points used for the comparison of flow rates include:

- Jindabyne Reserve- denoted “JR Outlet”
- Bluegum Crescent- denoted “BC Outlet”
- Wakehurst Parkway (North)- denoted WPN Outlet”
- Wakehurst Parkway (South)- denoted WPS Outlet”
- Fitzpatrick Avenue- denoted “FA Outlet”
- Warringah Road- “WR Outlet”
- Carroll Creek- denoted “CC1 Outlet”, “CC2 Outlet” and “CC3 Outlet”

The discharge points are identified in Figure 7.

Figure 7: Catchment Delineation



3.4.8 Impervious Areas

For the purpose of this study, three different cases will be assessed in the XP-RAFTS models (as outlined in Section 3.1) including Natural Condition, Existing Condition and Proposed Condition. Each model has had different impervious percentages applied as follows:

1. **Natural Condition** – All development catchments will be assumed to have no impervious areas i.e. 0% impervious area

Existing Condition – Impervious percentages were determined through an aerial imagery assessment and varies catchment to catchment.

Proposed Condition – The impervious percentages have been applied according to Council's requests for the following: 60% imperviousness for low density residential, 80% for medium density residential, 90% for high density residential and 100% for the town centre and hospital site. These percentages have been applied to all of the 'Development Catchments' (as identified in Figure 7). The 'Downstream and Upstream Catchments' and 'Existing Road Catchments' have the same impervious percentages as specified in the Existing Condition model.

3.4.9 Probable Maximum Precipitation

The Probable Maximum Precipitation (PMP) was calculated using the Generalised Short-Duration Method (GSDM) in accordance with the Bureau of Meteorology's *The Estimation of Probably Maximum Precipitation in Australia: Generalised Short-Duration Method (2003).* Probable Maximum Precipitation (PMP) is defined by the World Meteorological Organization (1986) as '*the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year*'.

This section describes the parameters used in determining the GSDM PMP rainfall intensity estimates for the subject site.

3.4.9.1 Duration Limits

The duration limits were determined in accordance with Figure 2 in *The Estimation of Probably Maximum Precipitation in Australia: Generalised Short-Duration Method (2003),* which shows the areas of Australia subject to the duration limits of 3 and 6 hours. The subject site falls within the 6-hour limit zone. The range of PMF design storms modelled in the analysis includes the 15, 30, 45, 60, 90, 120 and 180 minute duration storms.

3.4.9.2 Terrain Category

The terrain category of the catchment is required to calculate the percentages of the catchment that are 'rough' and 'smooth'. 'Rough' terrain is classified as that in which elevation changes of 50m or more within horizontal distances of 400m are common. 'Rough' terrain induces areas of low level convergence which can contribute to the development and redevelopment of storms, thereby increasing rainfall in the area over longer durations. If a catchment proves difficult to classify under these guidelines then the whole catchment should be classified as 'rough'.

Due to the steep topography of the subject site, particularly around Frenchs Forest Road W and the downstream catchment, the Precinct has been classified as rough to provide the most conservative estimate of the PMF flood extents. A value of 1 was applied to the roughness value and a value of 0 applied to the smoothness value. This has been adopted as a worst case approach.

3.4.9.3 Elevation Adjustment Factor

The mean elevation of the catchment should be estimated from a topographic map. If this value is less than or equal to 1500m the Elevation Adjustment Factor (EAF) is equal to 1.0. For elevations exceeding 1500 m the EAF should be reduced by 0.05 for every 300m by which the mean catchment elevation exceeds 1500m. The Frenchs Forest site has elevations ranging from 88m AHD – 155m AHD, therefore and EAF value of 1.0 was applied. This has been adopted as a worst case approach.

3.4.9.4 Moisture Adjustment Factor

The moisture index used in PMP work is the precipitable water value corresponding to the 24-hour persisting dewpoint. By assuming a saturated atmosphere with a pseudo-adiabatic lapse rate during storm conditions, the precipitable water value can be estimated from the surface dew point temperature, a commonly measured quantity. The ratio of the extreme moisture index for a storm location to the moisture index at the time of the storm was used in the maximisation process. The Moisture Adjustment Factor (MAF) was determined in accordance with Figure 3 in *The Estimation of Probably Maximum Precipitation in Australia: Generalised Short-Duration Method (2003),* and a value of 0.7 was applied.

3.4.9.5 Initial Rainfall Depths

The initial rainfall depth for the smooth and rough terrain categories were read from Depth-Duration-Area (DDA) curves. The DDA curves were produced by BOM by drawing enveloping curves to the highest recorded United States and Australian rainfall depths, which had been adjusted to correspond to a common moisture index. The initial rainfall depths were read in accordance with Figure 4 in *The Estimation of Probably Maximum Precipitation in Australia: Generalised Short-Duration Method (2003).*

3.4.9.6 GDSM Calculation Sheet

The aforementioned parameters were input into the GDSM calculation sheet to obtain the PMP estimates and corresponding rainfall intensity, as shown in Figure 8. The intensities were applied to the XP-RAFTS model as a Global Data input, and consequently tested for the critical storm duration.

Figure 8: GDSM Calculation Sheet

GSDM CALCULATION SHEET

LOCATION INFORMATION

Catchment: Frenchs Forest — Area (km^2): 0.6
State: NSW — Duration Limit (hours): 6
Latitude: -33.75 — Longitude: 151.23
Portion of Area Considered:
Smooth, S= 0 — Rough, R= 1

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation: 140 m
Adjustment for elevation (-0.05 per 300m above 1500m): 1.00
EAF= 1.00

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = 0.7

PMP VALUES (mm)

Duration (hours)	Initial Depth -Smooth	Initial Depth -Rough	PMP Estimate	Rounded PMP Estimate (nearest 10 mm)	Intensity mm/hour
0.25	250	250	175	180	720
0.5	350	350	245	250	500
0.75	440	440	308	310	413
1.0	510	510	357	360	360
1.5	580	655	459	460	307
2.0	650	780	546	550	275
2.5	690	850	595	600	240
3.0	725	940	658	660	220
4.0	795	1065	746	750	188
5.0	855	1180	826	830	166
6.0	900	1240	868	870	145

3.5 Natural Conditions Model

3.5.1 XP-RAFTS Model

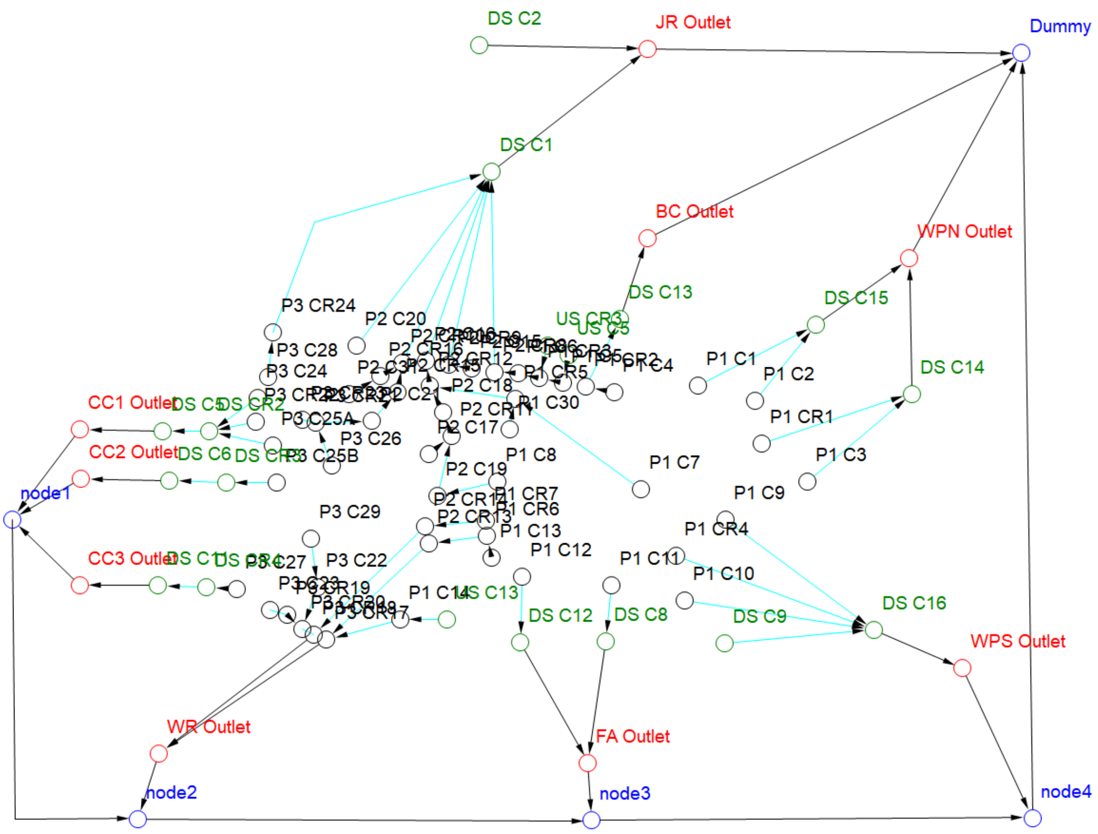
According to Council's *On-Site Stormwater Detention Technical Specification,* all proposed developments must restrict discharge from site to the Natural Conditions discharge rate. The Natural Conditions model assumed the entire catchment is completely pervious.

The XP-RAFTS models were formulated by incorporating the following:

- **Developable Catchment and Existing Road Catchment Nodes** (black) – were used to represent each of the sub-catchments within the precinct rezoning area, as delineated in Figure 9;
- **Downstream/Upstream Catchment Nodes** (green) – were used to represent each of the upstream and downstream sub-catchments, as delineated in Figure 9;
- **Outlet Nodes** (red)**-** were used to model the confluence of catchments at the most downstream point of each overland flow path which allowed both inflow and outflow hydrographs to be assessed;

- **Lag Links** (aqua) – were used as the links between the nodes and were modelled to provide the travel time (in minutes) for the peak flow to travel the length of this reach;
- **Nodes** (blue) – were used to ensure outlet points did not include flows from any other outlets. The nodes do not contain catchment areas and therefore do not create any additional flows.

Figure 9: Natural Conditions XP-RAFTS Network



Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Natural Conditions*

3.5.2 Assumptions

The following assumptions were made for the Natural Conditions XP-RAFTS model:

- No pipe networks have been modelled as discussed with Council (Pipe networks 600mm and above are to be modelled in TUFLOW);
- External catchments which are directed through the site have been included as part of the assessment and modelled in their natural state; and
- Lag times were estimated by hydraulic calculation of catchment peak velocities through downstream flow paths.

3.5.3 Natural Conditions Model Results

The results from the Natural Conditions XP-RAFTS model are shown in Table 7. The results were taken at all major outlet points of the site.

Table 7: Natural Conditions XP-RAFTS Results

Location	XP-RAFTS Node	Peak Flow Rate 20% AEP (m^3/s)	Peak Flow Rate 5% AEP (m^3/s)	Peak Flow Rate 1% AEP (m^3/s)	Critical Storm Duration (min)
Jindabyne Reserve	JR Outlet	17.379	26.541	36.309	120
Bluegum Crescent	BC Outlet	0.432	0.624	0.810	120
Wakehurst Parkway North	WPN Outlet	2.615	3.778	4.878	90
Wakehurst Parkway South	WPS Outlet	2.862	4.217	5.616	120
Fitzpatrick Avenue	FA Outlet	2.046	3.054	4.050	120
Warringah Road	WR Outlet	2.651	3.968	5.349	120
Carroll Creek (1)	CC1 Outlet	0.599	0.929	1.285	120
Carroll Creek (2)	CC2 Outlet	0.423	0.573	0.729	90
Carroll Creek (3)	CC3 Outlet	0.381	0.571	0.739	90

Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Natural Conditions*

Modelled flow rates were compared with calculated flow rates determined using the rational method to validate that they were within the expected range. The rational method is the most widely used empirical technique used for calculating design flow rates within Australia (as recommended in AR&R). The rational method calculates the peak flow rate corresponding to the time of concentration for the catchment. Note the estimated flow rates in the rational method are not related to a specific storm event.

Table 8: Rational Method Discharge Comparison to Natural Flow Rates

Location	XP-RAFTS Node	XP-RAFTS Peak Flow Rate 1% AEP (m^3/s)	Rational Method Peak Flow Rate 1% AEP (m^3/s)	Percent Difference (%)
Jindabyne Reserve	JR Outlet	36.309	33.728	7.1
Bluegum Crescent	BC Outlet	0.810	0.723	10.7
Wakehurst Parkway North	WPN Outlet	4.878	5.218	7.0
Wakehurst Parkway South	WPS Outlet	5.616	6.315	12.4
Fitzpatrick Avenue	FA Outlet	4.050	4.141	2.2
Warringah Road	WR Outlet	5.349	6.493	21.4
Carroll Creek (1)	CC1 Outlet	1.285	1.416	10.2
Carroll Creek (2)	CC2 Outlet	0.729	0.692	5.1
Carroll Creek (3)	CC3 Outlet	0.739	0.653	11.6

Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Natural Conditions*
^ All catchments assumed a 5-minute time of concentration due to the small catchment sizes except for JR Outlet which had a 10-minute time of concentration applied due to the larger catchment size.

As shown in Table 7 and Table 8 the flows generated in the XP-RAFTS model; when compared to the Rational Method calculations, vary across the site, though generally align at each of the primary outlets. Overall, the variances are considered acceptable, averaging a difference of 10%. Discrepancies are largely associated with the varying topography, catchment slopes, and lag routing; these factors are not considered in the empirical-rational method equation.

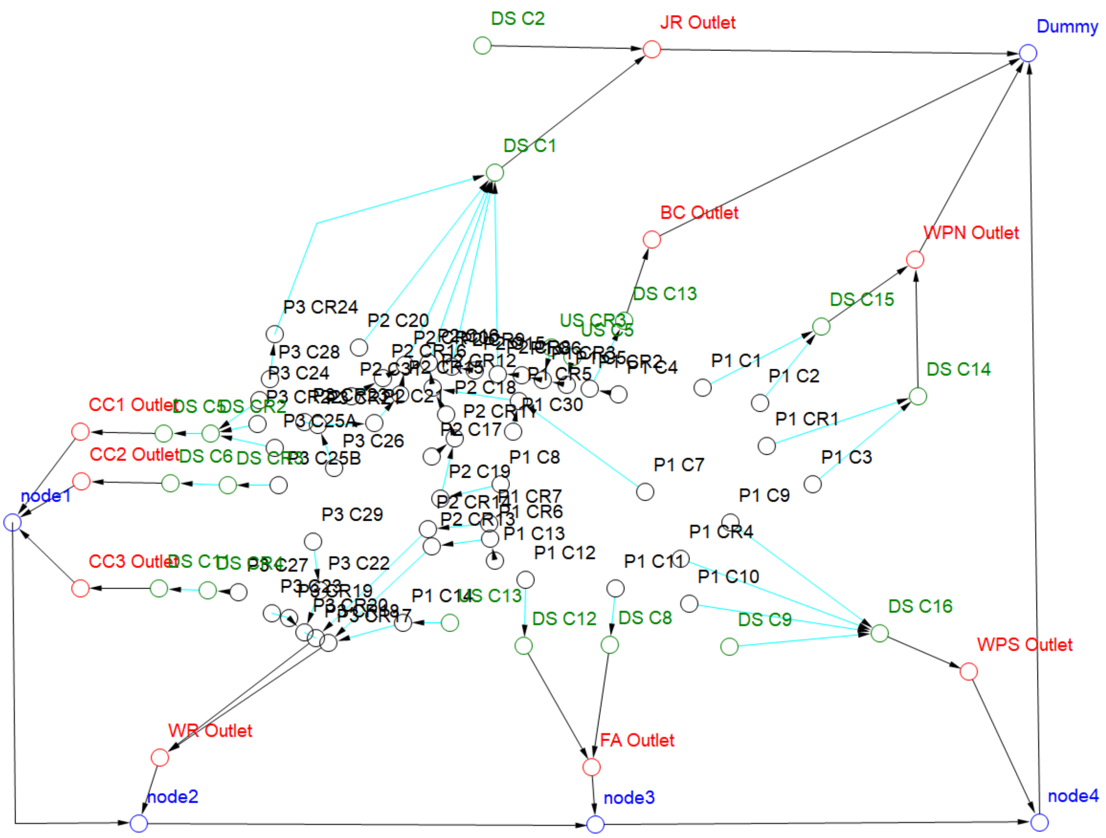
3.6 Existing Conditions Model

3.6.1 XP-RAFTS Model

An Existing Conditions XP-RAFTS model was completed in order to determine the cumulative impacts of the precinct rezoning on the existing developments. The XP-RAFTS model was formulated by incorporating the following:

- **Developable Catchment and Existing Road Catchment Nodes** (black) – were used to represent each of the sub-catchments within the precinct rezoning area, as delineated in Figure 10;
- **Downstream/Upstream Catchment Nodes** (green) – were used to represent each of the upstream and downstream sub-catchments, as delineated in Figure 10;
- **Outlet Nodes** (red) – were used to model the confluence of catchments at the most downstream point of each overland flow path which allowed both inflow and outflow hydrographs to be assessed;
- **Lag Links** (aqua) – were used as the links between the nodes and were modelled to provide the travel time (in minutes) for the peak flow to travel the length of this reach;
- **Nodes** (blue) – were used to ensure outlet points did not include flows from any other outlets. The nodes do not contain catchment areas and therefore do not create any additional flows.

Figure 10: Existing Conditions XP-RAFTS Network



Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Existing Conditions*

3.6.2 Assumptions

The following assumptions were made for the Existing Conditions XP-RAFTS model:

- No pipe networks have been modelled as discussed with Council (to be modelled in tuflow);
- External catchments which are directed through the site have been included as part of the assessment; and
- Lag times were estimated by hydraulic calculation of catchment peak velocities through downstream flow paths.

3.6.3 Existing Conditions Model Results

The results from the base case XP-RAFTS model are shown in Table 9. The results were taken at all major outlet points of the site, as identified in Figure 10.

Table 9: Existing Conditions XP-RAFTS Results

Location	XP-RAFTS Node	Peak Flow Rate 20% AEP (m^3/s)	Peak Flow Rate 5% AEP (m^3/s)	Peak Flow Rate 1% AEP (m^3/s)	Critical Storm Duration (min)
Jindabyne Reserve	JR Outlet	22.470	32.785	43.377	90
Bluegum Crescent	BC Outlet	0.496	0.708	0.901	120
Wakehurst Parkway North	WPN Outlet	3.234	4.466	5.620	90
Wakehurst Parkway South	WPS Outlet	4.543	6.145	7.733	90
Fitzpatrick Avenue	FA Outlet	2.580	3.698	4.772	90
Warringah Road	WR Outlet	3.912	5.382	6.836	90
Carroll Creek (1)	CC1 Outlet	1.114	1.504	1.889	90
Carroll Creek (2)	CC2 Outlet	0.538	0.715	0.897	90
Carroll Creek (3)	CC3 Outlet	0.506	0.688	0.863	90

Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Existing Conditions*

3.6.4 Existing Conditions Model Verification

Modelled flow rates were compared with calculated flow rates determined using the rational method, to validate that they were within the expected range. The rational method is the most widely used empirical technique used for calculating design flow rates within Australia (as recommended in AR&R). The rational method calculates the peak flow rate corresponding to the time of concentration for the catchment. Note the estimated flow rates in the rational method are not related to a specific storm event.

Table 10: Rational Method Discharge Comparison to Existing Flow Rates

Location	XP-RAFTS Node	XP-RAFTS Peak Flow Rate 1% AEP (m^3/s)	Rational Method Peak Flow Rate 1% AEP (m^3/s)	Percent Difference (%)
Jindabyne Reserve	JR Outlet	43.377	44.928	3.6
Bluegum Crescent	BC Outlet	0.901	1.104	22.5
Wakehurst Parkway North	WPN Outlet	5.620	5.787	3.0
Wakehurst Parkway South	WPS Outlet	7.733	8.26	6.8
Fitzpatrick Avenue	FA Outlet	4.772	4.9925	4.6
Warringah Road	WR Outlet	6.836	8.697	27.2
Carroll Creek (1)	CC1 Outlet	1.889	1.934	2.4

Location	XP-RAFTS Node	XP-RAFTS Peak Flow Rate 1% AEP (m^3/s)	Rational Method Peak Flow Rate 1% AEP (m^3/s)	Percent Difference (%)
Carroll Creek (2)	CC2 Outlet	0.897	0.9296	3.6
Carroll Creek (3)	CC3 Outlet	0.863	0.844	-2.2

Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Existing Conditions*
^ All catchment assumed a 5-minute time of concentration due to the small catchment sizes except for JR Outlet which had a 10-minute time of concentration applied.

From Table 10 the flows generated in the XP-RAFTS model alongside the Rational Method calculations, vary across the site, though generally align at each of the primary outlets. Overall, the variances are considered acceptable, averaging a difference of 8%. Discrepancies are largely associated with the varying topography, catchment slopes, and lag routing; these factors are not considered in the empirical-rational method equation.

3.7 Developed Conditions Model

Information on the anticipated land use for the precinct was supplied by the Department of Planning, dated 2017, and is shown in the NBHSP. The development will result in a significant increase in dwelling density via a rezoning process. The site is brownfield in nature and therefore will not require new road connections to support the rezoning. Therefore, road catchments have remained unchanged. The proposed rezoning plan is shown in Figure 3.

The developed model did not incorporate preliminary grading; therefore, the existing LiDAR information was used to determine the catchment data (slopes, impervious percentage, etc.) representing the developed scenario input for the XP-RAFTS hydrologic model.

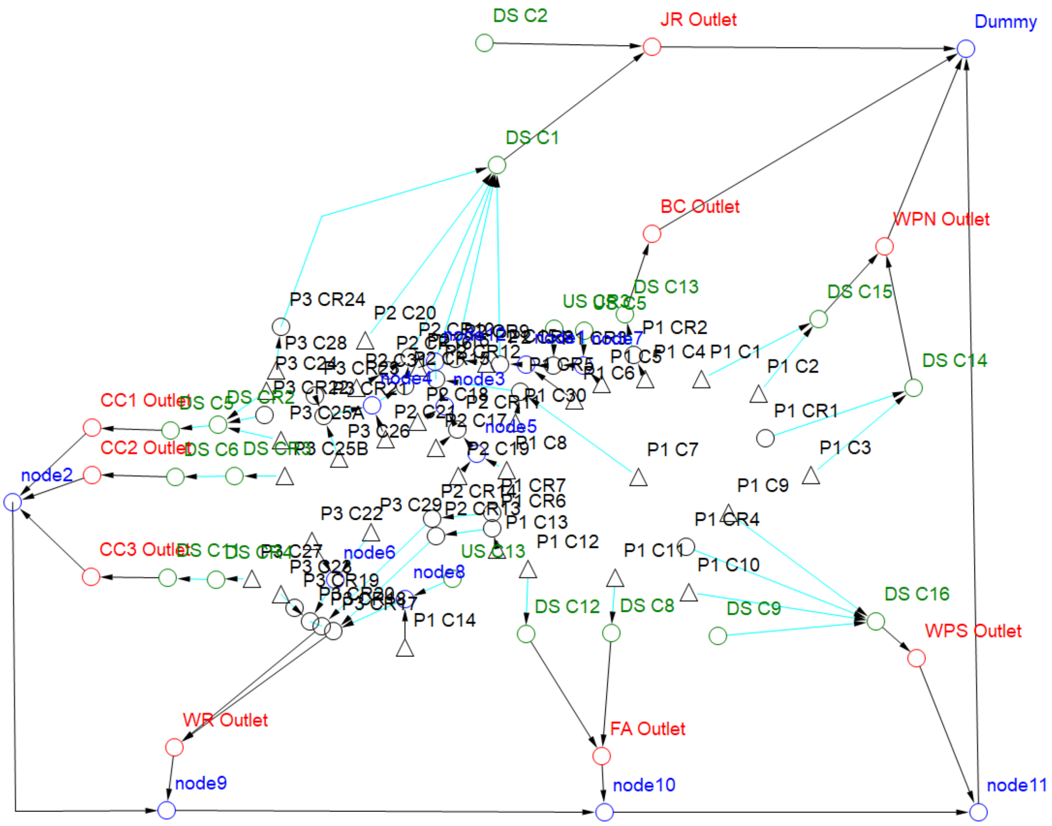
3.7.1 XP-RAFTS Model

The developed XP-RAFTS model was formulated by incorporating the following:

- **Developable Catchment and Existing Road Catchment Nodes** (black)- were used to represent each of the sub-catchments within the developable site area or road network, as delineated in Figure 11;
- **Downstream/Upstream Catchment Nodes** (green)- were used to represent each of the upstream and downstream sub-catchments, as delineated in Figure 11;
- **Outlet Nodes** (red)- were used to model the confluence of catchments at the most downstream point of each overland flow path which allowed both inflow and outflow hydrographs to be assessed;
- **Lag Links** (aqua)- were used as the links between the nodes and were modelled to provide the travel time (in minutes) for the peak flow to travel the length of this reach;
- **Basins** (fuchsia)– were used to represent the proposed detention basins utilised to ensure there is no increase in peak flows exiting the overall development, which could potentially have adverse impacts on downstream properties;
- **Nodes** (blue)- were used to ensure basins were not modelled in series (i.e. the discharge from one basin does not flow into the next downstream basin). The nodes do not contain catchment areas and therefore do not create any additional flows.

Four XP-RAFTS models were created for the proposed condition: without OSD, with OSD, for the PMF and for climate change. The Developed Conditions XP-RAFTS network with OSD is shown in Figure 11. Note all Developed Condition models have the same network.

Figure 11: Developed Conditions XP-RAFTS Network



Source: Mott MacDonald XP-RAFTS Model *393109 180720 FF Developed Scenario- with OSD*

3.7.2 Assumptions

The following assumptions were made for the proposed XP-RAFTS model:

- No pipe networks have been modelled in the XP-RAFTS model;
- External catchments which are directed through the site have been included as part of the assessment as being in their existing state; and
- Lag times were estimated by hydraulic calculations of catchment peak flows travelling through downstream flow paths.

3.7.3 Detention Strategy

Detention Basins were introduced in the hydrologic modelling for the developed conditions model and designed to perform in the full range of flood events between the 20% and 1% AEP storm events. A detention strategy was developed to determine the location and size of the detention basins.

The detention basins have been designed to attenuate the flows within each catchment, back to its natural flow rates, as described in Section 3.1 of this report. OSD has been provided for each developable catchment, and therefore a flow analysis has taken place at the outlet for each of these catchments in their natural state and in the proposed conditions with OSD. Cumulative flow comparisons were conducted at the major outlet points (JR, BC, WPM, WPS, FA, WR, CC1, CC2, and CC3 Outlet) to consider any potential downstream cumulative impacts. For simplicity and to provide a greater level of information, flood affectation maps have been generated for the whole study area this allows cumulative impact comparisons to be drawn at any location throughout the site. The Tuflow assessment was prepared using an 'envelope' approach that considers a number of storm durations and ARI events to compile a worst case synthetic scenario. Reference should be made to the results of the hydraulic assessment discussed in 4.9.1.2.

The basins have been sized for the purpose of showing that Council's current DCP controls on water quantity requirements will remain relevant post the rezoning of the Frenchs Forest Precinct. Future developers of the land will size their own basins in accordance with Council's DCP. It is noted that DCP part E11 condition A4 requires no flooding impacts arising from the development. Any impact that a development has on flooding is closely linked to the changes made to the topography and the local routing of runoff and overland flow paths. As such the impacts of the development shall be determined at the DA Stage when information on changes to ground levels is available for the development.

3.7.4 Developed Conditions Model Results

The following sections describe the results of the hydrological model and include discussion on various aspects and parameters of the modelling.

The detention strategy was developed to attenuate design flows such that there would be no increase in flow rates as a result of development. Design discharges were produced for a range of AEP's including the 20%, 5%, and 1% AEP storm events. Storm durations ranging from 25 minutes to 12 hours were modelled for each AEP to identify the peak flow for each outlet node. Extended duration storms were simulated to analyse any potential secondary peaks.

Discharge rates at outlet points for the Developed Conditions model without and with OSD are identified in Table 11 and Table 12.

Table 11: Developed Conditions (without OSD) XP-RAFTS Results

Location	XP-RAFTS Node	Peak Flow Rate 20% AEP (m^3/s)	Peak Flow Rate 5% AEP (m^3/s)	Peak Flow Rate 1% AEP (m^3/s)	Critical Storm Duration (min)
Jindabyne Reserve	JR Outlet	23.702	33.983	44.479	90
Bluegum Crescent	BC Outlet	0.581	0.805	1.020	120
Wakehurst Parkway North	WPN Outlet	3.550	4.818	6.016	90
Wakehurst Parkway South	WPS Outlet	4.763	6.373	7.995	90
Fitzpatrick Avenue	FA Outlet	2.650	3.735	4.769	90
Warringah Road	WR Outlet	4.182	5.681	7.138	90
Carroll Creek (1)	CC1 Outlet	1.078	1.481	1.868	90
Carroll Creek (2)	CC2 Outlet	0.550	0.727	0.904	90
Carroll Creek (3)	CC3 Outlet	0.524	0.711	0.889	90

Source: Mott MacDonald XP-RAFTS Analysis

Table 12: Developed Conditions (with OSD) XP-RAFTS Results

Location	XP-RAFTS Node	Peak Flow Rate 20% AEP (m^3/s)	Peak Flow Rate 5% AEP (m^3/s)	Peak Flow Rate 1% AEP (m^3/s)	Critical Storm Duration (min)
Jindabyne Reserve	JR Outlet	22.257	32.133	42.233	90
Bluegum Crescent	BC Outlet	0.467	0.647	0.817	90
Wakehurst Parkway North	WPN Outlet	2.707	3.570	4.586	90
Wakehurst Parkway South	WPS Outlet	3.345	4.378	5.482	90
Fitzpatrick Avenue	FA Outlet	2.485	3.546	4.554	90
Warringah Road	WR Outlet	3.438	4.650	5.911	90
Carroll Creek (1)	CC1 Outlet	0.675	1.000	1.298	90
Carroll Creek (2)	CC2 Outlet	0.469	0.605	0.743	90
Carroll Creek (3)	CC3 Outlet	0.490	0.660	0.825	90

Source: Mott MacDonald XP-RAFTS Analysis

3.8 Cumulative Impact Assessment

A cumulative impact assessment of the proposed development has been considered for the 20%, 5% and 1% AEP storm events. The cumulative impact assessment analyses the hydrographs at the specified downstream outlet points to ensure the detention strategy will not increase the peak flow rate. An increase in peak flow rate was considered possible to occur in the event of a coincidence of time of peaks of the total flow hydrographs. The cumulative impact assessment compares the Natural Conditions, Existing Conditions, Developed Conditions (without OSD) and the Developed Conditions Model (with OSD) and is shown in Table 13, Table 14 and Table 15.

The following observations can be made from the results:

- The Developed Conditions (with OSD) peak flow rates for all storm events are less than the Existing Conditions peak flow rates at all major outlets. This indicates that Council's current DCP water quantity control (to restrict flows back to the Natural Condition peak flow rate) will not cause any cumulative flooding impacts from the Existing Conditions.
- The Developed Conditions (with OSD) peak flow rates all storm events are less than the Existing Conditions peak flow are generally larger than the Natural Conditions peak flow rates. This is due to the existing road infrastructure which is included within the catchment. The rezoning does not model OSD for the existing roads as no changes are proposed to them. OSD was provided for all developable catchments within the precinct to restrict developed flow rates back to the natural state. Due to the addition of the road catchments without OSD, the Developed Conditions (with OSD) peak flow rates are sometimes larger than the natural flow rate. However, this does not indicate that the development will have a cumulative impact on the downstream properties.

Table 13: Peak Flow Comparison - 1% AEP

Location	XP-RAFTS Node	Natural Scenario Peak Flow (m^3/s)	Existing Scenario Peak Flow (m^3/s)	Developed Scenario without OSD Peak Flow (m^3/s)	Developed Scenario with OSD Peak Flow (m^3/s)
Jindabyne Reserve	JR Outlet	36.309	43.377	44.479	42.233
Bluegum Crescent	BC Outlet	0.810	0.901	1.020	0.817
Wakehurst Parkway North	WPN Outlet	4.878	5.620	6.016	4.586
Wakehurst Parkway South	WPS Outlet	5.616	7.733	7.995	5.482
Fitzpatrick Avenue	FA Outlet	4.050	4.772	4.769	4.554
Warringah Road	WR Outlet	5.349	6.836	7.138	5.911
Carroll Creek (1)	CC1 Outlet	1.285	1.889	1.868	1.298
Carroll Creek (2)	CC2 Outlet	0.729	0.897	0.904	0.743
Carroll Creek (3)	CC3 Outlet	0.739	0.863	0.889	0.825

Source: Mott MacDonald XP-RAFTS Analysis

Table 14: Peak Flow Comparison - 5% AEP

Location	XP-RAFTS Node	Natural Scenario Peak Flow (m^3/s)	Existing Scenario Peak Flow (m^3/s)	Developed Scenario without OSD Peak Flow (m^3/s)	Developed Scenario with OSD Peak Flow (m^3/s)
Jindabyne Reserve	JR Outlet	26.541	32.785	33.983	32.133
Bluegum Crescent	BC Outlet	0.624	0.708	0.805	0.647
Wakehurst Parkway North	WPN Outlet	3.778	4.466	4.818	3.570
Wakehurst Parkway South	WPS Outlet	4.217	6.145	6.373	4.378
Fitzpatrick Avenue	FA Outlet	3.054	3.698	3.735	3.546
Warringah Road	WR Outlet	3.968	5.382	5.681	4.650
Carroll Creek (1)	CC1 Outlet	0.929	1.504	1.481	1.000
Carroll Creek (2)	CC2 Outlet	0.573	0.715	0.727	0.605
Carroll Creek (3)	CC3 Outlet	0.571	0.688	0.711	0.660

Source: Mott MacDonald XP-RAFTS Analysis

Table 15: Peak Flow Comparison - 20% AEP

Location	XP-RAFTS Node	Natural Scenario Peak Flow (m^3/s)	Existing Scenario Peak Flow (m^3/s)	Developed Scenario without OSD Peak Flow (m^3/s)	Developed Scenario with OSD Peak Flow (m^3/s)
Jindabyne Reserve	JR Outlet	17.379	22.470	23.702	22.257
Bluegum Crescent	BC Outlet	0.432	0.496	0.581	0.467
Wakehurst Parkway North	WPN Outlet	2.615	3.234	3.550	2.707
Wakehurst Parkway South	WPS Outlet	2.862	4.543	4.763	3.345
Fitzpatrick Avenue	FA Outlet	2.046	2.580	2.650	2.485
Warringah Road	WR Outlet	2.651	3.912	4.182	3.438
Carroll Creek (1)	CC1 Outlet	0.599	1.114	1.078	0.675
Carroll Creek (2)	CC2 Outlet	0.423	0.538	0.550	0.469
Carroll Creek (3)	CC3 Outlet	0.381	0.506	0.524	0.490

Source: Mott MacDonald XP-RAFTS Analysis

3.9 Detention Strategy Assessment

Further to the assessment of cumulative impact on the downstream areas in section 3.8, the effect of the detention strategy on peak flows at the sub-catchments level is presented in the following tables. The Developed Conditions (with OSD) peak flow rates are compared with Natural Conditions peak flows for each sub-catchments in Table 20.

Many sub-catchments are at the boundary of the precinct and the sub-catchments peak flow comparison also reflects the precinct boundary conditions. However for precinct boundary locations where contributing catchment flow is a combination of land uses including road reserves, reference should be made to the results of the hydraulic assessment discussed in Section 4.9.1.2.

Table 16: Peak Flow Comparison - 100% AEP

XP-RAFTS Catchment	Natural Scenario Impervious Percentage (%)	Natural Scenario Peak Flow (m3/s)	Developed Scenario Impervious Percentage (%)	Developed Scenario with OSD Peak Flow (m3/s)
P1 C1	40	0.205	85	0.163
P1 C2	40	0.130	85	0.090
P1 C3	70	0.201	100	0.158
P1 C4	40	0.064	85	0.054
P1 C5	40	0.082	85	0.082
P1 C6	40	0.110	85	0.108
P1 C7	100	0.022	100	0.021
P1 C8	35	0.380	100	0.321
P1 C9	90	0.284	100	0.270
P1 C10	40	0.087	100	0.087
P1 C11	40	0.032	70	0.031
P1 C12	40	0.042	70	0.040
P1 C13	40	0.039	70	0.036
P1 C14	40	0.074	70	0.074
P1 C30	35	0.183	100	0.142
P2 C15	40	0.078	80	0.077
P2 C16	40	0.066	80	0.047
P2 C17	40	0.125	85	0.119
P2 C18	40	0.146	80	0.137
P2 C19	40	0.164	90	0.143
P2 C20	40	0.143	80	0.143
P2 C21	40	0.153	80	0.143
P2 C31	40	0.146	80	0.133
P3 C22	40	0.108	80	0.087
P3 C23	40	0.073	80	0.049
P3 C24	40	0.025	80	0.025
P3 C25A	95	0.077	80	0.072
P3 C25B	70	0.045	80	0.023
P3 C26	40	0.123	80	0.121
P3 C27	55	0.013	80	0.011
P3 C28	40	0.075	85	0.075
P3 C29	40	0.220	85	0.195

Source: Mott MacDonald XP-RAFTS Analysis

Table 17: Peak Flow Comparison - 50% AEP

XP-RAFTS Catchment	Natural Scenario Impervious Percentage (%)	Natural Scenario Peak Flow (m3/s)	Developed Scenario Impervious Percentage (%)	Developed Scenario with OSD Peak Flow (m3/s)
P1 C1	40	0.370	85	0.211
P1 C2	40	0.213	85	0.112
P1 C3	70	0.364	100	0.199
P1 C4	40	0.130	85	0.065
P1 C5	40	0.147	85	0.104
P1 C6	40	0.171	85	0.130
P1 C7	100	0.039	100	0.024
P1 C8	35	0.723	100	0.396
P1 C9	90	0.542	100	0.317
P1 C10	40	0.160	100	0.103
P1 C11	40	0.058	70	0.048
P1 C12	40	0.080	70	0.062
P1 C13	40	0.074	70	0.048
P1 C14	40	0.142	70	0.106
P1 C30	35	0.327	100	0.160
P2 C15	40	0.144	80	0.094
P2 C16	40	0.127	80	0.057
P2 C17	40	0.205	85	0.144
P2 C18	40	0.251	80	0.168
P2 C19	40	0.282	90	0.229
P2 C20	40	0.240	80	0.175
P2 C21	40	0.260	80	0.185
P2 C31	40	0.246	80	0.182
P3 C22	40	0.188	80	0.108
P3 C23	40	0.137	80	0.060
P3 C24	40	0.045	80	0.033
P3 C25A	95	0.158	80	0.093
P3 C25B	70	0.090	80	0.027
P3 C26	40	0.212	80	0.182
P3 C27	55	0.023	80	0.014
P3 C28	40	0.152	85	0.098
P3 C29	40	0.392	85	0.234

Source: Mott MacDonald XP-RAFTS Analysis

Table 18: Peak Flow Comparison - 20% AEP

XP-RAFTS Catchment	Natural Scenario Impervious Percentage (%)	Natural Scenario Peak Flow (m3/s)	Developed Scenario Impervious Percentage (%)	Developed Scenario with OSD Peak Flow (m3/s)
P1 C1	40	0.606	85	0.266
P1 C2	40	0.313	85	0.138
P1 C3	70	0.592	100	0.247
P1 C4	40	0.207	85	0.079
P1 C5	40	0.206	85	0.131
P1 C6	40	0.234	85	0.168
P1 C7	100	0.066	100	0.027
P1 C8	35	1.200	100	0.489
P1 C9	90	0.906	100	0.376
P1 C10	40	0.254	100	0.123
P1 C11	40	0.105	70	0.060
P1 C12	40	0.142	70	0.090
P1 C13	40	0.135	70	0.061
P1 C14	40	0.215	70	0.181
P1 C30	35	0.518	100	0.184
P2 C15	40	0.204	80	0.115
P2 C16	40	0.190	80	0.069
P2 C17	40	0.302	85	0.212
P2 C18	40	0.401	80	0.339
P2 C19	40	0.417	90	0.332
P2 C20	40	0.348	80	0.218
P2 C21	40	0.383	80	0.237
P2 C31	40	0.360	80	0.253
P3 C22	40	0.287	80	0.134
P3 C23	40	0.193	80	0.073
P3 C24	40	0.078	80	0.042
P3 C25A	95	0.256	80	0.119
P3 C25B	70	0.147	80	0.032
P3 C26	40	0.350	80	0.262
P3 C27	55	0.036	80	0.017
P3 C28	40	0.243	85	0.125
P3 C29	40	0.651	85	0.284

Source: Mott MacDonald XP-RAFTS Analysis

Table 19: Peak Flow Comparison - 5% AEP

XP-RAFTS Catchment	Natural Scenario Impervious Percentage (%)	Natural Scenario Peak Flow (m^3/s)	Developed Scenario Impervious Percentage (%)	Developed Scenario with OSD Peak Flow (m^3/s)
P1 C1	40	0.876	85	0.439
P1 C2	40	0.445	85	0.170
P1 C3	70	0.856	100	0.389
P1 C4	40	0.303	85	0.096
P1 C5	40	0.282	85	0.164
P1 C6	40	0.325	85	0.217
P1 C7	100	0.114	100	0.032
P1 C8	35	1.929	100	0.759
P1 C9	90	1.426	100	0.716
P1 C10	40	0.369	100	0.148
P1 C11	40	0.157	70	0.131
P1 C12	40	0.218	70	0.164
P1 C13	40	0.205	70	0.091
P1 C14	40	0.301	70	0.285
P1 C30	35	0.743	100	0.344
P2 C15	40	0.278	80	0.141
P2 C16	40	0.261	80	0.084
P2 C17	40	0.425	85	0.295
P2 C18	40	0.581	80	0.487
P2 C19	40	0.594	90	0.455
P2 C20	40	0.503	80	0.274
P2 C21	40	0.547	80	0.297
P2 C31	40	0.518	80	0.348
P3 C22	40	0.409	80	0.164
P3 C23	40	0.264	80	0.089
P3 C24	40	0.123	80	0.058
P3 C25A	95	0.407	80	0.233
P3 C25B	70	0.215	80	0.071
P3 C26	40	0.526	80	0.358
P3 C27	55	0.052	80	0.025
P3 C28	40	0.371	85	0.157
P3 C29	40	0.950	85	0.519

Source: Mott MacDonald XP-RAFTS Analysis

Table 20: Peak Flow Comparison - 1% AEP

XP-RAFTS Catchment	Natural Scenario Impervious Percentage (%)	Natural Scenario Peak Flow (m^3/s)	Developed Scenario Impervious Percentage (%)	Developed Scenario with OSD Peak Flow (m^3/s)
P1 C1	40	1.142	85	1.075
P1 C2	40	0.574	85	0.442
P1 C3	70	1.116	100	1.089
P1 C4	40	0.395	85	0.361
P1 C5	40	0.362	85	0.254
P1 C6	40	0.409	85	0.367
P1 C7	100	0.153	100	0.149
P1 C8	35	2.625	100	2.545
P1 C9	90	1.965	100	1.849
P1 C10	40	0.490	100	0.472
P1 C11	40	0.203	70	0.183
P1 C12	40	0.291	70	0.262
P1 C13	40	0.276	70	0.262
P1 C14	40	0.388	70	0.381
P1 C30	35	0.963	100	0.944
P2 C15	40	0.358	80	0.296
P2 C16	40	0.332	80	0.285
P2 C17	40	0.552	85	0.537
P2 C18	40	0.751	80	0.698
P2 C19	40	0.759	90	0.756
P2 C20	40	0.634	80	0.590
P2 C21	40	0.699	80	0.698
P2 C31	40	0.656	80	0.652
P3 C22	40	0.540	80	0.455
P3 C23	40	0.338	80	0.182
P3 C24	40	0.160	80	0.154
P3 C25A	95	0.562	80	0.546
P3 C25B	70	0.279	80	0.229
P3 C26	40	0.693	80	0.664
P3 C27	55	0.071	80	0.064
P3 C28	40	0.501	85	0.377
P3 C29	40	1.239	85	1.208

Source: Mott MacDonald XP-RAFTS Analysis

3.10 Probable Maximum Flood

The Probable Maximum Flood (PMF) event has been considered in the assessment to aid in the preparation of a flood evacuation plan. The PMF is defined as the largest flood that could conceivably occur at a particular location, taking into account the Probable Maximum Precipitation (PMP) coupled with worst-case assumptions for catchment conditions (i.e. no initial or continuing losses).

Probable Maximum Precipitation (PMP) was derived using the Bureau of Meteorology's Generalised Short-Duration Method (2003). A comparison between rainfall intensities and peak flow rates were made for the main outlet (Jindabyne Reserve). A comparison was made between the Developed Conditions (with OSD) 1% AEP storm event (90-minute critical duration) and PMF event (120-minute critical storm duration), as shown in Table 6.

Table 21: Comparison of 1% AEP and PMF Event

Location	1% AEP Intensity (mm/hr)	1% AEP Flow Rate (m^3/s)	PMF Intensity (mm/hr)	PMF flow rate (m^3/s)
Jindabyne Reserve	76.9	42.233	275	190.416

Source: Mott MacDonald XP-RAFTS Analysis

Based on the modelling, the peak PMF flow rate is approximately 4.5 times greater than the peak 1% AEP storm event at the Jindabyne Reserve outlet for the critical storm duration. The PMF event is explored further as part of the Hydraulic assessment and forms a basis of consideration for the site evacuation routes.

3.11 Climate Change Assessment

Council's Flood Risk Management Policy (2015) states that the impact of climate change on flood behaviour will be investigated in all Council flood investigations. Council will consider sea level rise projections and changes in rainfall and storm surge intensity and frequency, in accordance with latest guidelines and best available information for climate change.

Recommendations from the former Department of Environment and Climate Change document titled *Practical Consideration of Climate Change,* guide the modelling of flood scenarios to include a "sensitivity check" incorporating data on the projected effects of climate change on sea levels and rainfall intensities. Multiple iterations of flood models can be produced using different climate change affected rainfall intensities. For this report, a sensitivity analysis has been undertaken by applying a 20% increase to the IFD coefficients from the Bureau of Meteorology, as shown in Table 22. It is acknowledged that land developments in surrounding Local Government Areas have adopted a similar climate change percentage increase.

Table 22: Climate Change Rainfall Parameters

	Parameter	Current Conditions	Climate Change Conditions (20%)
Intensity (mm/hr)	2% AEP 1 hour	86.52	103.82
	2% AEP 12 hour	20.02	24.02
	2% AEP 72 hour	6.44	7.73
	50% AEP 1 hour	41.16	49.39
	50% AEP 12 hour	9.23	11.08
	50% AEP 72 hour	2.86	3.43
Geographic Factors	f50	15.87	15.87
	f2	4.3	4.3
Location Skew	-	0	0

Source: Bureau of Meteorology

Table 23 compares 1% AEP flow rates for the Developed Condition- with OSD model with the 1% AEP storm event with and without climate change applied. Peak flow rates were assessed for the 1% AEP storm event (90-minute critical storm) for all major outlets.

Table 23: Effects of Climate change of Peak Flow – 1% AEP

Location	XP-RAFTS Node	1% AEP Peak Flow Rate (m^3/s)	1% AEP Peak Flow Rate + Climate Change (m^3/s)	Percent Increase in Peak Flow Rate
Jindabyne Reserve	JR Outlet	42.233	51.558	22.080
Bluegum Crescent	BC Outlet	0.817	0.980	19.951
Wakehurst Parkway North	WPN Outlet	4.586	6.625	44.461
Wakehurst Parkway South	WPS Outlet	5.482	7.387	34.750
Fitzpatrick Avenue	FA Outlet	4.554	5.528	21.388
Warringah Road	WR Outlet	5.911	7.693	30.147
Carroll Creek (1)	CC1 Outlet	1.298	1.634	25.886
Carroll Creek (2)	CC2 Outlet	0.743	1.068	43.742
Carroll Creek (3)	CC3 Outlet	0.825	1.001	21.333

4 Hydraulic Assessment

4.1 Introduction

TUFLOW, a one and two-dimensional (1D/2D) hydraulic modelling program has been utilised to perform a detailed assessment of the existing and developed flooding conditions for the Frenchs Forest Precinct.

The objective of the flood assessment was to determine changes to flooding characteristics resulting from the development of the site and to determine in Council's DCP water quantity controls will result in any cumulative impacts to downstream properties. The flooding characteristics examined in the analysis include overland flow paths, water level, depth, and hazard category.

4.2 Flooding Context

The Frenchs Forest Precinct Rezoning area is located at the top of an existing ridge line and is not located in proximity to any defined creeks or rivers. Therefore, the site has no fluvial flood affectation (riverine flooding). The site has not been identified as mainstream flood affected by the Narabeen Lagoon Flood Study or the Dee Why South Catchment Study (2013).

The site will be subjected to pluvial flooding (surface flood) which is caused when heavy rainfall creates a flood event independent of an overflowing water body. Pluvial flooding can happen in any urban area, including areas with high elevations that lie above coastal and river floodplains. The flooding is a result of intense rain saturating the urban drainage system- causing the water to form overland flow paths.

4.3 Software Package

The TUFLOW (2D component) software package computes flow paths by dividing the floodplain into a grid of individual cells. The flow of water between cells is then computed repeatedly at regular time steps by solving two-dimensional shallow water equations to estimate the flood spread and flow. As each cell contains information on water levels, flows are routed in the direction that will naturally follow the modelled topography.

ESTRY (1D component) is a separate calculation engine which is incorporated into TUFLOW to handle flows through structures which cannot be accurately represented with grid cells. ESTRY is a network dynamic flow program suitable for mathematically modelling floods and tides (and/or surges) in a virtually unlimited number of combinations. By including non-linear geometry, ESTRY can provide an accurate representation of the way in which channel conveyance and available storage volumes vary with changing water depth. ESTRY has been developed in conjunction with TUFLOW to resolve complex 1D-2D flows across the floodplain interface.

The flood assessment was modelled using TUFLOW build 2018-03-AB-w64.

4.4 Flood Events

The following storm events were run in the TUFLOW model:

Table 24: Modelled Flood Events

Scenario	Storm Event
Existing Condition	• 1% AEP
Developed Condition	• 1% AEP • 1% AEP with Climate Change • PMF
Developed Condition (Phase 1 Only)	• 1% AEP
Developed Condition (Phase 1 and 2 Only)	• 1% AEP

Note: All Developed Condition models in the hydraulic assessment include OSD

4.4.1 Climate Change Events

To determine the effects of a warmer climate on the flood conditions within the catchment, NSW guidance and best practice for modelling of climate change events recommends the simulation of sensitivity design storms. As discussed in Section 3.11 of this report, a sensitivity analysis of a 20% increase in rainfall intensity has been included in the hydrological analysis. These design storms have been simulated in the hydraulic model with the same envelope approach as used for today's rainfall data.

4.5 Flood Management Strategy

Council requires that no surrounding developments are adversely affected as a result of the proposed rezoning of the Frenchs Forest Precinct. As discussed in Section 3 of this report, an increase in impervious surfaces will result from the rezoning which will create additional runoff and potentially increase the flood depths of downstream properties. To mitigate these flood risks, Council requires that OSD is utilised to restrict the peak flow rates in the Developed Conditions back to the Natural Conditions peak flow rates. By restricting flow rates to the Natural Conditions peak flow rate (rather than the Existing Conditions peak flow rate) it is unlikely that any adverse cumulative impacts will occur downstream. However, a complete flood assessment has been performed to confirm this statement.

In addition, a flooding assessment is necessary to ensure that there are not cumulative flooding impacts on downstream properties.

4.6 Flood Planning

In accordance with Council's DCP the following controls apply for 'Subdivision' works. Given the inherent intensification of works it is recommended that the Flood Planning Level (FPL) be set at the 1% AEP level plus 500mm freeboard in accordance with the LEP. It is also recommended that basement parking, where required, adopt this standard of protection or higher.

A. FLOOD EFFECTS CAUSED BY DEVELOPMENT

A2	Certification shall be provided in accordance with Northern Beaches Council's Standard Hydraulic Certification Form (Forms A and A1 of Northern Beaches Council's Guidelines for preparing a Flood Management Report) to the effect that the works have been designed and can be constructed to adequately address flood risk management issues.
A3	The applicant shall include in their submission, calculations to illustrate that any fill or other structures that reduce the total flood storage are replaced by Compensatory Works.

B. DRAINAGE INFRASTRUCTURE AND CREEK WORKS

B1	Flood mitigation works or stormwater devices that modify a major drainage system, stormwater system, natural water course, floodway or flood behaviour within or outside the development site may be permitted subject to demonstration through a Flood Management Report that they comply with the Flood Prone Land Design Standard found on Council's webpage.
B2	A Section 88B notation under the Conveyancing Act 1919 may be required to be placed on the title describing the location and type of flood mitigation works with a requirement for their retention and maintenance.

E. FLOOD EMERGENCY RESPONSE

E4	The application shall demonstrate that evacuation/shelter in place in accordance with the requirements of this DCP will be available for any potential development arising from a torrens title subdivision.

F. FLOOR LEVELS

F5	The applicant must demonstrate that future development following a subdivision proposal can be undertaken in accordance with this Control.

4.7 Model Parameters

4.7.1 Hydrologic Data

The runoff volumes from sub-catchments within the subject site have been determined through the hydrological XP-RAFTS modelling, and have been applied to the hydraulic model as hydrographs (flow vs time). With this approach, the hydraulic model simulates the convergence of sub-catchment rainfall at the lower portion of each sub-catchment where it enters more defined overland flow paths or streams. Refer to Section 3.4.2 for the rainfall data simulated in the XP-RAFTS model.

Losses through evaporation and infiltration to the soil have been applied in the hydrological model for all catchments, as discussed in Section 3.4.3 of this report. No additional losses were included within the TUFLOW materials file.

4.7.2 Grid Size and Orientation

The existing and proposed models were run with a 2m x 2m grid. This was deemed an appropriate grid size as the site is already urbanised. The small grid size will allow for more accurate representation of flows within roads.

4.7.3 Digital Elevation Model

The Digital Elevation Model (DEM) used in the existing and proposed condition models was developed from New South Wales 1m LiDAR data. Survey data was not available at the time of modelling.

4.7.4 Boundary Conditions

All outlets of the model code extents have been modelled as a stage-discharge relationship (HQ type), with a b value assigned to replicate the existing topographic slope of the outlet. Downstream boundary polylines were digitised long enough to ensure no glass walling occurred against the 2d_code layer.

4.7.5 Hydraulic Structures (1D ESTRY component)

In the existing and developed conditions model, the existing Council pit and pipe network was modelled for all pipes with a diameter greater than 600mm. Several modifications were made to the GIS network provided by Council due to missing data or an inference of incorrect pipe data. Changes to the GIS pipe network are discussed in the gap analysis in Section 4.8 of this report.

4.7.6 Detention Basins

Detention basins were not physically modelled in the proposed condition model. As each developable catchment had a basin modelled to restrict developed flows back to the natural flows, the OSD outflow hydrograph was exported from XP-RAFTS was applied and non-developable catchments had the total local flow hydrographs applied.

4.7.7 Materials File

Material roughness coefficients were defined in a TUFLOW Materials File (TMF) with coefficients as shown in Table 25 determined through consultation with Council. Aerial imagery was used to define the various surface types in the existing scenario, including water surfaces, open space and dense vegetation. In the proposed scenario, a very high roughness coefficient was assigned to residential and commercial/industrial footprints to minimise the flow of water across these areas, and re-direct it towards the road network.

Table 25: Material Roughness Coefficients

Material Category	Roughness Coefficient	Material Description
1	0.2	High Density Residential
2	0.15	Low Density Residential
3	0.2	Commercial/Industrial
4	0.04	Roads
5	0.08	Medium Vegetation
6	0.10	Heavy Vegetation
7	0.06	Recreational Land/Open Space
8	0.025	Waterbody

Source: Roughness Coefficients, 'Mannings n' adopted for this hydraulic analysis

4.8 Information Gap Analysis

An information gap analysis was performed to highlight any data which was not available or incomplete at the time of modelling. The following information gaps have been identified:

- The Natural Conditions surface topography. Note the LiDAR topography utilised already incorporated the Existing Conditions surface topography with developed roads and low-density housing. Therefore, a Natural Conditions TUFLOW model was not run as it would not form a true representation of the natural flow path depths and extents.
- Proposed development footprints. This study assesses precinct rezoning- and not development applications for individual sites. Therefore, future developers of individual sites will be required to complete their own water cycle management assessment with site specific data (such as percentage of impervious surfaces, type of water quality treatment, location of OSD, etc).
- The Council supplied pit and pipe GIS network. Several pipes included in the GIS shape files were drawn in opposite directions to the existing surface topography. A site visit was conducted to confirm the direction of fall of the pipes, and the data was modified accordingly.

4.9 Results

The following results section should be read in conjunction with the flood analysis drawings produced by Mott MacDonald, dated 9 August 2018. The TUFLOW flood maps are available in Appendix A of this report.

Existing Condition

- Flood Map 1A: Existing Condition – 1% AEP Flood Depth and Extents
- Flood Map 1B: Existing Condition – 1% AEP Flood Velocity
- Flood Map 1C: Existing Condition – 1% AEP Flood Hazard NSW FDM
- Flood Map 1D: Existing Condition – 1% AEP Critical Storm Duration

Developed Condition (All Phases)

- Flood Map 2A: Developed Condition – 1% AEP Flood Depths and Extents
- Flood Map 2B: Developed Condition – 1% AEP Flood Velocity
- Flood Map 2C: Developed Condition – 1% AEP Flood Hazard NSW FDM
- Flood Map 2D: Developed Condition – 1% AEP Critical Storm Duration
- Flood Map 2E: Developed Condition – 1% AEP with Climate Change Flood Depth and Extents
- Flood Map 2F: Developed Condition – PMF Flood Depth and Extents
- Flood Map 2G: Developed Condition – PMF Flood Velocity
- Flood Map 2H: Developed Condition – PMF Critical Storm Duration

Developed Condition (Phase 1 only)

- Flood Map 3A: Developed Condition (Phase 1 only) – 1% AEP Flood Depth and Extents
- Flood Map 3B: Developed Condition (Phase 1 only) – 1% AEP Flood Velocity
- Flood Map 3C: Developed Condition (Phase 1 only) – 1% AEP Flood Hazard NSW FDM

Developed Condition (Phase 1 and 2 only)

- Flood Map 4A: Developed Condition (Phase 1 and 2 only) – 1% AEP Flood Depth and Extents
- Flood Map 4B: Developed Condition (Phase 1 and 2 only) – 1% AEP Flood Velocity
- Flood Map 4C: Developed Condition (Phase 1 and 2 only) – 1% AEP Flood Hazard NSW FDM

Cumulative Impact Assessment

- Flood Map 5A: Depth Difference Developed Condition less Existing Condition – 1% AEP
- Flood Map 5B: Depth Difference Developed Condition (Phase 1 only) less Existing Condition – 1% AEP
- Flood Map 5C: Depth Difference Developed Condition (Phase 1 and 2 only) less Existing Condition – 1% AEP
- Flood Map 5D: Depth Difference Developed Condition less Existing Condition Sensitivity Test – 1% AEP

4.9.1 Overland Flow Paths and Flood Depth

4.9.1.1 Existing Condition

The model predicts that majority of the rezoning precinct will not be flood affected in the 1% AEP storm event, as shown in Flood Map 1A. One major overland flow path is identified running south to north towards Jindabyne Reserve, where the flow path eventuates into Middle Creek. Flood depths within Jindabyne Reserve reach over 2m at the confluence point.

The overland flow path is mostly contained within drainage easements running adjacent to the existing residential properties. However, the upstream tail of the overland flow path passes through existing residential properties between Rabbett Street and Cobb Street (refer to catchment P2 C16) with flood depths averaging 300mm. Excessive ponding is also identified at the sag on Frenchs Forest Road, with flood depths up to 700mm predicted. An existing 900mm diameter circular pipe connects the sag pits on Frenchs Forest Road to the open channel in Rabbett Reserve. Results from the 1D ESTRY files identify this pipe as running at 100% capacity. There is provision to increase the capacity of this pipe to minimise the ponding at the sag on Frenchs Forest Road which will ultimately reduce the flood depths and extents of the overland flow path affecting the properties within catchment P2 C16. Provision of additional OSD in the upstream catchment P2 C18 may also alleviate the downstream flood extents in catchment P2 C16.

Flood affectation is also identified on the existing properties between Frenchs Forest Road and Holland Crescent (refer to catchment P2 C18), with flood depths averaging 250mm. An existing 750mm pipe connecting into a 900mm dimeter circular pipe connects the sag pits on Holland Crescent to the sag pits on Frenchs Forest Road. Results from the 1D ESTRY files identify these pipes as running at 100% capacity. Provision to increase these pipes, as well as the downstream 900mm pipe aforementioned, may alleviate the flood depths and extents in this area. Flood depths within the Holland Crescent sag are predicted to reach 500mm.

There is a minor overland flow path running east to west which confluences with the major south-north Jindabyne Reserve flow path. A series of trapped low points on both sides of Bluegum Crescent cause the overflow/bypass from the existing sag pits to discharge through the existing properties in catchment P1 C5, P1 C6 and P2 C15. However, the flood depths are mostly less than 100mm, indicating that it is mostly sheet flow. There is a small pocket of depths up to 200mm in catchment P1 C6, however these are considered a result of the steep topography change at this location, and not reflective of true flooding behaviour. Flows through P1 C6 have a peak flow rate of 0.88m^3/s. Existing drainage runs through the catchments; however, they have been assumed to be fully blocked as they have a diameter less than 600mm and therefore have not been included in the TUFLOW modelling. Provision to increase these pipes may reduce the flood extents and depths.

Similar to above, minor overland flow paths (less than 100mm depth) are precited to run south-west to north-east, causing flood affectation on the existing properties located between Forest Way and Rabbett Street (refer to catchment P2 C21). An existing 600mm pipe connecting into a 675mm dimeter circular pipe connects the sag pits on Forest Way to the street drainage on Rabbett Street. Results from the 1D ESTRY files identify these pipes as running at 100% capacity. Provision to increase these pipes, as well as any downstream pipes, may alleviate the flood depths and extents in this area. However, due to small flood depths a more defined overland flow channel will assist in confining the flow path and reducing the flood extents.

Properties located between Ann Street and Forest Way (refer to catchment P3 C22) are similarly flood affected. However, the flood affectation is relatively minor and generally less than

100mm, indicating that it is not a major overland flow path. A more defined channel running along the back of these properties will confine the flow path and reduce the flood extents.

Runoff from the school site, catchment P1 C8, is largely shallow sheet flows, which develop into a flow path at the southern edge of the oval. The flow path travels west to the property boundary, with some ponding occurring along this flow path.

Flood depth results for the Existing Condition 1% AEP are presented in Flood Map 1A.

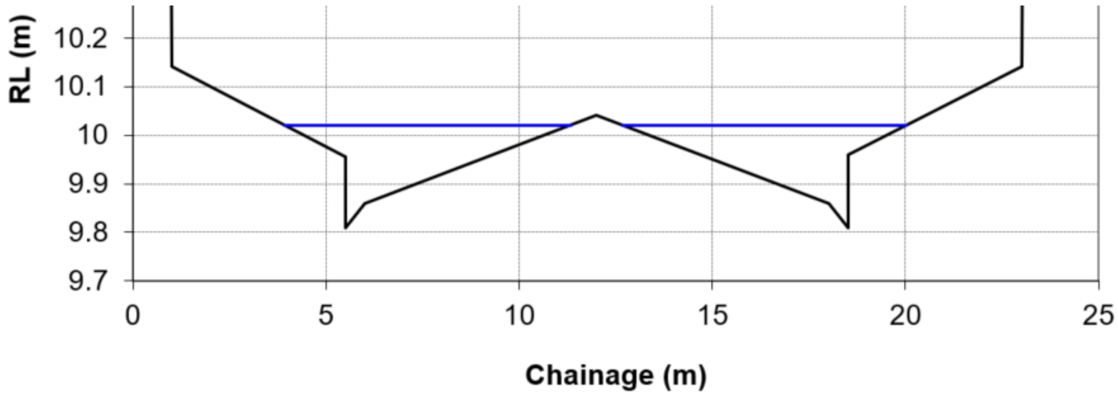
4.9.1.2 Developed Condition

Overland flow paths in the Developed Condition, are largely similar to the Existing Condition flow paths. A minor reduction in flood extents is observed. Flood depths in the Developed Conditions are generally less than the Existing Conditions flood depths due to the OSD being sized to attenuate the discharge flow rates to the natural flow rate.

Flood affectation in several developable catchments is still present; including catchments P2 C21, P2 C19, P2 C18, P2 C16, P2 C15, P2 C16, P1 C5 and P3 C22.

The developed condition modelling retains the sheet flow, and flow path development through the school site as is observed in the existing conditions, due to similar topography in both modelled cases. Through design of the school site, consideration of this flow path must be made and it is recommended the proposed major flow system of future roads accommodate the flow path along the southern edge of the oval in the existing conditions. A conservative estimate of the future major system flow path without considering the future pipe network is below, assuming the full catchment draining through a single road reserve. Based on the grade of the site, a standard 2-way, 2 lane road with parking spaces and verge footpaths will accommodate the 1% AEP flow of 2.55m³/s at a depth of 0.21m.

Figure 12: Indicative Future Flow Path



Source: Mott MacDonald hydraulic analysis

Flood depth results for the Developed Condition 1% AEP are presented in Flood Map 2A.

4.9.1.3 Developed Condition (Phase 1 only)

Overland flow paths in the Developed Condition (Phase 1 only), are largely similar to the Existing Condition and Developed Condition flow paths. A minor reduction in flood extents is observed within the Phase 1 catchments due to the implementation of OSD in these areas which restrict the discharge peak flow rates to the natural state. As expected, Phase 2 and Phase 3 catchments have predicted the same flood depths as the Existing Condition results as there is no change to these phases in this model.

Flood depth results for the Developed Condition (Phase 1 only) 1% AEP are presented in Flood Map 3A.

4.9.1.4 Developed Condition (Phase 1 and 2 only)

Overland flow paths in the Developed Condition (Phase 1 and 2 only), are largely similar to the Existing Condition, Developed Condition, and Developed Condition (Phase 1 only) flow paths. A minor reduction in flood extents is observed within the Phase 1 and 2 catchment areas due to the implementation of OSD in these areas which restrict the discharge peak flow rates to the natural state. As expected, Phase 3 catchments have predicted the same flood depths as the Existing Condition results as there is no change to these phases in this model.

Flood depth results for the Developed Condition (Phase 1 and 2 only) 1% AEP are presented in Flood Map 4A.

4.9.2 Flood Hazard

Flood hazard has been categorised in accordance with the NSW Floodplain Development Manual (2005) standards, including; low, intermediate, and high flood risk, as discussed in Section 2.3. Low hazard has been nulled from the flood maps for improved clarity.

4.9.2.1 Existing Condition

The majority of the developable catchments have a low hazard classification, with the exception of catchment P2 C16, which has an intermediate to high hazard classification. The high hazard affects the existing residential properties and is a result of the high flood depths (approx. 300mm) of the overland flow path running through the catchments (as discussed in Section 4.9.1.1).

Roads with intermediate to high hazard include Frenchs Forest Road (located towards the sag pit location), Wakehurst Parkway, Holland Crescent and Warringah Road.

Flood hazard results for the Existing Condition 1% AEP are presented in Flood Map 1C.

4.9.2.2 Developed Condition

The Developed Condition model indicates that all developable catchments will have a low hazard classification. Catchments previously exhibiting intermediate to high hazard have been removed due to the proposed OSD strategy. The reduced discharge rates of the developable catchments will have a positive impact on downstream catchments, particularly catchment P2 C16.

Flood hazard results for the Developed Condition 1% AEP are presented in Flood Map 2C.

4.9.3 Flood Affectation

Properties classified as flood affected will be subject to the Flood Planning Controls identified in Section 4.6 of this report. Four categories of flood affectation have been defined:

1. Flood affected in the 1% AEP storm event (depths greater than 100mm)

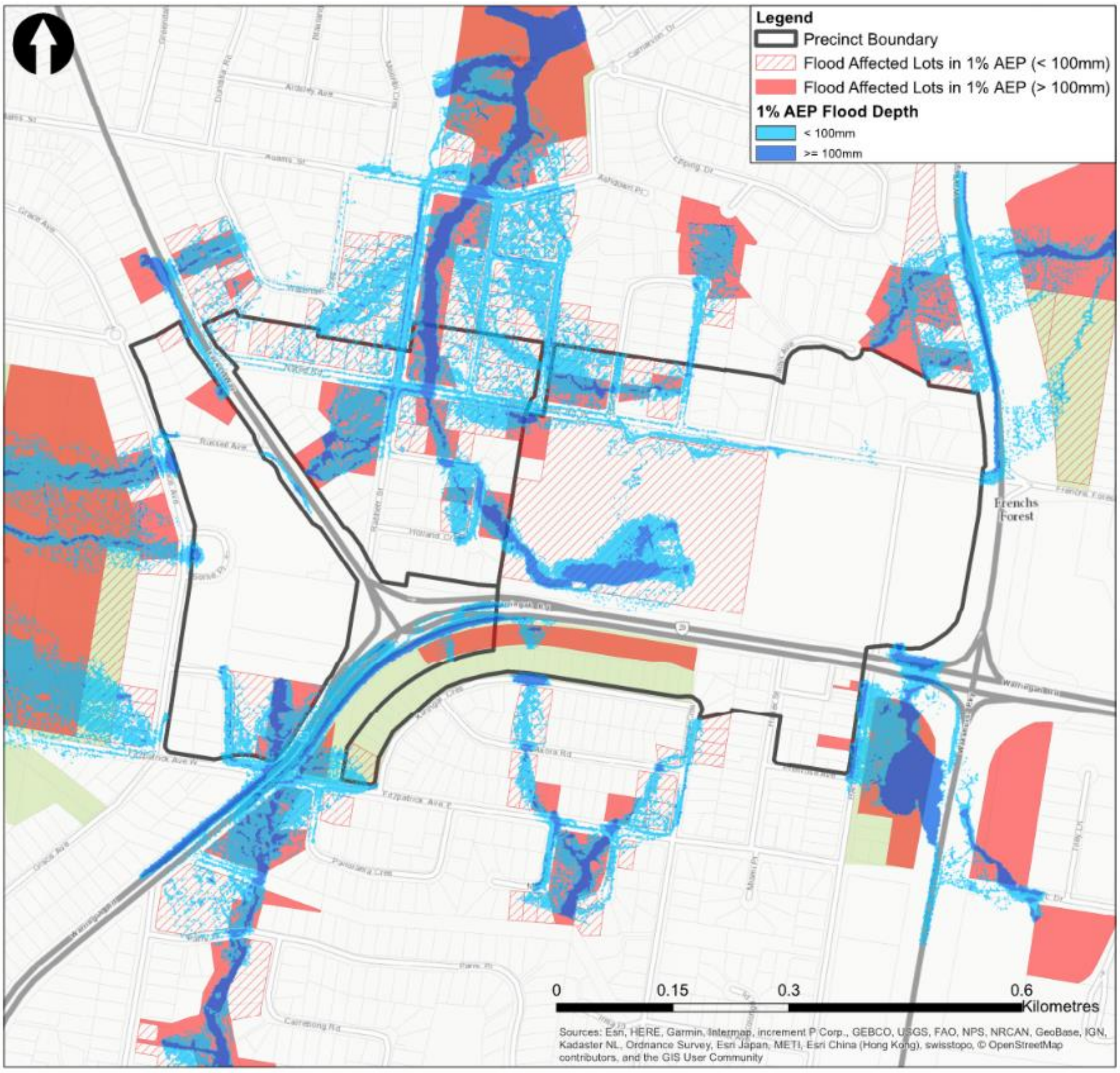
Flood affected in the 1% AEP storm event (depths less than 100mm)

Flood affected in the PMF storm event (depths greater than 100mm)

Flood affected in the PMF storm event (depths less than 100mm)

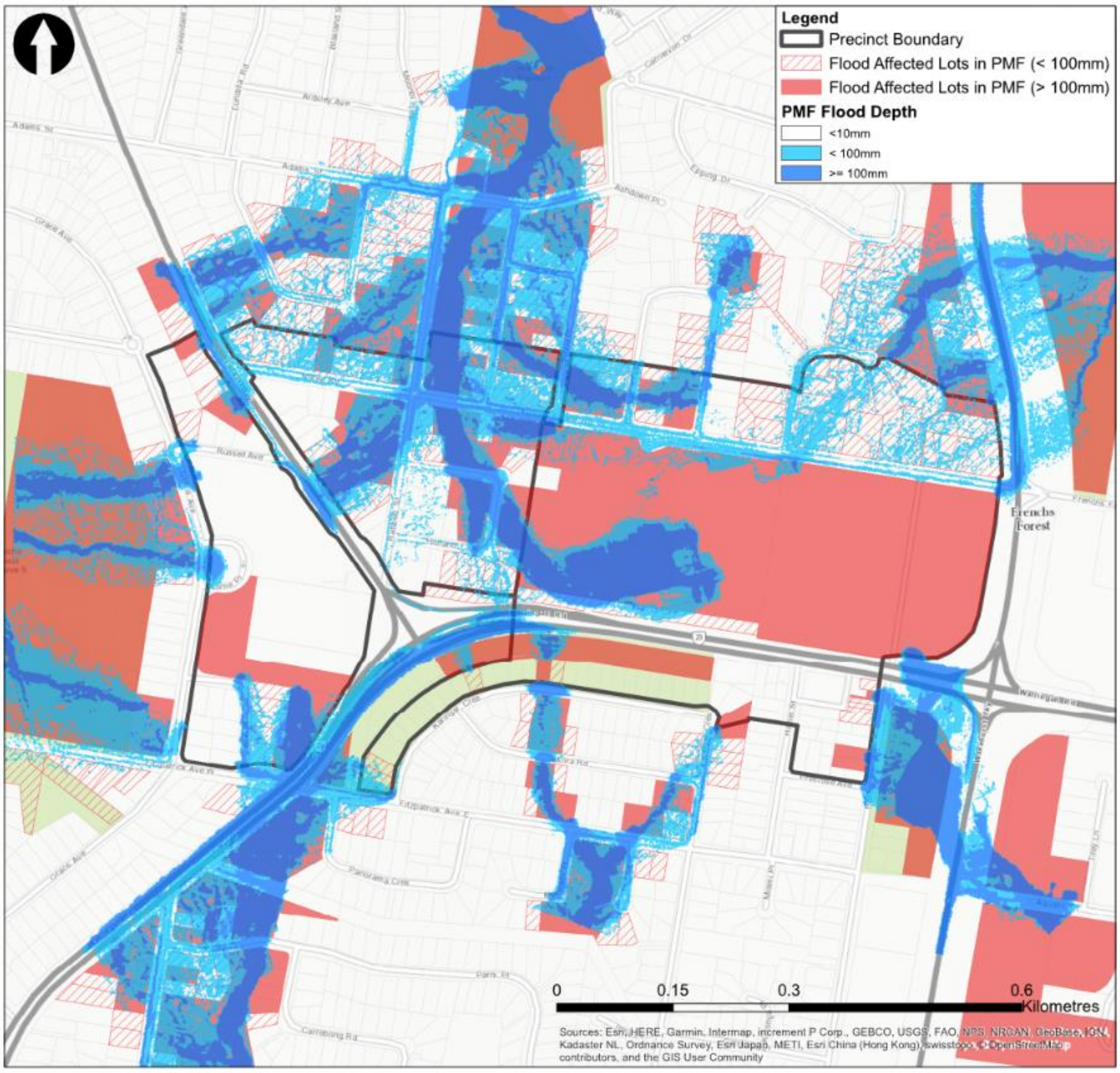
Flood affected properties in the 1% AEP and PMF storm events are shown in Figure 13 and Figure 14 respectively.

Figure 13: Flood Affected Properties - 1% AEP



Source: Flood depth results and flood affectation determined from Mott MacDonald TUFLOW Model for Developed Conditions (storm envelope approach)

Figure 14: Flood Affected Properties - PMF



Source: Flood depth results and flood affectation determined from Mott MacDonald TUFLOW Model for Developed Condition (storm envelope approach)

4.9.4 Cumulative Impact Assessment

Changes in flood depth were calculated to assess the cumulative impact of the proposed rezoning of the Frenchs Forest Precinct on downstream properties. The Cumulative impact assessment compares the Developed Conditions (including the rezoning of phases at different times) to the Existing Conditions of the precinct rezoning area. Depths of less than 10mm have been filtered out of the maps as they are considered within the tolerance of the TUFLOW model.

4.9.4.1 Depth Difference – Developed Condition less Existing Condition

It is evident from the results that the OSD strategy will result in a depth reduction in flood depths in the Developed Condition model for downstream properties compared to the Existing Condition. The depth reduction is attributed to Council's OSD requirements to restrict the Developed Conditions discharge peak flow rate to the Natural Conditions peak flow rate. Depth reduction (up to 120mm) is predicted within the major overland flow paths. Some small pockets of depth increase (up to 80mm) are predicted at the outlet of the OSD locations. However, these are all confined to the developable catchments are generally a consequence of an increased material roughness being applied to represent the higher density residential zoning- not due to inefficiencies in the OSD strategy.

Flood depth difference results between Developed Condition and the Existing Condition depth maximum results for the 1% AEP are presented in Flood Map 5A.

A sensitivity test was performed on the Developed Conditions model to determine the cause of the depth increases. A new Developed Conditions model was run which used the same manning's 'n' coefficients as the Existing Conditions model (opposed to adopting higher roughness values for the rezoned areas). The results indicate that there is no depth increase in the overland flow paths when the same manning's value is adopted. This implies that the small pockets of depth increase are localised at the outlet of the proposed OSD locations and due to the water travelling at a slower rate in the Developed Condition compared to the Existing Condition. As the water flows at a slower velocity, it has more time to pond- making it appear as a depth increase. In reality the Developed Conditions Model will have drainage easements to convey the overland flow paths through the parcels of land at a similar rate to the Existing Condition and will not be slower.

Flood depth difference results between Developed Condition and the Existing Condition sensitivity test for the 1% AEP are presented in Flood Map 5D.

4.9.4.2 Depth Difference – Developed Condition (Phase 1 only) less Existing Condition

Changes in flood depth were calculated to assess the cumulative impact of only completing Phase 1 of the proposed rezoning of Frenchs Forest Precinct on downstream properties. It is evident from the results that the OSD strategy will result in a depth reduction in the flood depth of all overland flow paths which originate within the Phase 1 rezoning area for downstream properties compared to the Existing Conditions. The depth reduction is attributed to Council's OSD requirements to restrict the developed discharge peak flow rate to the Natural Conditions peak flow rate. Depth reductions (up to 250mm) are precited within the major overland flow paths. Some small pockets of depth increase (up to 130mm) are predicted at the outlet of the OSD locations. However, these are all confined to the developable catchments within Phase 1 and are due to the increased roughness coefficient applied (as described in Section 4.9.4.1).

Flood depth difference results between Developed Condition (Phase 1 Only) and the Existing Condition depth maximum results for the 1% AEP are presented in Flood Map 5B.

4.9.4.3 Depth Difference – Developed Condition (Phase 1 and 2 only) less Existing Condition

Changes in flood depth were calculated to assess the cumulative impact of the only completing the Phase 1 and Phase 2 of the proposed rezoning of Frenchs Forest Precinct on downstream properties. It is evident from the results that the OSD strategy will result in a depth reduction in the flood depth of all overland flow paths which originate within the Phase 1 and Phase 2 rezoning area for downstream properties compared to the Existing Conditions. The depth reduction is attributed to Council's OSD requirements to restrict the developed discharge peak flow rate to the Natural Conditions peak flow rate. Depth reduction (up to 250mm) is precited within the major overland flow paths. Some small pockets of depth increase (up to 130mm) are predicted at the outlet of the OSD locations. However, these are all confined to the developable catchments within Phase 1 and Phase 2 and are due to the increased roughness coefficient applied (as described in Section 4.9.4.1). Flood depth difference results between Developed Condition (Phase 1 and 2 Only) and the Existing Condition depth maximum results for the 1% AEP are presented in Flood Map 5C.

4.9.5 Climate Change

As an extension of the climate change assessment undertaken in Section 3.11 the Developed Condition peak flow increases were assessed in the hydraulic flood model to determine the associated impacts and increases in flood levels. As a worst-case scenario, the 20% rainfall intensity climate change scenario was adopted.

The climate change scenario resulted in slightly wider flood extents compared to the Developed Conditions model. Flood depths increased throughout the model, with depths increasing by an average of 120mm across the defined overland flow paths (such as the path running through P2 C16). Shallower overland flow paths, such as those running through P1 C6, exhibited depth increases of approximately 10mm, and an average 20mm increase in catchment P3 C22.

4.9.6 Probable Maximum Flood

The PMF storm event was run for the Developed Condition model to determine the extents and depths of the largest conceivable flood which could occur. The results indicate that the flood depths in major overland flow paths generally increase by approximately 600mm. The overland flow path running south to north towards Jindabyne Reserve has flood depths up to 2m, with depths up to 1m running through the proposed developable catchment P2 C16. Minor overland flow paths generally have a predicted depth increase of 200-400mm.

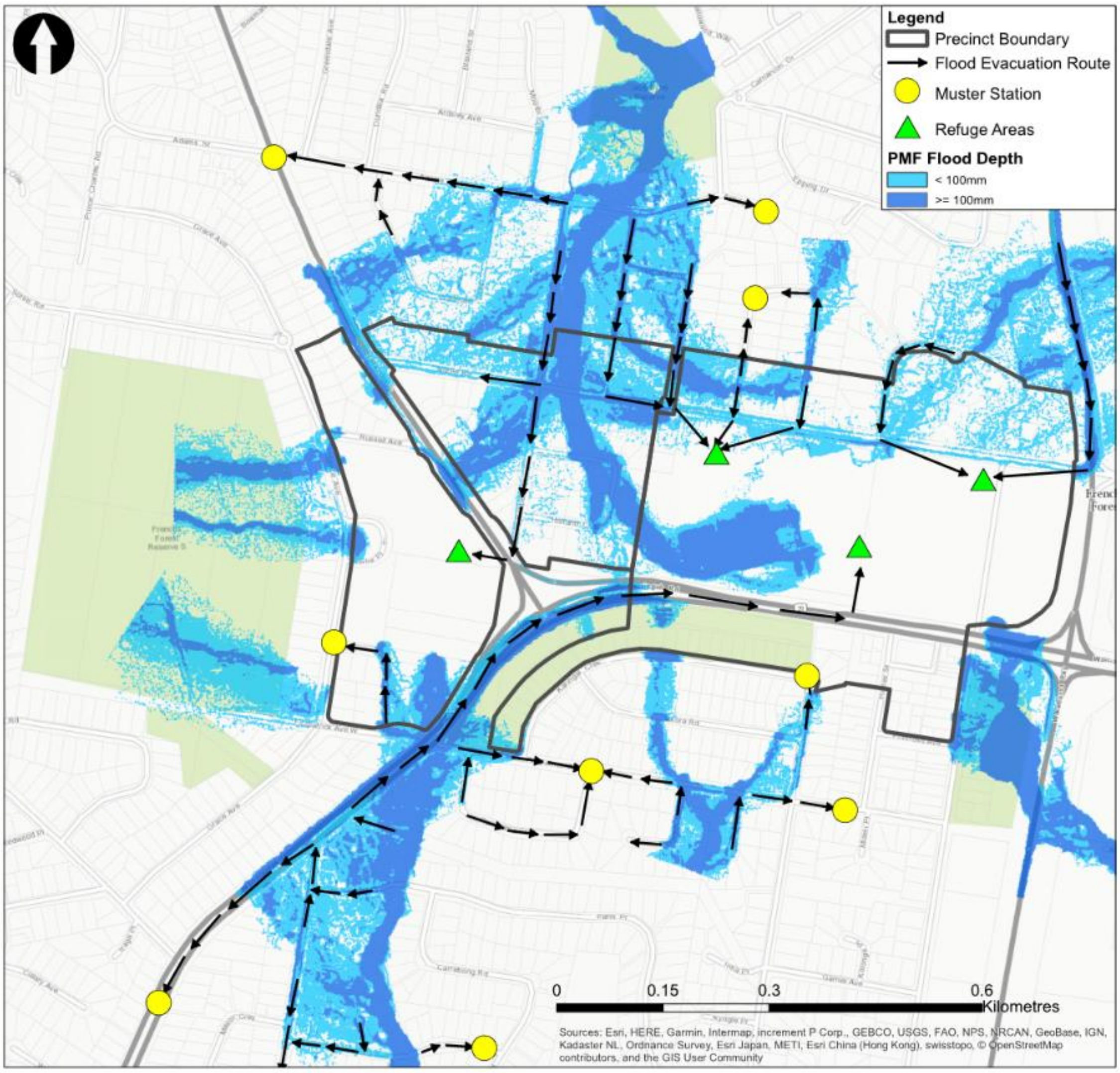
Overland flow paths that are conveyed above the existing piped network generally show the largest increase in flooding extents, as the piped network is already operating at capacity in the 1% AEP storm event.

As the Frenchs Forest Precinct is located on a ridge at the top of the catchment, there is a large amount of safe refugee areas available, which are not flood affected by the PMF. Key refuge areas include:

- The town centre;
- The hospital; and
- The shopping centre.

In locations where there is no safe evacuation route- a muster station has been identified. Muster stations have been identified to ensure that people do not need to cross major overland flow paths during the PMF flood event.

Figure 15: Sample Flood Evacuation Plan



4.9.7 Envelope Approach and Critical Storm Duration

The maximum flood depth grids for the 1% AEP 20, 25, 30, 45, 60, 90, 120, and 180-minute storm durations were assessed, and a worst case storm 'envelope' determined. The storm envelope is the combination of all maximum results and doesn't represent a credible flood scenario, rather the worst flooding conditions in all locations from every storm duration. A worst case storm index was calculated, to indicate the location specific critical storm duration. The storm durations from the hydrological XP-RAFTS model discussed in Section 3.4.2, identified a mix between the 90-minute and 120-minute storm duration as critical for the outlet. The hydraulic modelling assessment found the 90-minute and 120-minute storm durations are critical in the main overland flow paths.

These results are consistent with the results from the hydrological modelling performed in Section 3.6.3 of this report which indicate that most major outlets identified the 90-minute storm as being critical.

The critical storm duration for the Existing Condition for the 1% AEP storm event are presented in Flood Map 1D.

4.9.8 Trunk Drainage Assessment

4.9.8.1 Existing Condition

In the Existing Condition surcharging pits are predicted at four locations:

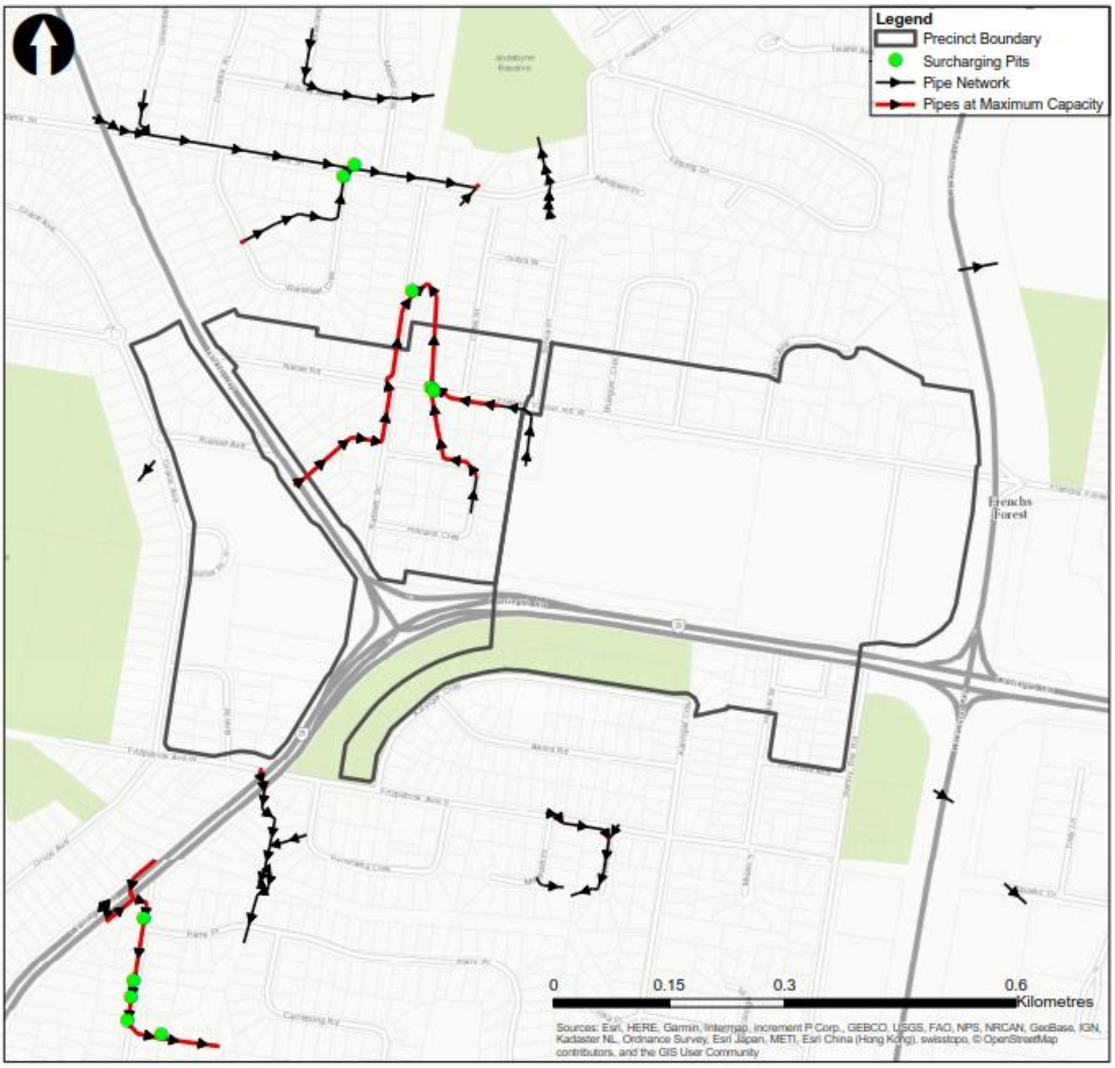
- The sag on Frenchs Forest Road (cumulative peak surcharge of 563L/s)
- Two pits along the Rabbett Street trunk drainage (cumulative peak surcharge of 116L/s)
- The junction of the trunk drainage on Adam Street and Wareham Crescent (cumulative peak surcharge of 403L/s)
- At various locations along the Maxwell Parade trunk drainage (cumulative peak surcharge of 2,396L/s)

The surcharge locations, along with pipes at maximum capacity, are show in Figure 16. These locations represent deficiencies in the existing trunk drainage to convey the 1% AEP flow rates. The Frenchs Forest Road, Rabbett Street and Maxwell Parade locations have a large portion of the trunk drainage running at 100% capacity during the 1% AEP storm event, indicating that they were not adequately sized for the existing development as the time of installation.

An immense amount of surcharging (1,872L/s) is predicted along the Maxwell Parade trunk drainage line. The GIS data obtained from Council identified this area as a 1200mm diameter pipe upstream of a 700mm pipe. This was confirmed via the site visit as being true. The bottle-neck pipe design is the likely cause of the surcharging pits along this trunk drainage line. Upgrading the last pipe in the line will likely have positive impacts on the flood affectation in this area by conveying more stormwater flows in the underground piped network.

The surcharging at Frenchs Forest Road is a key factor in the magnitude of the overland flow path running through the existing residential properties downstream (north) of the Frenchs Forest Road sag. It is noted that all upstream and downstream pipes at this sag location are running at 100% capacity- indicating that upgrading the trunk drainage will allow more water to be conveyed underground and reduce the flood depths and extents of the overland flow path inundating the existing residential properties.

Figure 16: Trunk Drainage Performance – Existing Conditions



4.9.8.2 Developed Condition

In the Developed Condition surcharging pits are predicted at four locations:

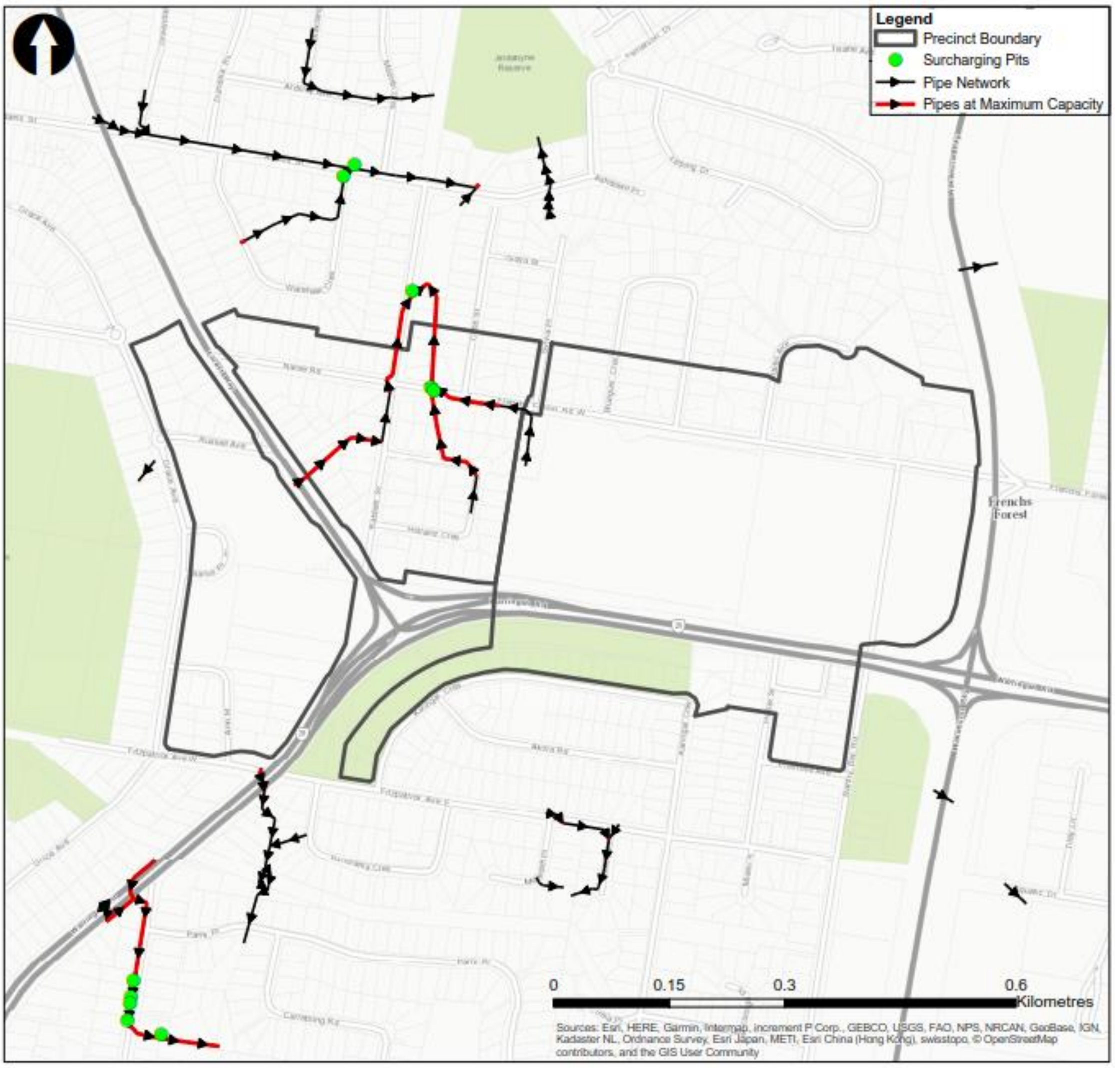
- The sag on Frenchs Forest Road (cumulative peak surcharge of 379L/s)
- One pit along the Rabbett Street trunk drainage (cumulative peak surcharge of 105L/s)
- The junction of the trunk drainage on Adam Street and Wareham Crescent (cumulative peak surcharge of 297L/s)
- At various locations along the Maxwell Parade trunk drainage (cumulative peak surcharge of 1,800L/s)

The surcharge locations, along with pipes at maximum capacity, are show in Figure 17. The key pit surcharge locations identified in the Existing Scenario are largely the same in the Developed Scenario with the exception of:

- Movement of the surcharging pit near Parni Place further downstream to a pit located at Maxwell Parade
- One les spit surcharging along the Rabbett Street trunk drainage
- One less pipe identified at maximum capacity along Rabbett Street

It is evident that the peak surcharging flow rate at each pit location identified will be significantly reduced in the Developed Scenario- attributed to the implementation of OSD restricting the flows of each developable sub-catchment back to the natural state flows.

Figure 17: Trunk Drainage Performance – Developed Condition



The table below presents the list of Council stormwater assets within the planned precinct or immediately downstream of the precinct boundary which are at capacity or have exceeded capacity in the design storm event, 20% AEP.

Table 26: Critical Pipes within Drainage Network, 20% AEP Storm

Asset Number	Diameter (m)	Issue
SPI11875	0.6	Pipe running over capacity
SPI11876	0.6	Pipe running over capacity
SPI12285	0.675	Pipe running over capacity
SPI11877	0.6	Pipe running over capacity
SPI00198	1.05	Pipe running over capacity
SPI00199	1.05	Pipe running over capacity
SPI00200	1.05	Pipe running over capacity
SPI11397	0.6	Pipe running over capacity
SPI11398	0.6	Pipe running over capacity
SPI11399	0.6	Pipe running over capacity
SPI12802	0.75	Pipe running over capacity
SPI13527	0.9	Pipe running over capacity
SPI13528	0.9	Pipe running over capacity
SPI11404	0.6	Pipe running over capacity
SPI12325	0.675	Pipe running over capacity
SPI08384	0.6	Pipe running over capacity

Source: Mott MacDonald Hydraulic Analysis

4.10 Recommendations

4.10.1 Phase 1

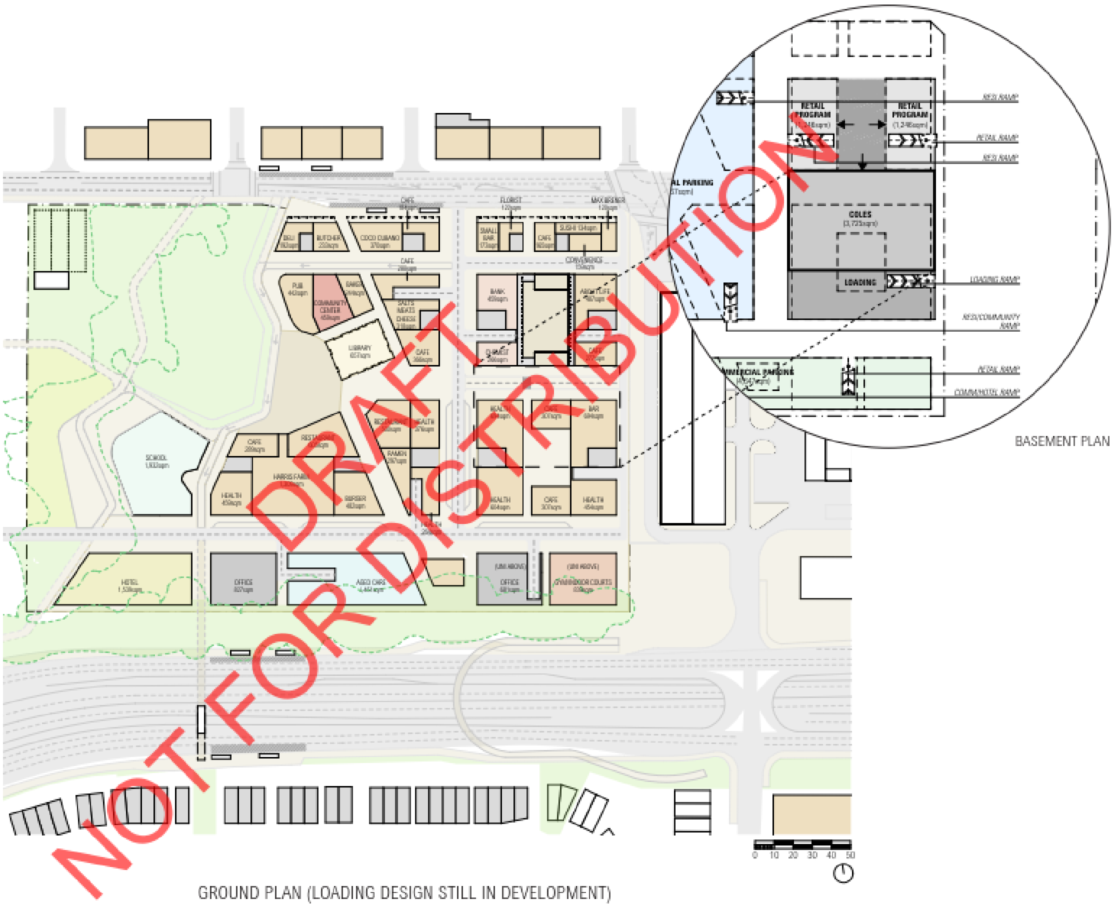
The residential lots located in the north-western corner of the Phase 1 boundary are depicted as flood affected in Figure 13 (refer to catchments P1 C5 and P1 C6). In the 1% AEP storm event the residential lots are subjected to minor local overland flows (predominantly exhibiting depths less than 0.1m) with a low hazard classification, opposed to mainstream flooding. This overland flow path can be easily managed by diverting it around proposed development footprints and formalising an above ground stormwater channel.

An existing 375mm circular culvert currently passes underneath the residential lots in catchment P1 C6. It is recommended that the culvert is maintained upon the rezoning of Phase 1. The drainage network and overland flow channel can be formalised and relocated accordingly to optimise the development footprint.

An underground supermarket is recommended to be located within the town centre (within catchment P1 C8), as shown in Figure 18. The proposed underground supermarket is not flood affected in any storm event up to and including the PMF, as shown in Figure 19, and therefore, Council’s controls for flood affected land do not apply.

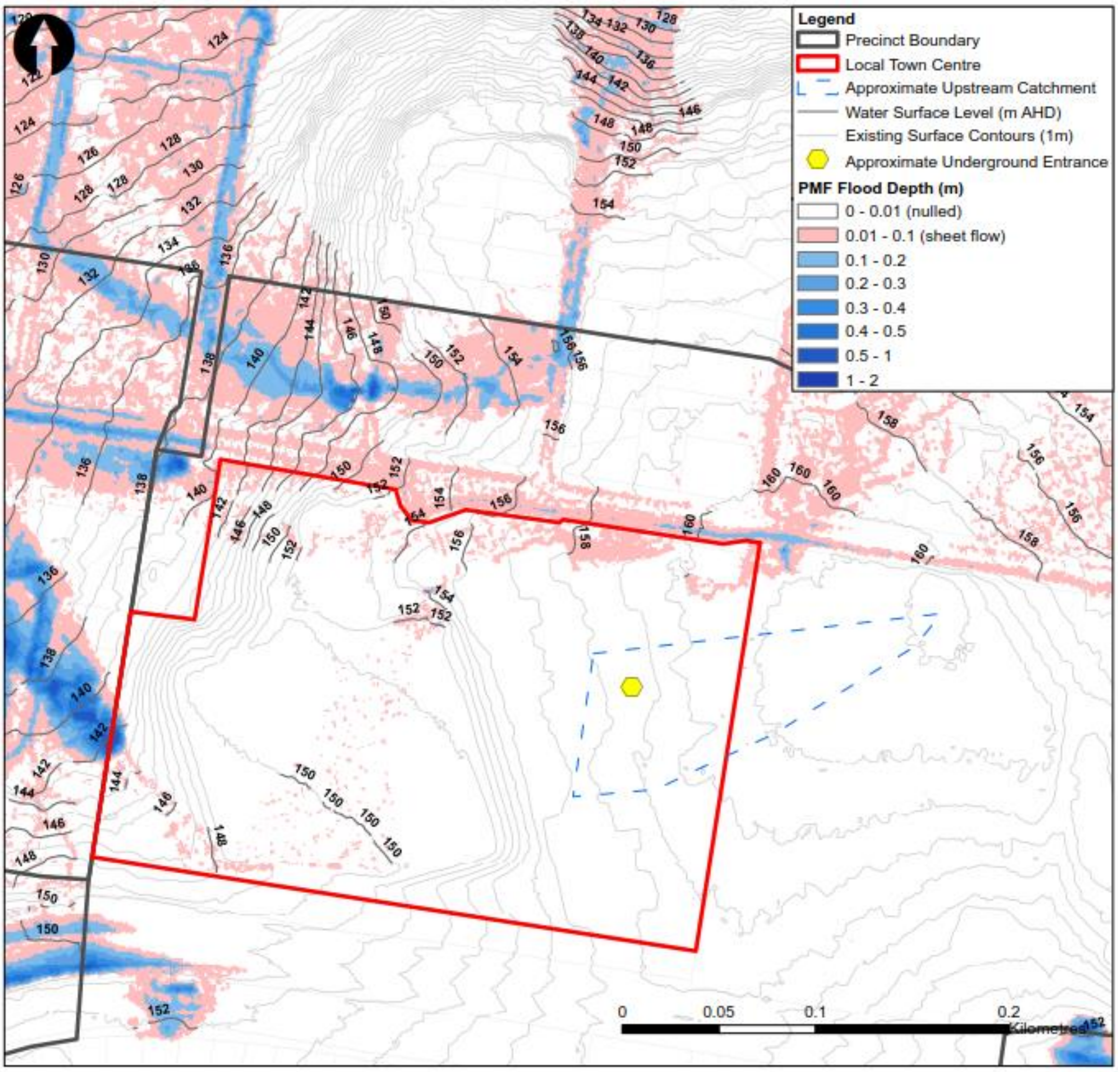
As a precaution, an increased level threshold of 0.3-0.5m is recommended in addition to the highest predicted PMF flood level at the entrance of the underground supermarket’s decline structure to stop nuisance flows from entering the facility. The closest and highest observed surface flood level is 160m AHD, however it is noted that this is mostly contained within the road reserve and consists of sheet flow. It is noted that the underground supermarket has a small upstream catchment which can be diverted away from the proposed entrance.

Figure 18: Underground Supermarket Preliminary Plan



Source: Chrofi (7/8/18)

Figure 19: Underground Carpark Approximate Location and PMF Flood Depths and Extents

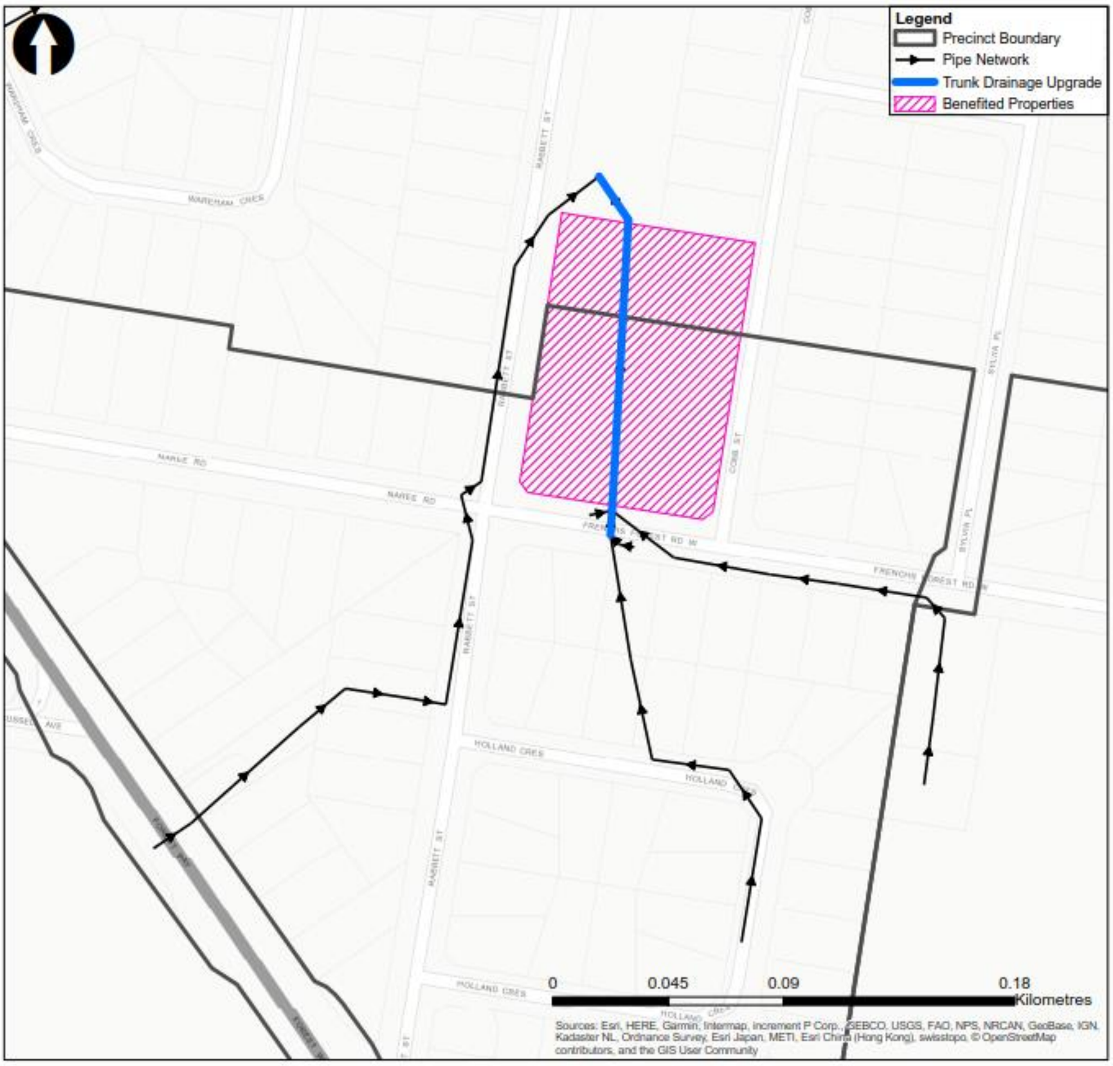


4.10.2 Phase 2

Whilst the rezoning of the Frenchs Forest Precinct will ultimately reduce the pressure put on the already over-burdened trunk drainage, further measures can be implemented to improve the conveyance of stormwater flows.

A key section of the existing trunk drainage to upgrade is located downstream of the sag pit on Frenchs Forest Road, as shown in Figure 20. Upgrading these pipes will further reduce the surcharging occurring at the Frenchs Forest Road sag and consequently reduce the flood depths and extents of the overland flow path passing through the existing residential properties (and future rezoned residential area). Further studies will be required to adequately size the trunk drainage upgrade.

Figure 20: Recommended Trunk Drainage Upgrade



4.11 Conclusion

The flooding assessment performed an analysis on the Existing Conditions and Developed Conditions to determine whether the rezoning of the Frenchs Forest Precinct will result in adverse cumulative flooding impacts on downstream properties. The assessment found that the rezoning will not have any adverse impacts on surrounding properties under the provision that future developments within the rezoning area adhere to Council's current water quantity requirements: to restrict Developed Condition peak flow rates back to the Natural Condition peak flow rate. Furthermore, if the rezoning is rolled out in stages, there will be no adverse downstream impacts if only Phase 1 is rezoned, or if only Phase 1 and 2 are rezoned. Existing stormwater infrastructure identified in Section 4.9.1.1 can be upgraded in order to reduce the flood extents.

There are existing parcels of land that have overland flow paths within their boundaries. These are Existing Conditions- the results of this assessment indicate that there will not be an adverse impact as a result of development. As DA's are progressed for the overland flow impacted lots, further modelling will need to be undertaken on each lot to manage the overland flow path and where desirable the DA may seek to formalise this flow path. These DA's will need to individually address the FDM and appropriate legislation to the satisfaction of Council, this is standard procedure. As rezoning is progressed for Phase 2 and 3 further refinement of the modelling in this report may be required.

5 Water Quality Assessment

5.1 Water Quality Objectives

As part of the planning proposal, WSUD procedures have been incorporated to improve water quality in local waterways. To manage the quality of runoff reaching the creek systems across the Northern Beaches Local Government Area, Northern Beaches Council has set target removal rates for key pollutants. These targets are shown in Table 27.

Table 27: Water Quality Targets

Pollutant	Reduction Target
Gross Pollutants	90%
Total Suspended Solids	85%
Total Phosphorus	65%
Total Nitrogen	45%

Source: Warringah Council Development Control Plan (2011)

5.2 Modelling Methodology

To demonstrate compliance with the pollutant removal targets specified in Table 27, treatment removal loads were analysed using MUSIC Version 6 software in the stochastic generation mode. MUSIC is a water quality modelling tool which was utilised to simulate urban stormwater systems operating at a range of temporal and spatial scales. MUSIC models the total amounts of gross pollutants, phosphorus, nitrogen, and total suspended solids produced within distinct types of catchments. It allows the user to simulate the removal rates expected when implementing water quality treatment devices to reduce the increased gross pollutant and nutrient levels created by the proposed development.

5.2.1 MUSIC Model Parameters

5.2.1.1 Rainfall Data

The water quality analysis requires historical rainfall data recorded by a pluviograph station. As such, pluviograph data from Sydney Observatory (066062 – 6-minute interval) was utilised for the site according to Council's WSUD & MUSIC Modelling Guidelines. The pluviograph is shown in Table 28.

Table 28: Sydney Observatory Pluviograph Data

Station No.	Location	Records	Data Interval
066062	Sydney Observatory	1981-1985	6-minute

Source: Bureau of Meteorology

5.2.1.2 Pollution Generation

The proposed development has been split into three surface types:

- Roof;
- Landscape; and
- Hardstand.

The stormwater pollutant generation parameters for total suspended solids, total phosphorus, and total nitrogen were determined in accordance with eWater's *Best Practise Modelling Guidelines* and the *NSW Draft MUSIC Modelling Guidelines.* The parameters for each surface type are specified in Table 29.

Table 29: MUSIC Parameters Rainfall Runoff

		Total Suspended Solids (TSS)		Total Phosphorus (TP)		Total Nitrogen (TN)	
		Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std dev**
Roof	Base Flow (mg/L)	-	-	-	-	-	-
	Storm Flow (mg/L)	1.30	0.32	-0.89	0.25	0.30	0.19
Landscape	Base Flow (mg/L)	1.20	0.17	-0.85	0.19	0.11	0.12
	Storm Flow (mg/L)	2.15	0.32	-0.60	0.25	0.30	0.19
Hardstand	Base Flow (mg/L)	1.20	0.17	-0.85	0.19	0.11	0.12
	Storm Flow (mg/L)	2.15	0.32	-0.60	0.25	0.30	0.19

Source: eWater's *Best Practise Modelling Guidelines*

5.2.1.3 Soil Data

The soil characteristics were adopted in accordance with the *Draft NSW MUSIC Modelling Guidelines (2010).* The parameters are specific to the land-use category and are shown in Table 30.

Table 30: MUSIC Soil Parameters

Soil Properties	Roof	Landscape	Hardstand
Impervious threshold (mm)	0.3	1.5	1.5
Soil storage capacity (mm)	108	108	108
Initial storage (% of capacity)	30	30	30
Field capacity (mm)	73	73	73
Infiltration coefficient 'a'	250	250	250
Infiltration coefficient 'b'	1.3	1.3	1.3
Initial groundwater depth (mm)	10	10	10
Daily recharge rate (%)	60	60	60
Daily base flow rate (%)	45	45	45
Daily deep seepage rate (%)	0	0	0

Source: Draft NSW MUSIC Modelling Guidelines (2010)

5.2.1.4 Evapotranspiration Data

The potential evapotranspiration (PET) values were derived from Council's WSUD and MUSIC Modelling Guidelines and are shown in Table 31.

Table 31: Evapotranspiration Data

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

Source: Table 3 of Council's WSUD and MUSIC Modelling Guidelines

5.2.2 Catchment Analysis

5.2.2.1 Land-Uses

The catchment plan for the site is shown in Figure 21. Catchments in the MUSIC model are categorised into the following land-uses:

- **Roof** – The roof area of all residential, commercial and aged care zoned land. Due to the varying land zoning of low, medium, high-density residential, commercial and aged care centres.
- **Landscape** – The pervious surfaces, such as backyards, contained within lots.
- **Hardstand** – The impervious surfaces, such as pavement, contained within lots.

The breakdown of each catchment into the different land-uses was determined based on the proposed rezoning of each catchment. The total impervious percentage of each catchment is consistent with the percentage applied in the XP-RAFTS modelling. The breakdown is shown in Table 32.

Table 32: Land-Uses for each Land Zone

Land Zone	Percentage of Roof Land-Use	Percentage of Landscape Land-Use	Percentage of Hardstand Land-Use	XP-RAFTS Total Impervious Percentage^
R2+	50%	30%	20%	70%
R3	60%	20%	20%	80%
R3+	70%	10%	20%	90%
Industrial/Commercial	80%	0%	20%	100%

Source: Mott MacDonald
^Note the total impervious percentage is equal to the roof percentage and hardstand percentage.

5.2.2.2 Impervious Percentage

For the purpose of the MUSIC modelling, the following impervious percentages were assumed by Mott MacDonald for each land-use, as shown in Table 33.

Table 33: Land Use Impervious Percentage

Land-Use	Impervious Percentage
Roof	100%
Landscape	0%
Hardstand	100%

5.2.2.3 Catchment Plan

The MUSIC catchment plan for the Frenchs Forest Precinct development is shown in Figure 21. A breakdown of each catchment and its associated land-uses is shown in Table 34.

Figure 21: MUSIC Catchment Plan

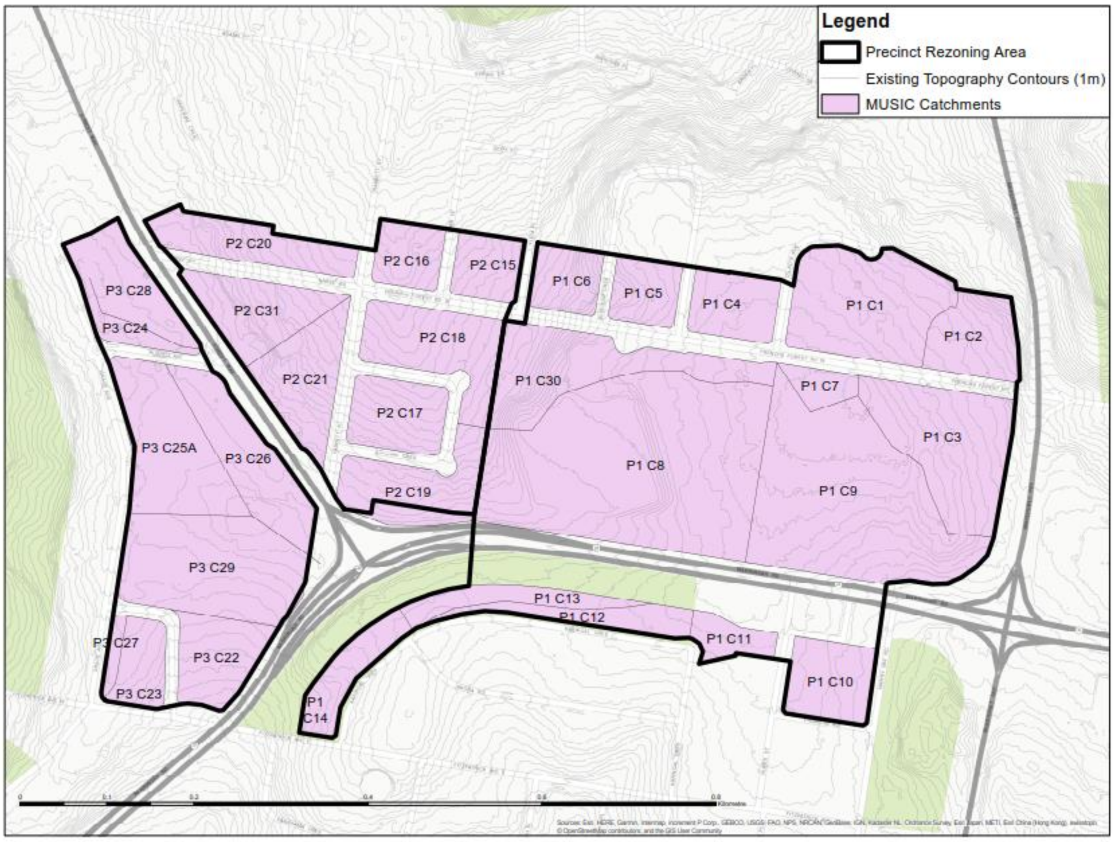


Table 34: Music Catchment Breakdown

Catchment	Roof (ha)	Hardstand (ha)	Landscape (ha)	Total (ha)
P1 C1	1.321	0.406	0.305	2.032
P1 C2	0.588	0.181	0.136	0.904
P1 C3	1.580	0.395	0.000	1.975
P1 C4	0.478	0.147	0.110	0.735
P1 C5	0.365	0.112	0.084	0.562
P1 C6	0.371	0.114	0.086	0.571
P1 C7	0.239	0.060	0.000	0.299
P1 C8	4.461	1.115	0.000	5.576
P1 C9	3.213	0.803	0.000	4.016
P1 C10	0.700	0.175	0.000	0.875
P1 C11	0.190	0.076	0.114	0.379
P1 C12	0.289	0.116	0.173	0.578
P1 C13	0.274	0.110	0.164	0.548
P1 C14	0.333	0.133	0.200	0.666
P1 C30	1.336	0.334	0.000	1.670

Catchment	Roof (ha)	Hardstand (ha)	Landscape (ha)	Total (ha)
P2 C15	0.339	0.113	0.113	0.565
P2 C16	0.334	0.111	0.111	0.556
P2 C17	0.564	0.174	0.130	0.867
P2 C18	0.781	0.260	0.260	1.302
P2 C19	0.838	0.239	0.120	1.197
P2 C20	0.593	0.198	0.198	0.989
P2 C21	0.667	0.222	0.222	1.111
P2 C31	0.618	0.206	0.206	1.030
P3 C22	0.552	0.184	0.184	0.920
P3 C23	0.324	0.108	0.108	0.539
P3 C24	0.170	0.057	0.057	0.284
P3 C25A	1.008	0.336	0.336	1.680
P3 C25B	0.307	0.102	0.102	0.511
P3 C26	0.769	0.256	0.256	1.282
P3 C27	0.082	0.027	0.027	0.137
P3 C28	0.575	0.192	0.192	0.958
P3 C29	1.348	0.449	0.449	2.247

Source: Mott MacDonald MUSIC Model: *393109 FF MUSIC*

5.3 Proposed Treatment

A baseline treatment train is proposed below, modelled on a catchment specific basis to demonstrate one method of achieving the water quality objectives above. Ultimately each development will produce a treatment train appropriate to the development arrangement and specific topography. A list of alternative water quality measure is presented in Section 5.3.3 below with further guidance on the implementation of these and other sustainability measures in the Frenchs Forest Planned Precinct Sustainability Plan prepared by Flux.

5.3.1 Proposed Treatment Train

The following sample treatment train is proposed for each catchment within the Precinct rezoning:

- **Rainwater tanks** (RWTs) are proposed for each residential building as an at source treatment device. It is a requirement of BASIX that all new developments provide rainwater tanks to reduce potable water usage. Rainwater tanks have been sized for residential dwellings only, with commercial sites excluded from the assessment;
- **Gross pollutant traps** (GPTs) will be utilised to capture larger pollutants and sediments before discharging to bioretention devices, local piped network and subsequent watercourses. The HumeGard® GPT has been incorporated into this sample MUSIC model; and
- **Bioretention “Raingardens”** are to be used for effective removal of finer sediments and nutrients.

Note that the final treatment train will be decided upon by the developer of the land. The sample treatment train is a guide to indicate that Council’s water quality objectives can be met upon development of the rezoned land. An example treatment train for the Town Centre site has been included in Appendix B.

5.3.2 Treatment Devices

5.3.2.1 Rainwater Tanks

Rainwater tanks are a requirement of BASIX for all new residential developments. Council does not provide any specifications on rainwater tank sizes in their DCP, therefore required tank sizes were derived from Campbelltown City Council's DCP which requires rainwater tanks be provided for all buildings with a roof area greater than 100m^2. The required capacity is based on the total roof area, as summarised in Table 35. Commercial and industrial developments exceeding 5,000m^2 must provide a plumbing connection in the building so rainwater can be utilised for toilet flushing.

Table 35: Rainwater Tank Requirements

Roof Area (m^2)	Required Tank Volume (kL)
101 – 200	3
201 – 1,000	5
1,001 – 5,000	10
5,001 – 10,000	20
10,001 – 20,000	50
>20,000	100

Source: Campbelltown (Sustainable City) Development Control Plan (2009)

The following assumptions have been adopted for the rainwater tanks:

- 80% of the total tank volume was modelled in MUSIC;
- Internal re-use rate = 0.1 kL/day; and
- External re-use rate = 0.4 kL/m2/year (distributed as PET - Rain)

5.3.2.2 Gross Pollutant Traps

Gross Pollutant Traps are proprietary devices used primarily for the capture and retention of larger sediments and gross pollutants from stormwater runoff generated by residential developments. They are usually sized based on their maximum treatable flow rate being equal to or greater than the 3-month ARI storm event.

In this treatment train the gross pollutant traps will be placed upstream of the Jellyfish® Filters to ensure large pollutants do not clog the filters and decrease their performance. The gross pollutant traps proposed in the treatment train are the HumeGard HG15 model from Humes which has a treatable flow rate of 130L/s. The removal rates are provided in Table 36.

The brand and type of pollutant traps will be specified by individual developers during the detailed design of each lot.

Table 36: Gross Pollutant Trap MUSIC Parameters

Pollutant	Input	Output	Reduction
Total Suspended Solids (mg/L)	500	295	41%
Total Phosphorus (mg/L)	5	3.3	34%
Total Nitrogen (mg/L)	5	3.8	24%
Gross Pollutants (kg/L)	15	2.2	85%

Source: Humes MUSIC node date for HumeGard® retrieved 2018

5.3.2.3 Bioretention “Raingarden”

Bioretention “raingardens” have been proposed as an end-of-line treatment for treatment of stormwater runoff from each catchment. Raingardens are more environmentally friendly ‘soft’ treatment device that are planted filtration systems where water is allowed to temporarily pond and fine sediments are filtered through a soil medium. In addition, raingardens are planted with nutrient removing plants which provide an effective means of extracting dissolved nitrates and phosphates. Unlined raingardens have been selected as appropriate for Frenchs Forest as they allow runoff to infiltrate the soil profile below the treatment area, replenishing groundwater. In developing the MUSIC model for the site, the following parameters have been used.

Table 37: Bioretention “Raingarden” MUSIC Input Parameters

MUSIC Input Parameter	Value adopted
Extended Detention Depth (m)	0.3
Filter Depth (m)	0.6
Saturated Hydraulic Conductivity (mm/hr)	100
Orthophosphate Content of Filter Media (mg/kg)	30

Source: Mott MacDonald MUSIC Model: *393109 FF MUSIC*

Table 38: Bioretention “Raingarden” Sizes

Catchment	Bioretention “Raingarden” Area (m^2)	Catchment	Bioretention “Raingarden” Area (m^2)
P1 C1	300	P2 C17	150
P1 C2	150	P2 C18	200
P1 C3	350	P2 C19	200
P1 C4	150	P2 C20	150
P1 C5	100	P2 C21	200
P1 C6	100	P3 C22	150
P1 C7	100	P3 C23	100
P1 C8	1000	P3 C24	50
P1 C9	700	P3 C25A	250
P1 C10	200	P3 C25B	100
P1 C11	50	P3 C26	200
P1 C12	100	P3 C27	20
P1 C13	100	P3 C28	150
P1 C14	100	P3 C29	350
P2 C15	100	P1 C30	300
P2 C16	100	P2 C31	200
P2 C17	150		

Source: Mott MacDonald MUSIC Model: *393109 FF MUSIC*

5.3.3 Alternative Treatment Devices

The above analysis achieves the minimum requirement for addressing water quality targets for the proposed site, and the treatment train is a nominal or baseline solution for achieving water quality targets. The below alternative options could be explored to incorporate a more holistic Environmentally Sustainable Design outcome.

5.3.3.1 Cartridge Devices

Cartridge based stormwater treatment is a precast underground treatment system which is used to remove suspended solids and other water pollutants from stormwater runoff. Each filtration cartridge provides a membrane surface area which allows runoff to travel through the membrane while removing the pollutants. This system can be used as an alternative to the bioretention “raingardens” proposed in Section 5.3.2. Off the shelf products are advantageous when there is limited space in the project site however the use of raingardens is preferred as a more sustainable solution.

5.3.3.2 Rainwater Harvesting & Reuse

In the proposed treatment train, rainwater tanks have been used to provide stormwater for non-potable purposes such as toilet flushing and garden watering while removing runoff from the stormwater system. Rainwater tanks can be further utilised for building cooling systems and as an alternative potable water source. Rainwater filtration and disinfection systems can be used as a way to provide safe potable drinking water from stormwater runoff. This will reduce the required water demand from potable water mains by providing an alternative means of supply.

5.3.3.3 Recycled Water

A recycled water reuse system allows for the reuse of greywater from the site to provide water to the system for non-potable purposes. Greywater includes wastewater from the laundry, bathroom, shower, and basins, excluding areas from which the water is considered heavily polluted (kitchen and toilet). If treated, greywater systems can be used for garden irrigation, clothes washing and toilet flushing. This is dependent on the level of treatment provided.

Recycled water systems can be provided to allow for blackwater (toilet and kitchen wastewater) treatment however this would require additional treatment measures. Treatment systems can be limited depending on the soil characteristics and local water table.

5.3.3.4 Green Roofs

Providing green roofs of at least 30% of the available rooftop will aid in reducing high nutrient loaded runoff from the roof space. Additional advantages include providing heating and cooling insulation, improved air quality, increase renewable energy efficiency, and increasing biodiversity in the area.

5.3.3.5 Tree Pit Filters

Tree pit filters are typically located in highly impervious areas to treat relatively small catchments. Generic street trees require access to water, adequate soil volume and a good soil mixture. This active watering isn’t always practical which can result in a reduced life span of the tree, however consideration of this water demand during the planning stage for each development means appropriate watering arrangements can be allowed for.

5.3.3.6 Stormwater Pit Filters

Pit filters are a flexible solution as they can be retrofitted to existing pits or removed at a later stage if required. The filters allow run off to be treated at source and if pits are placed adjacent tree pit filters, ensure the street trees are passively watered. Stormwater pits can substantially reduce the nitrogen and other pollutant loads in the water.

5.3.3.7 Permeable Paving

Permeable paving allows runoff to drain through the pavement and infiltrate to the under-lying base-course. Water drains through the sand and gravel and is then collected by standard subsoil drains. Particulates and other pollutants are removed by filtration and absorption by the filter media. Porous paving reduces the amount of directly connected impervious areas and increases the amount of surface water penetrating into the underlying soil to replenish groundwater.

5.3.3.8 Vegetated Swales and Buffer Strips

Vegetated swales are used for conveyance of runoff from impervious areas. Swales can be used instead of pipes to convey stormwater and provide a buffer between the receiving environments and the impervious areas of a catchment. Swales can be incorporated in street designs and add to the aesthetic character of the area. Vegetated swales are often used as an alternative to kerb and gutter along roadways but can also be used to convey stormwater flows in recreation areas and car parks. Vegetated swales perform the following functions:

- Removing sediments from the runoff by filtration through the vegetated surface;
- Reduction in runoff volumes, due to the promotion of infiltration; and
- Delaying the peak runoff by reducing flow velocities.

Swales are effective in the removal of Total Suspended Solids (TSS) but provide limited removal of Total Nitrogen (TN) and Total Phosphorus (TP). As such, they provide an important pre-treatment function, but need to be used in conjunction with other WSUD treatment measures such as wetlands and bioretention systems to form an overall Treatment Train.

5.3.3.9 Sand Filters

Sand filters typically comprise of a bed of filter medium through which stormwater is passed to treat it prior to discharging to the downstream stormwater system. The filter media is usually sand but can also contain sand/gravel and peat/organic mixtures. Sand filters provide a number of functions including:

- Removing fine to coarse sediments and attached pollutants by infiltration through a sand media layer; and
- Delaying runoff peaks by providing retention capacity and reducing flow velocities.

5.3.3.10 Floating Wetlands

Wetlands are shallow water body systems, densely vegetated with emergent aquatic macrophytes. Wetlands are effective in trapping suspended solids, as well as chemical and biological uptake of pollutants.

Wetlands are effective in removing sediment and nutrient loads typically generated from urban development. They do however require a large footprint area in relation to the catchment size. Wetlands also require a significant amount of maintenance. They are susceptible to algal blooms and require recirculation systems. Considerations of public safety measures are also required due to permanent deep water areas.

Floating wetlands are man-made systems designed to emulate the features of natural wetlands. The systems are generally comprised of a system of floating mats, wetland plant species and anchors. Floating vegetation provides a biological filtration system for the removal of nutrients and other pollutants from water bodies.

The combination of plants and bacteria provide the means of converting contaminants to forms that are benign in terms of water quality effects. This is achieved by plant absorption and the action of various types of bacteria that inhabit the panel and plant structure. The floating structure itself and the root mass in the water column provide the range of micro-environments that allow these processes to operate.

A square metre of floating wetland has the capacity to process about 5 kg on Nitrogen and 2 kg of Phosphorus based nutrients per year. In practical situations about 3-5% coverage of the water surface is normally recommended.

Benefits of floating wetlands:

- Suppression of algal blooms and eutrophication through high efficiency stripping of nutrients.
- Absorption of dissolved heavy metals
- Clarification of water through the flocculating effect of bacteria
- Removal of dissolved organic matter
- Reduction of odours
- Suppression of waves
- Provision of habitat for aquatic fauna and birds
- Aesthetically pleasing effect of floating gardens
- Reduced evaporation through the shading effect on water

5.4 MUSIC Results

Results of the MUSIC analysis indicate that by including the nominated treatment train as described in this report, the water quality improvement objectives for total suspended solids, total phosphorus, total nitrogen and gross pollutants (as set out in Section 5.1 of this report) are achieved for each catchment within the Frenchs Forest Rezoning Precinct. A summary of the results are provided in Table 39.

Table 39: Catchment Results

Pollutant	Generation (kg/year)	Residual Load (kg/year)	Removal Rate (%)
Catchment P1 C1			
Total Suspended Solids	1300.0	191.0	85.3
Total Phosphorus	3.9	1.0	74.2
Total Nitrogen	46.7	18.3	60.9
Gross Pollutants	519.0	0	100
Catchment P1 C2			
Total Suspended Solids	587.0	77.6	86.8
Total Phosphorus	1.7	0.4	76.2
Total Nitrogen	21.0	8.0	61.9
Gross Pollutants	231.0	0	100
Catchment P1 C3			
Total Suspended Solids	1330.0	197.0	85.2
Total Phosphorus	4.2	1.1	74.2
Total Nitrogen	51.3	19.6	61.7
Gross Pollutants	597.0	0	100
Catchment P1 C4			
Total Suspended Solids	486.0	58.0	88.0
Total Phosphorus	1.4	0.3	78.6
Total Nitrogen	16.8	5.9	64.7
Gross Pollutants	188.0	0	100
Catchment P1 C5			
Total Suspended Solids	362.0	47.5	86.9
Total Phosphorus	1.1	0.3	76.1
Total Nitrogen	12.8	4.8	62.4
Gross Pollutants	143.0	0	100
Catchment P1 C6			
Total Suspended Solids	369.0	48.5	86.9
Total Phosphorus	1.1	0.3	76.2
Total Nitrogen	13.1	5.0	62.5
Gross Pollutants	146.0	0	100
Catchment P1 C7			
Total Suspended Solids	199.0	21.6	89.2
Total Phosphorus	0.6	0.1	80.6
Total Nitrogen	7.7	2.6	66.1
Gross Pollutants	90.4	0	100
Catchment P1 C8			
Total Suspended Solids	3570.0	502.0	85.9
Total Phosphorus	11.7	3.0	74.6

Pollutant	Generation (kg/year)	Residual Load (kg/year)	Removal Rate (%)
Total Nitrogen	144.0	54.6	62.0
Gross Pollutants	1690.0	0	100
Catchment P1 C9			
Total Suspended Solids	2600.0	381.0	85.3
Total Phosphorus	8.4	2.2	74.2
Total Nitrogen	103.0	39.9	61.4
Gross Pollutants	1210.0	0	100
Catchment P1 C10			
Total Suspended Solids	560.0	67.6	87.9
Total Phosphorus	1.8	0.4	77.6
Total Nitrogen	22.5	7.9	64.7
Gross Pollutants	265.0	0	100
Catchment P1 C11			
Total Suspended Solids	244.0	35.4	85.5
Total Phosphorus	0.687	0.172	74.9
Total Nitrogen	7.61	3.03	60.1
Gross Pollutants	79.4	0	100
Catchment P1 C12			
Total Suspended Solids	380.0	47.5	87.5
Total Phosphorus	1.0	0.2	78.4
Total Nitrogen	11.5	4.2	63.2
Gross Pollutants	121.0	0	100
Catchment P1 C13			
Total Suspended Solids	357.0	42.0	88.3
Total Phosphorus	1.0	0.2	78.9
Total Nitrogen	11.0	4.0	63.7
Gross Pollutants	115.0	0	100
Catchment P1 C14			
Total Suspended Solids	430.0	57.3	86.7
Total Phosphorus	1.2	0.3	76.4
Total Nitrogen	13.3	5.1	61.4
Gross Pollutants	139.0	0	100
Catchment P1 C30			
Total Suspended Solids	1090.0	156.0	85.7
Total Phosphorus	3.5	0.9	74.3
Total Nitrogen	43.2	16.7	61.5
Gross Pollutants	505.0	0	100
Catchment P2 C15			
Total Suspended Solids	367.0	46.5	87.3
Total Phosphorus	1.1	0.3	76.8
Total Nitrogen	12.3	4.6	62.8
Gross Pollutants	136.0	0	100
Catchment P2 C16			
Total Suspended Solids	351.0	42.0	88.0
Total Phosphorus	1.1	0.2	77.4
Total Nitrogen	12.2	4.5	62.9

Pollutant	Generation (kg/year)	Residual Load (kg/year)	Removal Rate (%)
Gross Pollutants	134.0	0	100
Catchment P2 C17			
Total Suspended Solids	560.0	73.1	86.9
Total Phosphorus	1.7	0.4	76.4
Total Nitrogen	20.0	7.4	62.2
Gross Pollutants	222.0	0	100
Catchment P2 C18			
Total Suspended Solids	841.0	120.0	85.7
Total Phosphorus	2.5	0.6	75.3
Total Nitrogen	28.6	11.1	61.3
Gross Pollutants	312.0	0	100
Catchment P2 C19			
Total Suspended Solids	783.0	110.0	86
Total Phosphorus	2.4	0.6	75.0
Total Nitrogen	28.4	10.9	61.5
Gross Pollutants	325.0	0	100
Catchment P2 C20			
Total Suspended Solids	632.0	88.1	86.1
Total Phosphorus	1.9	0.5	75.5
Total Nitrogen	21.5	8.4	61.0
Gross Pollutants	237.0	0	100
Catchment P2 C21			
Total Suspended Solids	722.0	91.0	87.4
Total Phosphorus	2.1	0.5	77.2
Total Nitrogen	24.4	9.0	63.1
Gross Pollutants	267.0	0	100
Catchment P2 C31			
Total Suspended Solids	656.0	74.4	88.7
Total Phosphorus	2.0	0.4	78.2
Total Nitrogen	22.5	8.2	63.7
Gross Pollutants	247.0	0	100
Catchment P3 C22			
Total Suspended Solids	603.0	81.1	86.6
Total Phosphorus	1.8	0.4	76.1
Total Nitrogen	20.0	7.6	62.1
Gross Pollutants	221.0	0	100
Catchments P3 C23			
Total Suspended Solids	346.0	41.4	88.0
Total Phosphorus	1.0	0.2	77.8
Total Nitrogen	11.7	4.3	63.7
Gross Pollutants	130.0	0	100
Catchments P3 C27			
Total Suspended Solids	87.6	12.6	85.6
Total Phosphorus	0.3	0.1	74.5
Total Nitrogen	3.0	1.1	60.9
Gross Pollutants	32.7	0	100

Pollutant	Generation (kg/year)	Residual Load (kg/year)	Removal Rate (%)
Catchments P3 C24			
Total Suspended Solids	182.0	22.1	87.8
Total Phosphorus	0.5	0.1	77.5
Total Nitrogen	6.2	2.3	63.2
Gross Pollutants	68.1	0	100
Catchment P3 C25A			
Total Suspended Solids	1090.0	156.0	85.6
Total Phosphorus	3.2	0.8	74.8
Total Nitrogen	36.8	14.3	61.1
Gross Pollutants	403.0	0	100
Catchment P3 C25B			
Total Suspended Solids	330.0	39.0	88.2
Total Phosphorus	1.0	0.2	78.4
Total Nitrogen	11.3	4.1	64.0
Gross Pollutants	123.0	0	100
Catchment P3 C26			
Total Suspended Solids	821.0	115.0	86.0
Total Phosphorus	2.4	0.6	75.3
Total Nitrogen	27.9	10.7	61.7
Gross Pollutants	308.0	0	100
Catchment P3 C26			
Total Suspended Solids	821.0	115.0	86.0
Total Phosphorus	2.4	0.6	75.3
Total Nitrogen	27.9	10.7	61.7
Gross Pollutants	308.0	0	100
Catchment P3 C29			
Total Suspended Solids	1440.0	165.0	88.6
Total Phosphorus	4.2	1.1	74.0
Total Nitrogen	48.8	18.2	62.7
Gross Pollutants	539.0	0.5	99.9

Source: Mott MacDonald MUSIC Model: *393109 FF MUSIC*

5.5 Stream Erosion Index Modelling

5.5.1 Introduction

The purpose of the Stream Erosion Index (SEI) is to protect streams from increased erosion potential resulting from urban development. The SEI is the ratio of the Developed Conditions stormwater runoff exceeding the 'stream forming flow' to the Natural Conditions stormwater volume exceeding the 'stream forming flow'. The stream forming flow (or critical flow) is typically taken as a proportion of the 50% AEP Natural Conditions flow. Increased frequency and duration of flows above the stream forming flows occur from the increased percentage of impervious which is synonymous with development. It can result in bank toe of streams eroding more rapidly- destabilising the bed and banks, and ultimately leading to increased stream erosion.

5.5.2 Parameters and Methodology

The SEI was calculated in accordance the NSW MUSIC Modelling Guide (2015). Northern Beaches Council does not specify specific SEI objectives, therefore the objectives have been utilised from Blacktown City Council, who requires that the Developed Conditions stream forming flows shall be no greater than 3.5 times the Natural Conditions stream forming flows, with a stretch target of 1.

The Four Steps for Estimating Stream Erosion Index are:

1. Estimate the critical flow for the receiving waterway above which mobilisation of bed material or shear erosion of bank material commences.

Develop and run a calibrated MUSIC model of the area of interest for pre-development conditions to estimate the mean annual runoff volume above the critical flow.

Develop and run a MUSIC model for the post-developed scenario to estimate the mean annual runoff volume above the critical flow.

Use the outputs from steps 3 and 4 to calculate the SEI for the proposed scenario.

5.5.2.1 Step 1: Critical Flow Estimation

Using the area of the site (in km^2), the time of concentration for each outlet was calculated using the probabilistic rational method from equation 1.4 of AR&R Volume 1, Book 4. The rainfall intensity was derived using IFD data for the Frenchs Forest catchment as described in Section 3.4.2 of this report. The corresponding critical flow rate for each outlet was calculated in accordance with 1.4.1 of AR&R Volume 1, Book 4 and are shown in Table 40.

.

Table 40: Critical Flow Estimation

Catchment	Area (km^2)	Time of Concentration (mins)	Rainfall Intensity (mm/hour)	50% AEP Runoff Coefficient	50% AEP Flow Rate (m^3/s)	Critical Flow Rate (m^3/s)
Jindabyne Reserve	0.185	24	67.2	0.444	1.54	0.38
Bluegum Crescent	0.007	7	115.1	0.444	0.10	0.03
Wakehurst Parkway North	0.049	15	84.0	0.444	0.51	0.13
Wakehurst Parkway South	0.049	14	86.7	0.444	0.52	0.13
Fitzpatrick Avenue	0.010	8	109.4	0.444	0.13	0.03
Warringah Road	0.049	15	84.0	0.444	0.51	0.13
Carroll Creek (1)	0.015	9	104.4	0.444	0.19	0.05
Carroll Creek (2)	0.005	6	121.8	0.444	0.08	0.02
Carroll Creek (3)	0.001	4	139.9	0.444	0.02	0.01

5.5.2.2 Step 2: Natural Conditions MUSIC Model

A Natural Conditions MUSIC model was created to assess the mean annual flows of the site, as shown in Table 41. A generic node was inserted into the model directly upstream of the receiving node, in accordance with Section 19.3 of Council's *NSW MUSIC Modelling Guide (2015).* The generic node was set up to convert all inflows at, or below the critical flow to zero outflows. Flows above the critical flow will be passed through the node at the magnitude by which flow exceeds the critical flow.

The Natural Conditions mean annual flows exceeding the stream forming flow for each catchment are shown in Table 41.

5.5.2.3 Step 3: Developed Conditions MUSIC Model

A post-development model MUSIC model was created to assess the mean annual flows of the site, as shown in Table 41. The same generic node described in Section 5.5.2.2 were inserted into the MUSIC model with the proposed treatment train. The Developed Conditions mean annual flows exceeding the stream forming flow for each catchment are shown in Table 41.

5.5.2.4 Step 4: SEI Calculation

The SEI is calculated as the ratio of the output mean annual flow from the generic node for the post-developed model over the corresponding value for the pre-development model as detailed below:

$$SEI = \frac{Sum\ of\ all\ Developed\ Condition\ flows\ exceeding\ the\ stream\ forming\ flow}{Sum\ of\ all\ Natural\ Condition\ flows\ exceeding\ the\ stream\ forming\ flow}$$

The results of the calculations are provided in Table 41.

Table 41: SEI Calculation

Catchment	$Q_{Natural}$ Exceeding Stream Forming Flows (ML/yr)	$Q_{Developed}$ Exceeding Stream Forming Flows (ML/yr)	SEI
Jindabyne Reserve	15.80	28.90	1.8
Bluegum Crescent	0.46	0.72	1.6
Wakehurst Parkway North	3.66	6.91	1.9
Wakehurst Parkway South	3.58	7.31	2.0
Fitzpatrick Avenue	0.61	0.88	1.4
Warringah Road	3.65	5.90	1.6
Carroll Creek (1)	1.51	2.62	1.7
Carroll Creek (2)	0.31	0.47	1.5
Carroll Creek (3)	0.07	0.08	1.1

Source: Mott MacDonald MUSIC Model 393109 180822 SEI Natural and 393109 180914 SEI Developed

The SEI for all major outlets is less than 3.5, indicating that the proposed rezoning of the Frenchs Forest Precinct will have acceptable stream forming flows discharging from the site.

Appendices

A. TUFLOW Flood Maps

B. Town Centre Example Mitigation Measures

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