Blackbutt Creek Flood Study

KU-RING-GAI COUNCIL

Final Report

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Blackbutt Creek Flood Study

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Contents

Appendices

Executive Summary

A flood study has been undertaken for the Blackbutt Creek catchment which drains to the Lane Cove River. Development in the study area is at risk to flooding during heavy rainfall events due to the nature of the urban environment and the limited capacities of the natural and built drainage network. Such flooding has occurred in recent history in 2007, 2010, 2011 and 2012, leading to widespread flooding and damage to properties.

This flood study has been commissioned by Ku-ring-gai Council (“Council”), with the assistance of NSW Office of Environment and Heritage, and defines the existing flood behaviour in the study area, the hazard posed to existing development and the capacity of the community to respond to a flood emergency.

Analysis of design floods has been undertaken using the DRAINS stormwater modelling software to estimate inflows throughout the catchment, and the TUFLOW two-dimensional, unsteady flow modelling package to determine the hydraulic characteristics of the catchment flooding.

The TUFLOW model defines the surface of the catchment in 2D using a 2m grid of the topography, while allowing features such as the stormwater pit and pipe network, trunk drainage channels, culverts and bridges as 1D objects. The hydraulic roughness of the catchments was varied according to land use. Buildings were defined as solid obstructions to overland flow. Partial blockage and all-clear (zero blockage) scenarios of pits, culverts, bridges and mesh-type fencing at waterway crossings were considered to determine worst-case flooding in design events.

Inflow hydrographs from the DRAINS models were input at the sub-catchment outlets in the TUFLOW model, with stormwater pit inlets intercepting the flows up to the system capacity. Excess flows surcharge and form overland flow, which flows over the 2D model domain in patterns according to the topography and modelled obstructions.

A joint-model calibration was conducted for the combined DRAINS-TUFLOW models, with the estimated depths of flooding for the February 2010 (2 - 5% AEP (Annual Exceedance Probability)) and February 1990 (< 20% AEP) historic storm events compared to observed depths reported by local residents. The flood model results were generally comparable to the observed depths. The modelling was therefore considered to be reliable and suitable for defining existing flood behaviour in the study area.

Flood behaviour was defined for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and Probable Maximum Flood (PMF) events. Flood depths have been mapped for all events, while flood levels, hydraulic categories and provisional flood hazard have been mapped for selected events.

By nature, overland flood modelling using two-dimensional hydraulic models often produce results which display large areas of shallow sheet flow which are of minor significance to the flood study objectives. Areas of larger flow and depth, which pose a risk to people and property, are of greater concern. Filtering of the raw model 2D results was therefore undertaken to remove the shallow sheet flow areas from the data set, thus retaining the main areas of flow.

Flood planning areas have been defined based on the 1% AEP flood surface plus a specified freeboard. The adopted freeboard is 0.3m for overland flood areas and 0.5m for mainstream flood areas.

Areas within the catchment have been classified based on the floodplain risk management guideline *Flood Emergency Response Planning – Classification of Communities* (DECC, 2007). The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community. In summary, in the 20% AEP flood, there are only a few properties which are so flood-affected that the residents ability to evacuate is significantly impacted. In the 1% AEP and PMF events, there are a number of areas which become cut-off by floodwaters and there are several dwellings which become surrounded by high hazard floodwaters that pose a risk to life for their occupants.

A number of scenarios have been assessed for the 1% AEP flood event to test the sensitivity of the model results to changes in the adopted parameter values. The modelling indicates that peak flood levels are not overly sensitive to the varied rainfall loss and hydraulic roughness scenarios tested, with increases in 1% AEP flood levels typically less than 100mm in developed areas. However, some significant flood level increases of up to 450mm were observed for the fully blocked hydraulic structures scenario. Existing development would be impacted by these increases.

The impact of climate change on flooding in the study area has been assessed for increases in 1% AEP storm rainfall intensity of 10%, 20% and 30%. The DRAINS model was rerun with the increased rainfall intensities, and the resulting sub-catchment hydrographs input into the TUFLOW model. Existing development would be affected by increases in peak flood levels in overland flow paths of up to 0.2m in the 30% rainfall intensity increase scenario. Development along the main watercourses would be affected by increases of up to 0.3m, while undeveloped areas along watercourses would experience up to a 0.5m increase in flooding.

Lady Game Drive culvert

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to of document the undertaking and outcomes of the Blackbutt Creek Flood Study. In accordance with the scope of services set out in the contract between Jacobs and Ku-ring-gai Council. That scope of services, as described in this report, was developed with Ku-ring-gai Council.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Ku-ring-gai Counciland/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Ku-ring-gai Council (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

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1. Introduction

1.1 General

Ku-ring-gai Local Government Area (LGA) encompasses an area of 85.4km^2 on Sydney's North Shore with a number of separate catchments draining to the Lane Cove River, Middle Harbour and Cowan Creek systems. Blackbutt Creek is one creek system within the LGA which drains to the Lane Cove River and is rated as a high priority catchment in terms of risk of flooding to existing development.

Patterns of urbanisation and associated construction of drainage infrastructure dating back to as early as the 1940's, have resulted in a number of watercourses being piped or crossed by road embankments and development occurring in sometimes unsuitable locations, putting this development at risk to flooding during heavy rainfall events. Such flooding has occurred in recent history in 2007, 2010, 2011 and 2012, leading to widespread flooding and damage to properties.

Hydrologic and drainage studies have been undertaken in the study area in the past, though some of these studies are up to 10 years old and most do not define the flood behaviour to the level of detail required in the NSW Government's *Floodplain Development Manual* (2005), which forms the current guidance for management of development and flood risk in NSW. Further, a significant amount of urban redevelopment has occurred in the catchment in recent years which has the potential to increase rainfall-runoff and hence flooding.

Ku-ring-gai Council ("Council") commissioned Jacobs to undertake a flood study for the Blackbutt Creek catchment. This report documents the development and outcomes of the flood study to determine the existing nature of flooding in the study area.

1.2 Purpose of this Flood Study

The purpose of this study is to investigate the existing and future flood risks in the study area and to develop the subsequent floodplain risk management study and plan in accordance with the NSW Government's *Floodplain Development Manual*.

Key objectives of this study are to:

- Develop and calibrate hydrologic and hydraulic models for the estimation of overland and mainstream flood behaviour in the study area, taking into account the performance of the stormwater drainage network including overflows from the drainage network. The overflows contribute to overland flooding in some areas.
- Determine flooding behaviour and flood risk in the study area for a range of flood events.
- Map the flood hydraulic and hazard categories.
- Determine the flood planning areas for the 1% AEP event.
- Identify the flood emergency response categories for different parts of the catchment and community.
- Assess the sensitivity of flood behaviour to changes in hydrologic and hydraulic characteristics in the catchments.
- Assess the impact of climate change on flood levels in the study area.

The outcomes from this flood study will form the basis for the identification, assessment and prioritisation of management measures during the subsequent floodplain risk management study and plan.

2. Background on Study Area

2.1 Catchment Description

The catchment has a total area of 4.9km^2 and includes a number of watercourses and overland flow paths within the suburbs of Pymble, West Pymble, Gordon and Killara. The catchment is bounded by the Pacific Highway to the east and Fiddens Wharf Road to the south, and is traversed by Ryde Road, Pymble Avenue and Livingstone Avenue on its western boundary. Blackbutt Creek discharges into the Lane Cove River at the south-western corner of the catchment. The study area is depicted in **Figure 2-1**.

Ground elevations range from 8m AHD at the catchment outlet up to and exceeding 110m AHD at the northern corner of the catchment. The catchment is particularly steep in the north-western portion of the catchment with watercourse grades of 1 in 6 to 1 in 10.

Watercourses are generally ephemeral in the upper reaches, and begin to hold permanent flows downstream from the middle reaches. Flow paths and watercourses are generally well-defined. The creek passes through deeply-incised valleys which extend into the middle reaches in the southern portion of the catchment, and nearing the headwaters in the northern portion of the catchment.

2.2 Existing Development

Land use in the catchment is predominantly low-density residential housing with high density apartment development and commercial development along the western boundary, particularly in Gordon and Pymble.

Development is confined to the ridge tops and upper hillsides as the valleys are generally too steep for development. The valleys are vegetated with natural bushland.

Watercourses in the catchment flow through a number of private properties and are crossed by driveway culverts and bridges in addition to minor footbridges. In some locations the watercourse has been built over by the dwelling itself.

There are two large open space areas in the catchment, consisting of Gordon Golf Course and the Killara Golf Club course which are both located in the southern portion of the catchment.

Ryde Road is a major road which crosses Blackbutt Creek in its middle reaches. A number of roads, including Ryde Road, Vale Street, Norfolk Street, Calvert Avenue and Warwick Street, have been constructed in fill over the creeks and waterways, which have been piped under the roads. In some locations the road embankments pose significant obstructions to flow and cause ponding of floodwaters on private properties on the upstream side of the roads.

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Blackbutt Creek Flood Study

Figure 2-1

STUDY AREA

2.3 History of Flooding

Flooding in the catchment has recently occurred during June 2007, February 2010, February 2011 and April 2012. The February 2010 event was particularly severe, with flooding of a number of properties exceeding 1m in depth and above floor levels. **Plate 2-1** to **Plate 2-6** shows the flooding during February 2010. The photos were taken on the morning of the 7th February following the peak of the flood, which occurred at 9pm the previous night (6th February).

Plate 2-1 Floodwaters exiting front yards into street in Gordon

Plate 2-2 Floodwaters flowing through front yard

Plate 2-3 Pooled floodwaters and damage to front yard

Plate 2-4 Pooled floodwaters in driveway

Plate 2-5 Floodmarks and damage to house

Plate 2-6 Car was washed across yard from carport on left of frame

3. Review of Available Data

3.1 List of Reference Data

The following data was used in the hydrologic and hydraulic modelling:

- DRAINS hydrologic and stormwater drainage model of the study area (URS, 2005).
- Preliminary flood outlines for the 1% Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF) events from the 2011 Mott McDonald study.
- Spatial data (stormwater assets, LEP zoning, riparian zones, soil landscapes)
- Development Applications for high density developments in the study area lodged since 2008.
- Various site photos from site inspection and previous studies.
- AUSIMAGE aerial imagery dated 2011.
- LiDAR data collected in 2007 and provided by Council.
- Survey of selected open channels and hydraulic structures commissioned for this study.
- Rainfall data recorded at 5 minute intervals for historic calibration events purchased from Sydney Water.

Specific findings and issues relating to the above data are discussed in the sections below.

3.2 Reports

Jacobs collected and reviewed the following relevant reports:

- *Local Catchment Plan – Lane Cove River Southern Region Catchments, Preliminary Report*, prepared by URS, July 2005. Provides details on the set up of existing DRAINS models for the study area, including Blackbutt Creek. The report states that a significant amount of effort was undertaken to correct and verify the drainage asset data set provided by Council, and involved field inspections. The report also states that it is possible that some errors in the updated data set may remain, given the enormous quantity of data contained in the data set.
- *Ku-ring-gai Council Preliminary Flood Mapping Report, Final*, November 2011, prepared by Mott MacDonald Hughes Trueman. This report presented mapping of 5% and 1% AEP flood extents in several catchments in Ku-ring-gai LGA, including Blackbutt Creek. The floodplains were estimated based on DRAINS hydrologic/drainage modelling and HEC-RAS 1D hydraulic modelling of watercourses. The DRAINS models were originally developed by URS (2005).

3.3 LiDAR Ground Elevation Data

LiDAR data with a vertical accuracy of approximately ±0.15m that encompasses the Blackbutt Creek catchment and adjacent areas. The data has been separated into ground, non-ground, buildings and vegetation data points. The heavily vegetated character of the study area results in numerous gaps in the ground point data set, requiring interpolation of levels across these gaps. Based on site observations, it was noted that there were errors in the order of ±3m in some locations, particularly in areas where a dense tree canopy covers the creek channel. This justified the collection of additional ground survey in selected locations, which is discussed in **Section 3.5**.

3.4 Existing Models

3.4.1 DRAINS Hydrologic Model

3.4.1.1 Drainage Network Details

Council indicated that the existing DRAINS model (URS, 2005) was based on measured stormwater pit depths in conjunction with 2m contour data, from which pit surface levels and pipe invert levels were deduced. The pit and pipe levels were updated during this study using the LiDAR data, which is considered to be more accurate than the 2m contour data. This resulted in a number of pipes in the model having an inverse grade, that is, the downstream end being higher than the upstream end, which is likely to be erroneous as pipes are conventionally laid with a downward slope to aid drainage. This was thought to be due to either:

- the LiDAR being potentially inaccurate at these locations; or
- pit depth measurements being potentially inaccurate particularly at pits which are inaccessible (covered or buried). The pit depths at these locations may have been assumed for the purposes of setting up the original DRAINS model.

Survey of pit surface levels was commissioned at selected pits that were connected to pipes greater than 750mm. This data was incorporated into the TUFLOW model.

3.4.1.2 Catchment Development Conditions

A number of high density residential developments have occurred in the study area since the existing DRAINS model was developed in 2005, particularly along the upper sections of the catchment in Pymble and Gordon in the vicinity of the Pacific Highway. The locations of these developments were confirmed by on-site inspection by Council officers in December 2013 in addition to review of recent Development Application information for proposed developments. This data was used to update the catchment imperviousness of selected sub-catchments in the DRAINS model.

3.4.2 HEC-RAS Hydraulic Model

The HEC-RAS model developed by Mott MacDonald Hughes Trueman (2011) was reviewed for details on hydraulic structures. No hydraulic structures including waterway crossings were represented in the model and hence data on the structures was not available.

3.5 Aerial Photography

AUSIMAGE aerial photography dated 2011 was obtained by Jacobs for the study area, and is the latest available imagery for the catchment. Council has indicated that some townhouse and unit development has occurred since 2011 which would not be shown by the imagery. Site inspections were undertaken to verify the current status of these developments.

3.6 Streamflow Data

Gauging of overland flows has been undertaken in the catchment at two locations in the past:

- Gordon Golf Course: Gauging was undertaken by Council officers from 24 December 2004 to 28 March 2005, however Council has indicated that the flow data may not be reliable due to the gauging methodology employed.
- In the natural flow path on the private property at 67 Dumaresq Street, Gordon: Gauging was undertaken by Manly Hydraulics Laboratory (MHL) on behalf of Council from 26 April to 19 September 2007. This

monitoring period recorded a number of storm events during June and July 2007. A maximum flow of $0.46m^3/s$ was recorded on 16 June 2007, which is not considered a particularly large flow. This gauging is considered to be a reliable data set.

3.7 Rainfall Data

3.7.1 Historic Rainfall

Historic event pluviograph data at 6 minute intervals was provided in accompaniment with the Dumaresq Street flow gauging data from MHL. The rainfall was gauged at Pymble Pool, in West Pymble for the period 26 April to 19 September 2007.

Additional historic rainfall data was obtained from Sydney Water from their depot on Telegraph Road, Pymble, approximately 400m north of the study area. The data was purchased for storm events in February 2010 and April 2012.

3.7.2 Intensity-Frequency-Duration Data

Design Intensity-Frequency-Duration (IFD) rainfall information is contained in the existing DRAINS model of the catchment. It is proposed to utilise this information for generating design flows for the study using the DRAINS model. The IFD data (ARR 1987) is summarised in **Table 3-1**.

Table 3-1 IFD Parameters for Study Area

Parameter	2 year ARI	50 year ARI
1hr Event Intensity (mm/h)	17	82.5
12hr Event Intensity (mm/h)	8.3	17
72hr Event Intensity (mm/h)	2.8	5.5
Frequency Factor	4.29	15.8
Skewness	0	

3.8 Council Register of Flooding Complaints

Council's register of previous flooding complaints was reviewed, however, only limited information relating to locations of previous complaints was available, with no reports in the register following 1990.

3.9 Site Inspection

A site visit was undertaken on 10 May 2013 by Jacobs project staff and Council officers. Locations inspected on the site visit included potential trouble spots identified by Council, road crossings and potential obstructions to overland flow. Observations made during the site visit included:

- There were numerous private driveway crossings with variable culvert/bridge design and sizing - some of these were potentially at high risk to blockage from yard objects (including play equipment and trampolines);
- In some locations, roads were built on embankments thus creating a dammed area on the properties on the upstream side;
- The majority of dwellings adjacent to watercourses have their floor levels built up above ground level;
- There were a number of properties identified with brick walls that could potentially obstruct overland flow.

Further site inspections were undertaken following model verification for locations where there remained uncertainty or queries about the flooding behaviour. Observations and measurements of key hydraulic structures were taken at these locations as these features were not previously represented in the hydraulic model. The likely flood behaviour at critical locations in the study area was also validated during the ground truthing.

3.10 Works-As-Executed Plans of Recent Developments

Existing ground surface levels and stormwater systems were observed to be markedly different to those presented in the LiDAR terrain data and Council drainage GIS, particularly at the newer residential apartment complex developments in Pymble and Gordon. Work-As-Executed plans were obtained for developments at Avon Road, Pymble, and 6-14 Dumaresq Street, Gordon, and input into the model. However, this information was not available for a number of remaining developments in McIntyre Street, Dumaresq Street and Moree Street in Gordon and the terrain data is approximate only. The modelled flood behaviour at these locations should therefore be treated with care.

3.11 Ground Survey

Survey was collected from June to September 2013 of ground elevations along watercourses, driveway crossings, culverts, bridges and other hydraulic structures at key locations in the study area. The locations were selected based on the proximity of properties to watercourses and likely driveway crossing culverts, which were not represented in the available spatial data from Council. Features including footbridges, retaining walls and free-standing brick walls on private property were also surveyed. Major structures including the Honeysuckle Creek Dam on Killara Golf Course and Lady Game Drive Bridge were also surveyed.

3.12 Community Consultation

Questionnaires were distributed to property owners within the study area, with 364 responses received from approximately 5,000 questionnaires mailed out. 40 responses included observations of flood behaviour and flood depths greater than 0.1m which were considered to be potentially useful in model validation. 20 observations were received from the February 2010 and April 2012 flood events, which were used in the model calibration. Refer to **Section 6**. A summary of the questionnaire responses is provided in **Appendix A.**

A community forum was held at Council's Pymble Operations Depot on 6th November 2013. Approximately 20 residents attended the forum and were briefed on the objectives and progress of the flood study and invited to provide feedback on preliminary results, including preliminary model calibration results. The forum attendees generally agreed with the preliminary model calibration results mapping. Refer to **Appendix B** for a summary of the forum proceedings. Residents were contacted following the forum to gather further information on recent flooding.

4. Hydrologic Modelling

4.1 Overview

The existing DRAINS model (URS, 2005) represents the entire stormwater pit and pipe system in the Blackbutt Creek catchment, which was divided into 736 sub-catchments. The model was used in this study primarily to estimate sub-catchment runoff hydrographs for subsequent input into the hydraulic model. Flow capacities and pipe hydraulics were not assessed in the DRAINS model in this study.

4.2 Sub-Catchment Data

Mapping of the sub-catchment boundaries was not available from Council and hence is not produced in this report. The boundaries of several sub-catchments were re-created based on LiDAR contour data, in order to update the catchment imperviousness due to recent urban development in the study area. The surface areas of these sub-catchments were consistent with the DRAINS model.

Recent urban developments were estimated from aerial photography to be 70% impervious in area. This information was used to increase the sub-catchment imperviousness in the DRAINS model.

4.3 Hydrologic Parameters

The following parameter values were adopted in the DRAINS modelling for the design storms:

- Depression storage: Paved areas – 1mm; Grassed areas – 5mm.
- Soil type: Type 3, which represents a not-particularly well drained soil landscape.
- Antecedent Moisture Condition: This represents the degree of soil wetness at the onset of a storm, which affects its infiltration capacity. A value of 3 was adopted for storms up to and including the 1% AEP event, which represents “rather wet” (but not saturated) soil conditions due to total rainfall of between 12.5 and 25mm in the preceding 5 days prior to the modelled storm event (DRAINS User Manual, Watercom, 2012). It was assumed that the ground would be completely saturated during extreme storm events, therefore, a value of 4 was adopted for the PMP event.

4.4 Design Rainfall

The storm events including the 20%, 10%, 5%, 2% and 1% Annual Exceedance Probability (AEP) events were modelled as Australian Rainfall and Runoff 1987 (ARR87) Zone 1 storms in DRAINS.

Design rainfall time series were derived for the Probable Maximum Precipitation (PMP) events, based on the Generalised Short Duration Method (GSDM) in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (BOM, 2003).

5. Hydraulic Modelling

5.1 Model Selection

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model has been developed for this study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex flow patterns on the floodplain, including flows through street networks and around buildings.
- Capability in representing the stormwater drainage network, including pit inlet capacities and interflows between the network and floodplain including system surcharges.
- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

The model was developed and run in TUFLOW version 2012-05-AD-w64, in double-precision mode.

5.2 Configuration of Hydraulic Model

5.2.1 Extent and Structure

The TUFLOW model is comprised of:

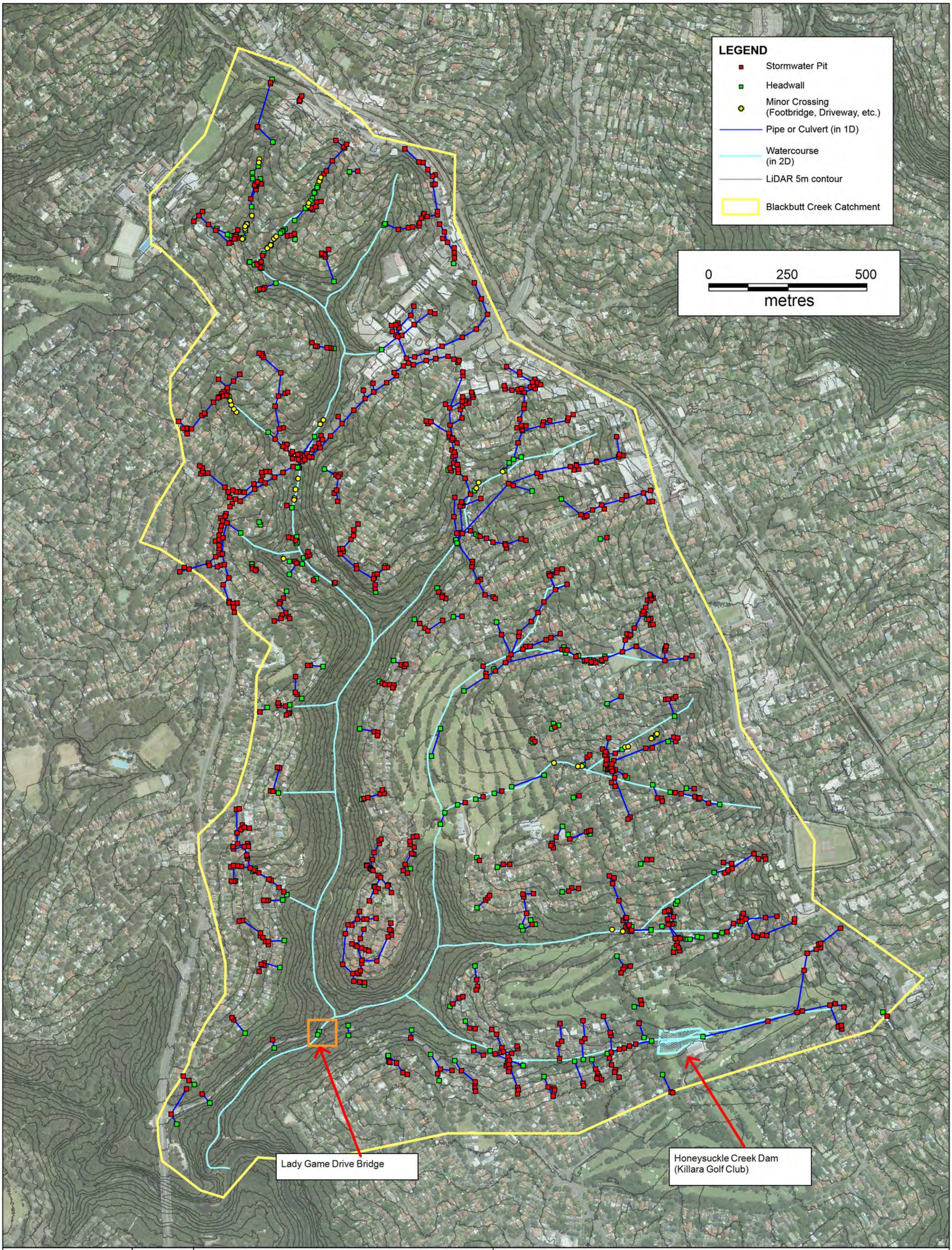
- A 2D domain of the catchment surface reflecting the catchment topography, with varying roughness as dictated by land use.
- A 1D network of pits and pipes representing the stormwater network. The pits have a defined inflow capacity as dictated by their type and size.
- Additional hydraulic structures including culverts (1D) and footbridges (2D).
- Obstructions to flow are represented as 2D objects, including existing buildings and identified free-standing walls.

Refer to the following report sections for details on these features. The locations of various features in the TUFLOW model are shown on **Figure 5-1**.

5.2.2 Model Topography

The topography of the catchment is represented in the model using a 2m grid. This level of precision in the grid is considered necessary in order to represent detailed flood behaviour in a fully developed catchment. The basis of the topographic grid used in the TUFLOW model is the LiDAR data set in addition to ground survey at key locations. The model topography is shown in **Figure 5-2**.

Bed levels of the Honeysuckle Creek Dam on Killara Golf Course were estimated from the LiDAR and ground survey, assuming a maximum pond water depth of 4m (based on the dam wall height).



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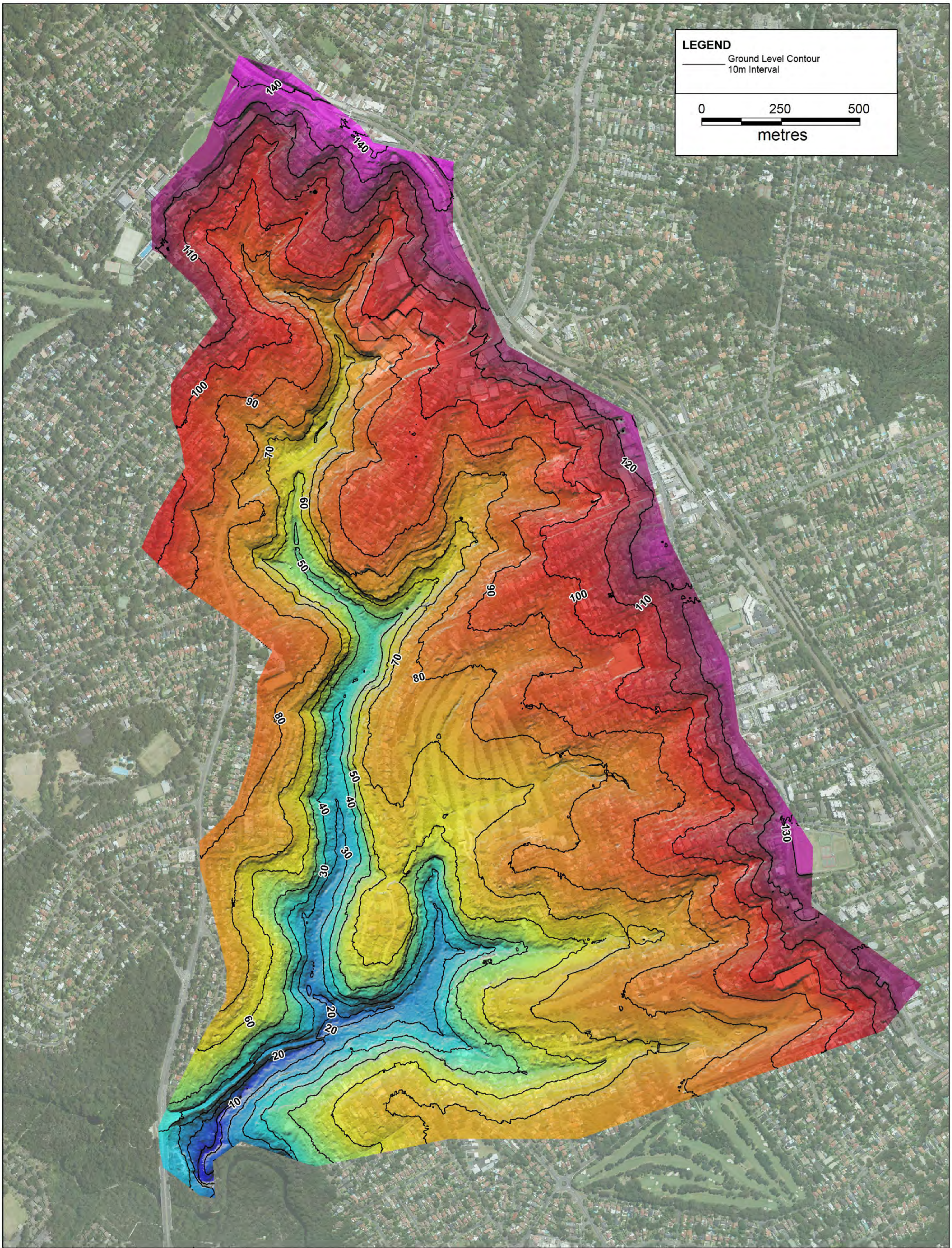

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Blackbutt Creek Flood Study

Figure 5-2

TUFLOW MODEL TOPOGRAPHY

5.2.3 Stormwater Pits

The stormwater pits provide a dynamic linkage between the underground drainage network and the 2D TUFLOW model domain, representing the floodplain. Water is able to flow between the drainage network and floodplain, depending on the hydraulic conditions.

The location of the stormwater pits and associated attributes were exported directly from the DRAINS model to GIS format. Pit inflow relationships were defined in terms of flow depths versus pit inflow. The pit types and inflow relationships adopted in the DRAINS model were also used in the TUFLOW model.

TUFLOW automatically calculates hydraulic energy losses in the pits based on the alignment of pipes connected to each pit and the flows in each pipe. The calculations are based on the Engelhund manhole loss approach (*TUFLOW User Manual*, BMT WBM, 2010).

5.2.4 Stormwater Conduits

Each of the stormwater pits and pipes in the DRAINS models are also modelled in the TUFLOW models. Pipes down to a diameter of 225mm are represented. The conduits are represented as circular pipes or rectangular culverts with dimensions matching those adopted in the DRAINS models.

Details of additional pipes and culverts which were not in the DRAINS model were collected during ground survey. This included culverts at road crossings and driveway crossings. The road crossing and driveway crossing locations are indicated on **Figure 5-1**.

5.2.5 Building Polygons

This study considers buildings as solid objects in the floodplain. This means that buildings form impermeable boundaries within the model, and while water can flow around buildings, it cannot flow across their footprint.

The building footprints in the TUFLOW model were digitised based on the 2011 aerial imagery. The building polygons were superimposed on the model grid to make model computational cells under the footprints inactive.

5.2.6 Property Fencelines

Fencelines have typically not been explicitly represented in the model and floodwaters are allowed to flow across them freely. Although fences may obstruct overland flood flows in some parts of the catchment, experience indicates that representing fences in the hydraulic model requires making unvalidated assumptions about depths at which fences overflow or fail.

Hence, the potential obstruction to flow caused by fences was represented in the model by increasing the cell roughness (Manning's n values) for certain land uses, as described in **Section 5.2.7**. The limitation of this approach is that the flood levels may be slightly overestimated and flow velocities slightly underestimated for flooding within properties depending on the actual locations of obstructions and the interaction of flood flows with these obstructions. However, this approach does preserve the likely typical flooding behaviour, in which floodwaters use the road corridor as the preferential flow path.

Where identified, free-standing brick walls such as those along property boundaries were modelled as solid obstructions to flow.

5.2.7 Surface Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness values according to the LEP zoning and ground cover, refer to **Table 5-1**. These are based on engineering experience and typical values used in previous flood studies undertaken in the Sydney Region by Jacobs and other consultants. The relatively high Manning's n values for the residential land use accounts for expected obstructions such as minor structures (sheds, etc.) and fences.

Table 5-1 TUFLOW Model Grid Hydraulic Roughness Values

Land Use Type	Manning's n	Comment
Road	0.020	
Grassed area	0.030	Golf courses and other large grassed areas
Commercial and Industrial	0.035	Assumed mainly paved
Watercourse	0.045	
Residential (low and high density)	0.080	Accounts for landscaping and fences
Natural vegetation	0.120	

5.2.8 Footbridges

Details of identified footbridges in the study area were obtained from survey, including soffit, deck and hand railing levels. Footbridges were modelled as 2D structures and their locations are indicated on **Figure 5-1**.

5.2.9 Floodways through Existing Buildings

A floodway was identified through the North Shore Gym building on West Street, Pymble. Overland flows running down Bridge Street and onto West Street are able to enter and flow through the understorey car park and into the gully below on the south-western side of the building and into Blackbutt Creek. This location is indicated on **Figure 5-1.**

5.3 Boundary Conditions and Initial Conditions

5.3.1 Model Inflows

Runoff generated in the sub-catchments from the DRAINS model was input to the TUFLOW model via one of two methods:

- At the pits located at the outlet of each sub-catchment. Sealed pits are not assigned a flow. The amount of surface flow entering the pit is dictated by the pit inflow relationship. Flows in excess of the pit inlet capacity remain in the 2D model domain as point inflows, subsequently forming overland flow.
- At the outlet to the sub-catchment if there are no pits in that sub-catchment, for example, in forested sub-catchments, or if there was a large sub-catchment (say, greater than 3 hectares) draining through private properties. The latter was done to ensure that flooding was not underestimated on these properties. Flows are initially input at the lowest point of the sub-catchment and then distributed to wet areas in the catchment as the storm progresses.

Pit surcharge flows are caused when flows in the drainage network exceed network capacity and spill out of the pits and into the 2D domain. Pit surcharges would similarly form overland flow in the model. Depending on the hydraulic conditions in the pipe system, overland flows can re-enter the pipe system via the stormwater pits.

6. Model Calibration

6.1 Overview

Rigorous model calibration of overland flood models cannot generally be carried out because direct measurements of overland flows and accurate measurements of flood levels are usually not available. Hence, overland flood models are often verified using observations of flood depths and flood behaviour as a way of "sanity-checking" the modelling and confirming its reliability.

This study has relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information is considered indicative as only the general location of the observation is usually given, with the observer unlikely to have measured actual depths and may have estimated the depth of flow in the watercourse from a distance, and the depths are often rounded up to the nearest 0.1m. However, the reported flood depths are still useful information for validating the general behaviour of flooding predicted by the flood models.

The general approach involved running the hydrologic and hydraulic models and comparing the flood depths and flow patterns to reported observations. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations. Rainfall losses, inflow locations and topographic features (particularly where the LiDAR data was patchy due to vegetation cover) were adjusted within reason.

6.2 Selection of Calibration Events

The 6 February 2010 and the 18 April 2012 storm events were selected for calibration of the hydrologic and hydraulic models as these were recent storm events which Council reported as causing significant flooding. Additionally, there were a relatively large number of flood depths observed and reported by local residents in the questionnaire responses.

Rainfall data at 5 minute intervals was obtained from the Sydney Water rainfall gauge at the ex- Pymble Bowling Club site (Station 566073), now a Sydney Water depot at Telegraph Road/Bungalow Avenue in Pymble. The site is approximately 400m north of the study area. Characteristics of the selected storm events are provided in **Table 6-1**.

Table 6-1 Calibration storm event characteristics

Event Date	Daily Rainfall Depth	Main Storm Burst Rainfall Depth & Duration	Approximate Event AEP
6 February 2010	206mm	96mm/2 hours	2 – 5%
18 April 2012	100mm	40mm/1 hour	< 20%

6.3 Adopted Parameter Values for Model Verification

6.3.1 Rainfall Losses

An Antecedent Moisture Condition (AMC) value of 4, representing "saturated" soils, was adopted for both calibration event runs in the DRAINS hydrologic model. This is based on guidance in the *DRAINS User Manual* (Watercom, 2012) which suggests this value for an accumulated rainfall depth greater than 25mm over the preceding 5 days. The rainfall total depth in the days preceding the main storm bursts of the calibration events exceeded 25mm.

6.3.2 Blockages

Culverts and bridges were assumed to be unblocked for the model calibration events, as there was no available evidence of significant blockages at the hydraulic structures. Stormwater pit inlets were assumed to be 20% blocked for on-grade pits and 50% blocked for sag pits for the calibration runs.

6.3.3 Initial Water Levels

Honeysuckle Creek Dam storage was assumed to be near full capacity, with an initial water level of 73m AHD and approximately 0.3m from spilling. This assumption was based on review of the daily rainfall in the period prior to the calibration storm events, with the observation that there was a significant amount of rainfall (greater than 100mm) in the 7 – 10 days leading up to both events (BOM rainfall station 066120, Gordon Golf Club). This would have contributed to a significant volume of inflow into the dam storage.

It is unlikely that the model calibration would be sensitive to the assumed initial water level in the Dam in any case. There is only one calibration point on this tributary, approximately 800m downstream of the Dam, and for the April 2012 event only. There are numerous other calibration points for the February 2010 and April 2012 events in other parts of the catchment.

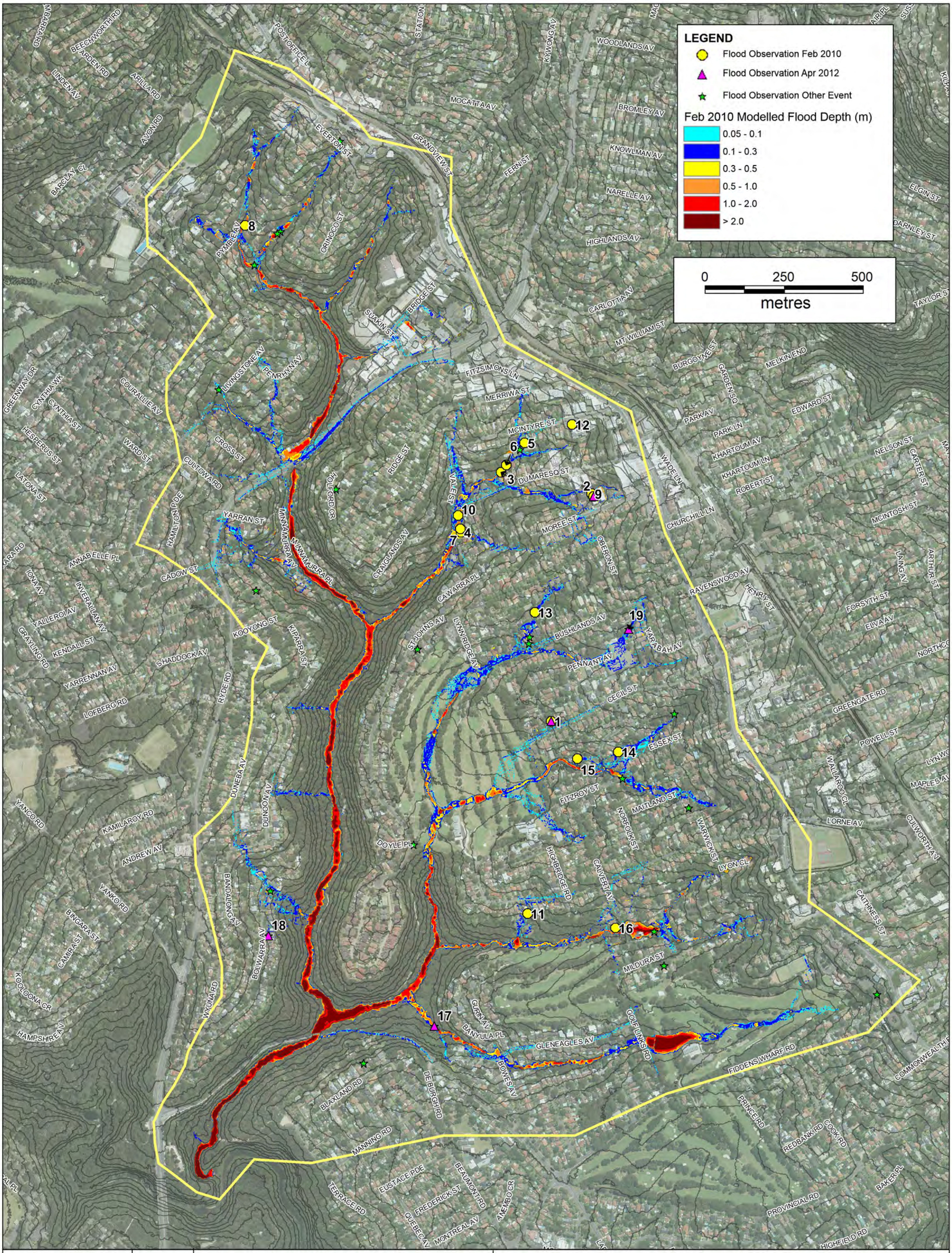
6.3.4 Tailwater Conditions

A normal depth condition has been assumed at the downstream boundary for the calibration events. Given the steep terrain of the Blackbutt Creek valley and that existing development is located at least 15m higher than the Creek near its outlet, the flooding conditions on private properties and at calibration points are not considered to be sensitive to this assumed tailwater condition.

6.4 Comparison to Observed Flood Depths

There were 16 observed flood depths for the February 2010 event and 5 observations for the April 2012 event. These, and the remaining flood observations greater than 0.1m, are shown on **Figure 6-1**. The resulting flood depths from the calibrated hydrologic and hydraulic models are compared to observed flood depths in **Table 6-2** and **Table 6-3** for the February 2010 and April 2012 events, respectively.

There were 20 additional flood observations provided in the questionnaire responses which were not related to the February 2010 and April 2012 events. These additional obsesrvations were used to provide a general comparison of flood behaviour between the model results and observed conditions.



JACOBS SKM

Blackbutt Creek Flood Study

Figure 6-1
HISTORIC FLOOD DEPTH OBSERVATIONS

Table 6-2 Comparison of TUFLOW Results to Observed Flood Depths – February 2010 Event (refer to Figure 6-1 for locations)

ID	Observed Depth (m)	Modelled Depth (m)	Difference (m)	Comment
1	0.4	0.31	-0.09	Satisfactory fit next to house.
2	0.5	-	-	Resident reported 0.5m flooding in basement. Considered a drainage issue and not assessed in the TUFLOW model. Additionally, available terrain data not reliable at this location.
3	1.5	1.00	-0.5	Model produces 1m deep flows in watercourse in Gordon Glen.
4	1.4	1.61	0.21	Resident indicated depth of 1.4m at front of house. Patchy LiDAR coverage in front yard due to tree canopy. Model ground elevations were adjusted based on site inspection observations.
5	0.5 – 1.0	0.66	-	Within reported range.
6	0.5	0.47	-0.03	Not a direct observation by resident – only witnessed signs of water entry into garage. The modelled depth is at the top of creek bank at the rear of the property.
7	0.5	1.2m max	0.7	Consistent with reliable flood levels on adjacent properties.
8	0.5	0.5	0.00	Achieved 0.5m in model at top of bank of watercourse.
9	0.5	2.50		Flows in model are allowed to build up against solid obstruction (apartment building). In reality the flows would be able to enter the basement and spread out to a lesser depth.
10	0.4	0.3 – 0.6	-	Model indicates 0.3 – 0.6m depths on the property. Consistent with observed depth.
11	0.2	0.36	0.16	At garage entrance
12	0.2	-	-	Not located on a flow path – possible stormwater ingress and not considered suitable for model calibration.
13	0.2	0.1 – 0.7	-	Modelled depths are between 0.1 – 0.7m deep. Uncertainty about exact location of the observation.
14	0.2	0.25	0.05	Up to 0.25m at rear of property
15	0.18	0.24	0.06	Reported 0.18m in garage, modelled 0.24m at garage
16	0.05 - 0.15	0.06 – 0.13	0.01 – 0.02	Reported 2 inches (0.05m) in garage and 6 inches (0.15m) in garden. Modelled 0.06m at house and 0.13m in yard.

Table 6-3 Comparison of TUFLOW Results to Observed Flood Depths – April 2012 Event (refer to Figure 6-1 for locations

ID	Observed Depth (m)	Modelled Depth (m)	Difference (m)	Comment
1	0.3 – 0.4	0.23	0.07 – 0.17	Some uncertainty with the reported depth for this event as the same depth was reported for the February 2010 event at this location.
2	0.3	-	-	Same comment as in **Table 6-2**.
17	2	1.3 – 1.5	0.5 – 0.7	Modelled depths of 1.3 – 1.5m in the creek. Reported depth likely to have been estimated of the creek from a distance. Considered to be a satisfactory fit.
18	0.2	0.14	-0.06	
19	0.15	0.10	-0.05	

7. Estimation of Design Floods

7.1 Hydraulic Model Parameters for Design Events

7.1.1 Blockages

The catchment was considered to have a high potential for blockage of hydraulic structures due to widespread dense vegetation, steep slopes and the presence of large floatable objects in the yards of private residences within or alongside main flow paths. Objects such as cars, rubbish bins and children's play equipment were observed during the site inspection which could act as flood debris (refer **Plate 7-1**).

The design events were run with consideration of the partial blockages described above, in addition to an all-clear scenario, in accordance with the guidance in *Australian Rainfall and Runoff Revision Projects – Project 11 Blockage of Hydraulic Structures* (Engineers Australia, 2012). Partial blockage factors were applied at stormwater pit inlets, culvert inlets and bridges and are summarised below:

- Sag pits: for the typical combination kerb inlet slot/grated inlet pits, assume full blockage of the grate and zero blockage of the slot.
- On-grade pits: for the typical combination kerb inlet slot/grated inlet pits, assume 10% blockage of the combined slot inlet and grate.
- Surface grate inlets: for the typical flush-mounted surface grates, assume 80% blockage of the grate.
- Culverts: 20% blockage for inlet height <3m or width <5m (typical dimensions);
- Lady Game Drive Bridge was treated as a culvert with inlet height >3m or width >5m as it is a single open span with no piers. A blockage factor of 10% was applied.

Worst-case flooding occurs under either the partial blockage or the all-clear scenario at different locations in the catchment. An envelope of the maximum flood parameter values (level, depth, velocity etc.) was derived from the results of each scenario run. Differences in peak flood level of up to 0.3m were observed between the two scenarios in the 1% AEP design runs.

7.1.2 Tailwater Conditions

Concurrent flooding is assumed not to occur in the Lane Cove River, allowing Blackbutt Creek to discharge freely. A normal depth condition has been assumed at the downstream boundary. Given the steep terrain of the Blackbutt Creek valley and that existing development is located at least 15m higher than the Creek near its outlet, the flooding conditions on private properties is not considered to be sensitive to this assumed tailwater condition.

7.1.3 Initial Water Levels

Honeysuckle Creek Dam storage is assumed to be near full capacity, with an initial water level of 73m AHD and approximately 0.3m from spilling. The remainder of the catchment is assumed to be dry at the start of the design storm runs.

Plate 7-1 Typical yard adjoining watercourse in Blackbutt Creek catchment. Note the heavy vegetation and children's' play equipment which may cause blockage of nearby culvert during flood event.

7.2 Simulated Design Events

The storm events modelled include the 20%, 5%, 2%, 1% and 0.5% AEP and PMF events. The storm durations assessed include the 15, 25, 60, 90 and 120 minute duration for the 20% to 0.5% AEP events, and the 15, 30, 45, 60 and 90 minute durations for the PMF event.

8. Results Mapping and Analysis

8.1 Foreword on the Flood Mapping

The maximum envelope of flood behaviour parameters (depth, level, velocity, velocity x depth, flood hazard) was derived for each event AEP, considering the maximum values over each combination of storm event duration and design blockage scenarios.

By nature, overland flood modelling using two-dimensional hydraulic models often produce results which display large areas of shallow sheet flow which are of minor significance to the flood study objectives. Areas of greater flow and depth which pose a risk to people and property are of greater concern. Post-processing of the raw model 2D results is therefore undertaken to remove the shallow sheet flow areas from the data set, retaining the main areas of flow.

Several filters were applied to the 2D model results on the flood mapping, based on thresholds on depth, flow velocity and depth-velocity product. These are described in **Table 8-1**.

Table 8-1 Flood Mapping Filters

Criteria	Comment
• Depth ≥ 0.3m	Includes areas of significant flooding depths.
• Depth ≥ 0.1m AND Velocity x Depth > 0.1m^2/s	Includes areas with depth 0.1 – 0.3m but only with some flow component.
• Depth ≥ 0.05m AND Velocity x Depth > 0.025m^2/s	Includes areas of shallower flow between areas of more significant flow. These areas have been included on the mapping to illustrate continuity of flow paths.

Further manual trimming of the flow spatial extents was then undertaken to remove broad, shallow sheet flow areas and isolated ponding areas located away from the flow paths. This has been conducted for all events mapped.

Note that the floodplain within the study area is depicted as being the area below Council's most upstream stormwater pits in the catchments. Local drainage issues may still occur in the areas above the most upstream pits, which have not been assessed in this study.

8.2 Flood Depth and Flood Level Mapping

Flood depth mapping is presented in **Appendix C** for the 20%, 5%, 2%, 1% and 0.5% AEP events and the PMF event.

Flood level mapping is presented in **Appendix D** for the 5% and 1% AEP events and the PMF event.

8.3 Summary of Peak Flows

Peak overland, piped and total flows are tabulated and mapped for selected locations in **Appendix E** for each storm AEP and for both the all clear and partial pipe/structure blockage scenarios.

8.4 Hydraulic Categories Mapping

The three flood hydraulic categories identified in the *Floodplain Development Manual* (NSW Government, 2005) are:

- Floodway, where the main body of flow occurs and blockage could cause redirection of flows. Generally characterised by relatively high flow rates; depths and velocities;
- Flood storage, characterised by deep areas of floodwater and low flow velocities. Floodplain filling of these areas can cause adverse impacts to flood levels in adjacent areas; and
- Flood fringe, areas of the floodplain characterised by shallow flows at low velocity.

There is no firm guidance on hydraulic parameter values for defining these hydraulic categories, and appropriate parameter values may differ from catchment to catchment. For example, the minimum threshold flows and depths which might define a floodway in an urban overland flow catchment may be markedly lower than those for a large lowland river due to the different scale of flooding.

Various combinations of flow, depth and velocity were trialled for appropriate threshold values for the hydraulic categories. For the purposes of this study, the hydraulic categories were defined as per the criteria in **Table 8-2**.

Table 8-2 Hydraulic Categories Criteria

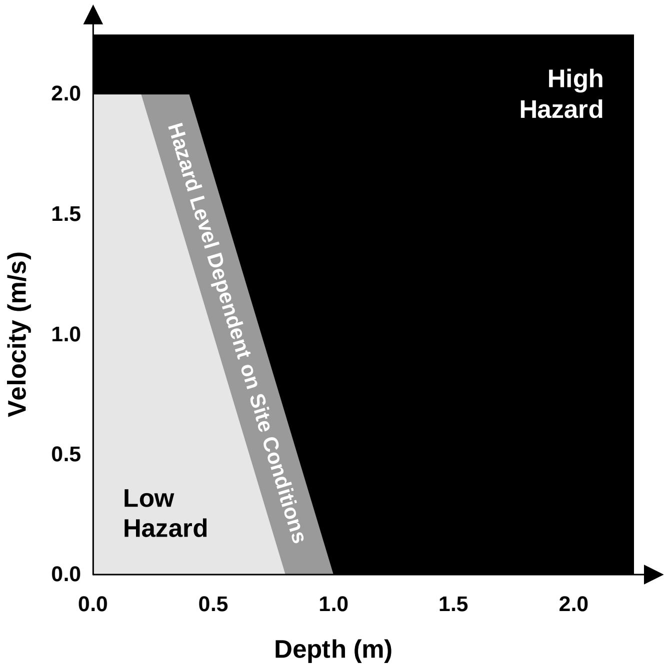
Hydraulic Category	Criteria
Floodway	Area within 1% AEP flood extent where: • Velocity x Depth > $0.3m^2/s$ AND • Velocity > 0.5m/s AND • Depth > 0.15m
Flood Storage	Remaining area within 1% AEP flood extent where Depth > 0.15m
Flood Fringe	Remaining area in the floodplain (i.e. area within PMF extent) outside the Floodway and Flood Storage areas.

The hydraulic categories mapping is presented in **Appendix E** for the 20%, 5% and 1% AEP events and the PMF event.

8.5 Provisional Flood Hazard Mapping

The TUFLOW modelling results were used to delineate the preliminary flood hazard areas for the study area from interpretation of the 20%, 5%, 1% AEP and PMF event results, based on the hydraulic hazard category diagram presented in the *Floodplain Development Manual* (DECC, 2005), shown in **Figure 8-1**, and from discussion with Council. The TUFLOW model calculates the hazard rating at each cell and computational time step, rather than calculating the rating based on the peak depth and peak velocity.

Figure 8-1 Hydraulic Hazard Category Diagram (reproduced from Figure 6-1 in *NSW Floodplain Development Manual*)



Hazard categories delineated in this study are based on depths and velocities of floodwaters and do not consider evacuation, isolation, flood damages and social impacts of flooding, hence, these categories are considered provisional. The provisional flood hazard mapping is presented in **Appendix G**.

8.6 Flood Planning Area

The flood planning area is defined by the extent of the area below the flood planning level (usually the 1% AEP flood plus freeboard) and delineates the area and properties where flood planning controls are proposed, for example, minimum floor levels to ensure that there is sufficient freeboard of building habitable floor levels above the 1% AEP flood. Other controls may be considered, such as policies on fence construction or rezoning.

A freeboard of 0.5m is often selected for defining the flood planning level on mainstream floodplains, however, a reduced freeboard of 0.3m may be more appropriate in catchments affected by overland flows.

A review of the sensitivity test model results (refer to **Section 8.8**) indicates that the peak 1% AEP flood levels generally do not increase by more than 0.2m approximately, and hence would be accommodated by a 0.3m freeboard. However, there are two locations on Blackbutt Creek where flood level increases up to 0.45m would potentially occur, due to full blockage of culverts at Ryde Road and Minnamurra Place. This suggests that a 0.3m freeboard is appropriate for areas affected by overland flooding whilst a 0.5m freeboard should be applied for mainstream flooding areas (those along the main watercourses).

It was considered appropriate to delineate the flood planning area on the more significant flow paths and not on those with shallow flows which are unlikely to pose a risk to private property. These shallow flow paths are presented on other flood mapping to show continuity of flow paths through the catchment area.

The areas for delineation of the flood planning area were selected via the following steps:

1) Filter out areas with depth <150mm. Such shallow flow depths are unlikely to pose a risk.
2) Identify areas of isolated ponding <100m^2 for potentially filtering out.
3) If there are a number of small "ponds" almost connecting up then this indicates an active flow path and hence should be included (the ponds are to be joined up for the flood planning area).
4) Cross-check against the ground level contours. Gullies in the contours would indicate active flow paths.
5) A sanity check was undertaken of whether particular properties should/shouldn't have a flood planning level attached to it, considering the susceptibility or resilience of the property to flood damage, such as whether the existing dwelling is located in a low point.

The flood planning area mapping is provided in **Appendix H** and indicates the overland and mainstream flood planning areas where the 0.3m and 0.5m freeboard above 1% AEP flood level are recommended, respectively.

8.7 Preliminary Emergency Response Classification of Communities

Areas within the catchment have been classified based on the floodplain risk management guideline *Flood Emergency Response Planning – Classification of Communities* (DECC, 2007). The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community. The classification has been undertaken for the 20% and 1% AEP and PMF events, with mapping provided in **Appendix I**.

The categories identified included:

- Indirectly Affected: Areas which are not flood affected and whose access is not cut-off, but may be affected by flood impacts to services and infrastructure in the area.
- Rising Road Access: Areas that become inundated by flooding which can be evacuated by vehicles on roads with continuously rising grade to high ground.
- Overland Escape Route: Areas where vehicular access is cut-off but can be evacuated on foot to high ground.
- High Trapped Perimeter: Areas which are partially or wholly above the peak flood level but whose evacuation routes are cut-off. These areas are not surrounded by flood waters but there may be a physical barrier preventing evacuation overland.
- High Trapped Island: Areas which are above the peak flood level but surrounded by flood waters and whose evacuation routes are cut-off.
- Low Trapped Island: Areas which are surrounded by flood waters during early stages of the flood, and which become submerged as the flood peaks.

The guideline is largely geared towards classification of communities in mainstream floodplains with longer flooding response times, hence some assumptions were made to suit the shorter-duration flash flooding in the Blackbutt Creek catchment:

- Given the relatively shallow flows in the majority of overland flow paths which would not necessarily be hazardous, areas of high flood hazard were used to indicate where flooding may pose a risk to life and hence where evacuation would be required.
- Access routes were deemed to be cut-off if fully crossed by areas of high flood hazard. Roads with patchy high hazard areas were considered to be accessible by heavy vehicle or on foot on the road verge.

- Property boundary fences were assumed to be barriers to overland escape routes on foot as they may be too high for some members of the community to climb.
- Some properties are located in depressions in the terrain and their dwellings become surrounded by high hazard flooding. While there may be a rising road evacuation route available, due to the rapid rise in flood level, there may be insufficient warning time before the dwelling is surrounded by deep floodwaters and subsequently inundated. These areas were treated as **Low Level Islands** since there was no information available on habitable floor levels of these dwellings.
- Properties where the dwelling is surrounded by floodwaters but have some dry land adjoining the dwelling, were deemed to be **High Flood Islands**.
- Properties whose street frontage is fully blocked off by high flood hazard areas in the street but which were otherwise not affected by high flood hazard areas, were classed **High Trapped Perimeter**. Similarly, properties located on a cul-de-sac which is cut off by high flood hazard areas, were classed as High Trapper Perimeter.
- Properties with either vehicular or foot access to the street were classed **Indirectly Affected**.

8.8 Sensitivity Analysis

A number of scenarios have been assessed for the 1% AEP flood event to test the sensitivity of the model results to changes in the adopted parameter values. The scenarios are described and the impacts summarised in **Table 8-3**. The sensitivity runs consider both partially blocked and all clear blockage scenarios as per the design runs, with exception of the fully blocked sensitivity run.

The modelling indicates that peak flood levels are not overly sensitive to the varied rainfall loss and hydraulic roughness scenarios tested, with increases in 1% AEP flood levels typically less than 100mm in developed areas. However, some significant flood level increases of up to 450mm were observed for the fully blocked hydraulic structures scenario. Existing development would be impacted by these increases.

Flood conditions in the developed areas of the catchment were considered to be insensitive to tailwater levels in the Lane Cove River, given the large drop in elevation from the existing development to the Creek at the catchment outlet. Hence, an elevated tailwater condition scenario was not assessed in the hydraulic model.

8.9 Impact of Climate Change on Flooding

The impact of climate change on flooding in the study area has been assessed for increases in 1% AEP storm rainfall intensity of 10%, 20% and 30%. The DRAINS model was rerun with the increased rainfall intensities, and the resulting sub-catchment hydrographs input into the TUFLOW model.

The climate change impacts on flood depths are mapped in **Appendix J** at the study area scale, and summarised in **Table 8-4**. Existing development would be affected by increases in peak flood levels in overland flow paths of up to 0.2m in the 30% rainfall intensity increase scenario. Development along watercourses would be affected by increases of up to 0.3m.

The Lane Cove River at the Blackbutt Creek outlet is not tidal and is located upstream of the weir at Lane Cove National Park, and hence is not affected by sea level rise projections to the year 2100.

Table 8-3 Sensitivity Analysis Description and Results

Scenario	Description	Change in Flood Level[1]
Rainfall losses – increase	Updated DRAINS hydrology - adopt AMC[2] of 2 and double the depression storage (2mm for paved areas; 10mm for grassed areas)	• Typically zero change in areas of shallow sheet flow. • Up to 40mm decrease in most minor flow paths through existing development. • Up to 80mm decrease in some flow paths and storages in developed areas (e.g. Calvert Ave). • Decreases in the main branch of Blackbutt Creek ranging from 100mm upstream of Ryde Road to 350mm at Lady Game Drive.
Rainfall losses – decrease	Updated DRAINS hydrology - adopt AMC of 4 and 0mm in the depression storage	• Typically zero change in areas of shallow sheet flow. • Up to 40mm change in most minor flow paths through existing development. Some isolated increases of up to 70mm. • Changes in the main branch of Blackbutt Creek ranging from 50mm upstream of Ryde Road to 150mm at Lady Game Drive. Up to 300mm increase in isolated locations downstream of Lady Game Drive.
Friction	Increase Manning's n in TUFLOW 2D domain by 20%	• Typically zero change in areas of shallow sheet flow. • Up to 40mm change in most minor flow paths through existing development. Some isolated increases of up to 50mm. • Decreases of up to 100mm at some storages (e.g. Ryde Road crossing, Lady Game Drive crossing). • Up to 150mm increase in flood levels in main Blackbutt Creek channel.
Blockage	Full blockage at culverts, bridges and pits in TUFLOW	Increases in flood levels at selected locations include: • Rand Ave/Pymble Ave: 170mm increase • Livingstone Ave: 180mm increase • Ryde Road/Nadene Pl: 400mm increase • Minnamurra Pl: 450mm increase • Lower end Dumaresq St: 150mm increase • Vale St: 250mm increase • Calvert Ave south: 120mm increase • Bowes Ave: 140mm increase.

1 Comparison of sensitivity case to design case peak flood level in 1% AEP event.

2 Antecedent Moisture Condition.

Table 8-4 Climate Change Impact Summary

Increase in Rainfall Intensity[1]	Typical Increase in Flood Depth[2]			
	Overland Flow Paths	Watercourses	In Main Storages	At Catchment Outlet
10%	Typically up to 0.05m, some locations up to 0.1m	0.1 – 0.2m	Up to 0.06m in Vale St Up to 0.05m in Calvert Ave No change in Honeysuckle Creek Dam	0.3m
20%	Up to 0.1m, some locations up to 0.2m	0.1 – 0.4m [3]	Up to 0.11m in Vale St Up to 0.10 in Calvert Ave No change in Honeysuckle Creek Dam	0.5m
30%	Up to 0.1m, some locations exceeding 0.2m	0.1 – 0.5m [3]	Up to 0.16m in Vale St Up to 0.14 in Calvert Ave No change in Honeysuckle Creek Dam	0.8m

1 Increase from 1% AEP design rainfall intensity.

2 Change from existing conditions.

3 Flood level increases limited to 0.3m adjacent to developed areas.

9. Conclusions

The existing DRAINS hydrologic model has been updated to reflect current catchment development conditions in the Blackbutt Creek catchment and run to output inflow hydrographs at numerous locations in the catchment. A two-dimensional, unsteady flow TUFLOW hydraulic model has also been developed, with the model assumptions and adopted parameter values documented in this report.

The models have been calibrated to the February 2010 and April 2012 flood events, which were the most significant flood events in recent times in the study area. There is some uncertainty about the actual depths and locations of the reported flood observations, since these observations by local residents were anecdotal in nature. Nevertheless, the calibrated DRAINS and TUFLOW models presents flood behaviour which is reasonably consistent with the reported observations to the precision offered by the available calibration data.

Design flood events between the 20% AEP event up to the PMF event, for a range of event durations up to 2 hours have been simulated. Flood mapping of depth, flood level, flood hydraulic categories and provisional flood hazard has been undertaken for selected event AEPs.

The flood planning area mapping has been conducted for areas deemed to be affected by active flows in the 1% AEP event. This has been determined by consideration of flooding depth, continuity of the mapped flood inundation, presence of incised gullies in the flow path terrain and susceptibility of existing development.

Properties within the study area were classified for flood emergency response based on NSW Government floodplain risk management guidelines. The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community.

Sensitivity testing indicates that peak flood levels are not overly sensitive to the varied rainfall loss and hydraulic roughness scenarios tested, with increases in 1% AEP flood levels typically less than 100mm in developed areas. However, some significant flood level increases of up to 450mm were observed for the fully blocked hydraulic structures scenario. Existing development would be impacted by these increases.

Climate change impact modelling indicates that existing development would be affected by increases in peak flood levels in overland flow paths of up to 0.2m in the 30% rainfall intensity increase scenario. Development along watercourses would be affected by increases of up to 0.3m, while undeveloped areas along watercourses would experience up to a 0.5m increase in flooding.

Appendix A. Community Questionnaire Response Summary

File Note

Date	7 August 2013
Project No	EN04175
Subject	Blackbutt Creek Flood Study - Community Questionnaire summary of responses

1.1 Purpose

A questionnaire was distributed to residents and businesses within the study area in order to understand the community's experience of flooding and identify areas that are flood-prone. This file note provides an analysis on the responses provided by the community on the questionnaire.

1.2 Distribution of Questionnaire

A letter and a questionnaire were distributed to properties by post in June 2013. In total 4910 questionnaires were distributed to residents by Council, with 364 responses received by Council by 30th July 2013. The responses have been counted for each question in the questionnaire, in **Table 1**. Some of the questionnaires were not filled in completely and hence the number of responses to each question may not equal the number of questionnaires returned.

A spreadsheet data base has been created to log the full details in each response.

A total of 70 responses were provided with an observed depth of flooding during previous storm events. Forty-four responses were of a flood depth exceeding 0.1m, excluding two reports of flooding in apartment car parks at the top of the catchment, and an additional 3 responses reported a depth of flooding inside the house or garage. These observations will be mapped for model verification.

Table 1: Summary of Questionnaire Responses

Question		Question and Answer
1.		**Do you own or rent your residence in the study area?**
	☐	Own (340)
	☐	Rent (12)
	☐	How long have you lived in the study area? (Please write number of years.)……….
2.		**Do you own or manage a business in the study area?**
	☐	Yes (31), For how many years? ………………
	☐	No (307)
3.		**What kind of business?**

Question		Question and Answer
	☐	Home based business (16)
	☐	Shop/commercial premises (8)
	☐	Others, please write type of business ………………………
4.		**Have you ever experienced any flooding in the area?**
	☐	Yes (42)
	☐	**No** (197)
		If so, which floods (recorded high rainfall events)
	☐	18th April 2012 (20)
	☐	February 2011 (14)
	☐	6th February 2010 (22)
	☐	16 June 2007 (10)
	☐	Other (10) ……………………………………………………
5.		**How deep was the floodwater in the worst flood that you experienced?**
		Please estimate the depth (70 responses, from 1cm to 1-2m) ……………………..
		Did floodwaters enter your (tick multiple boxes if needed):
	☐	House? (36)
	☐	Garage? (51)
	☐	Yard/garden? (14)
	☐	Other…………………………………………
		What year was the flood? ……………………..
		Can you please describe the location that you saw flooding? For example, front or back of property, street address. An accurate location of your observation is needed to calibrate the flood model.

Question		Question and Answer
6.	☐ ☐ ☐	**How long did the floodwaters stay up?** Few minutes (9) Less than one hour (18) More than one hour (47) Estimated time of day? ………………………………..
7.	☐ ☐ ☐ ☐ ☐	**Do you have any information on flooding on your property?** (You can tick more than one box). Please write any descriptions at the end of the questionnaire (a) No information (156) (b) Own experience (71) (c) Information from Council (2) (d) Photographs (9) (e) Other …………………………………………………..
8.	☐ ☐ ☐	**Was vehicle access to/from your property via local roads disrupted due to floodwaters during the worst flooding?** Not affected (184) Minor disruption (roads flooded but still driveable) (25) Access cut off (2)
9.		**Do you wish to comment on any other issues associated with the development of the Flood Study? Please add comments at the back of the questionnaire.**

Question		Question and Answer
10.		**Do you wish to remain on the mailing list for further details, Newsletters etc?**
	☐	Yes (please provide contact details, see next question) (177)
	☐	No (98)
		Additional comments (180)

A summary of the questionnaire responses reporting significant (>100mm) depths of overland and mainstream flooding are provided in **Table 2 overleaf**.

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Appendix B. Community Flood Study Information Forum – Summary of Proceedings