A part of BMT in Energy and Environment

Throsby, Cottage and CBD

Flood Study

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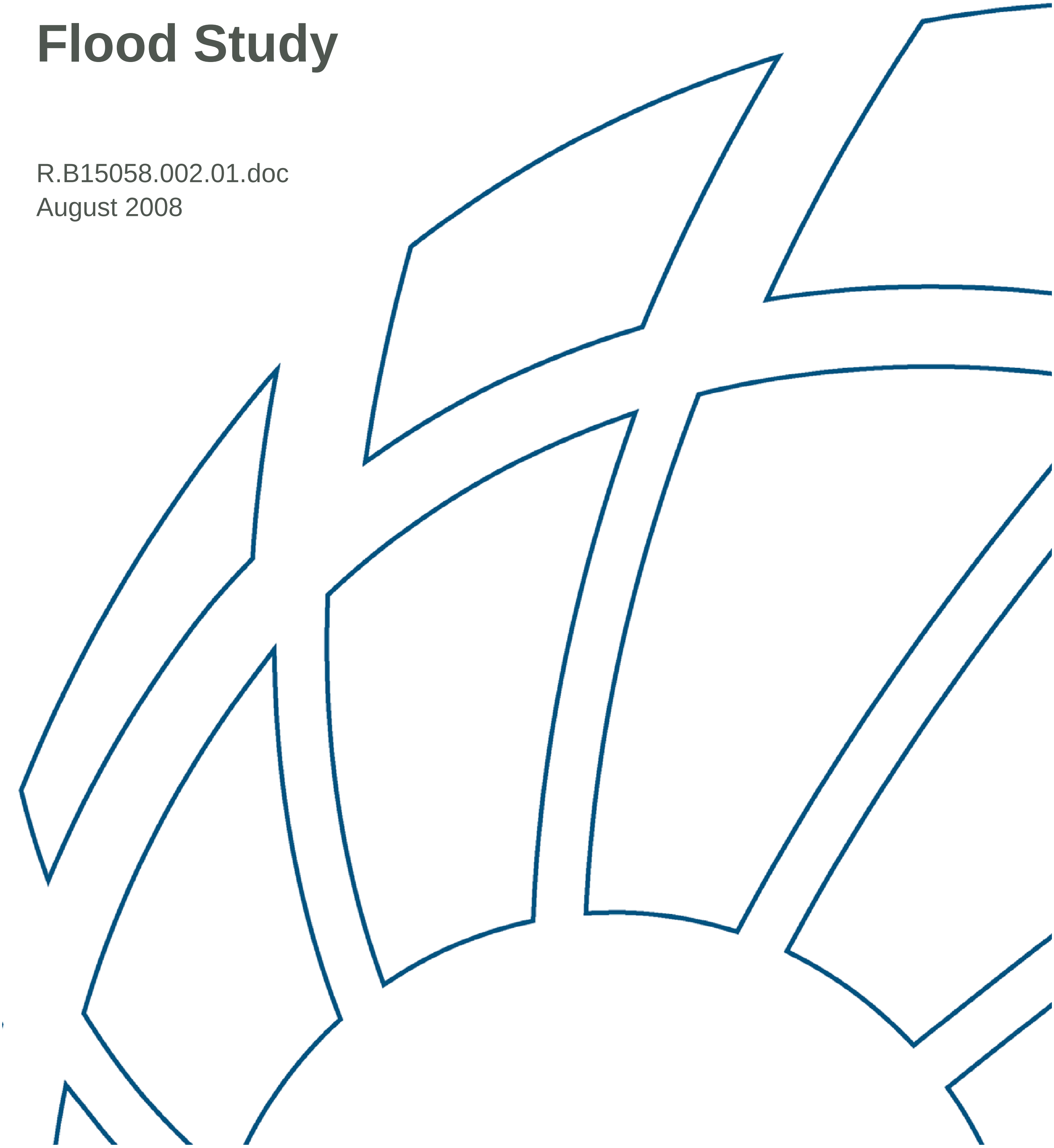

Throsby, Cottage and CBD Flood Study

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1 INTRODUCTION

1.1 Background

Throsby and Cottage Creeks, and to a lesser extent the Newcastle CBD, have an established history of flooding. The catchments are steep around their perimeter, but drain onto low-lying, flat areas, where it is difficult for floodwaters to escape. In response to the flooding problems, the creeks have been heavily engineered into concrete lined stormwater channels, or replaced by underground pipes and box culverts. In a number of areas, the creek lines have become non-existent, with the pipes and culverts being relied upon to carry the floodwaters. Roads also act as flowpaths once the capacity of the channels and culverts is exceeded. A number of rail, road and other embankments exacerbate the flood problem by diverting and blocking floodwaters.

While the engineering works have reduced the flood risk, problem areas remain and it is not unfeasible for floods to exceed the capacity of the channels and culverts, with the potential for wide-spread flooding, risk to life-and-limb and damage to buildings and infrastructure. This was demonstrated during the April 1988, February 1990 and June 2007 floods.

This Flood Study of Throsby and Cottage Creeks, and the Newcastle CBD area, was carried out to better understand the flood behaviour and the flood risk to the community. A product of the study is leading-edge computer based models that simulate the flooding processes of the whole catchment, and also the potential interaction between catchments in the low-lying areas, hence the combining of the three catchments into one study. The study is carried out in preparation for a Flood Risk Management Study that will investigate options and planning strategies for reducing the flood risk and minimising damage to buildings and infrastructure. Drawing 1-1 shows the locality and coverage of the study area.

The computer models were developed to quantify flood discharges, the speed of floodwaters, flood heights and the flood depths. As part of their development process, the models were calibrated to historical flood events, to demonstrate their ability to reproduce reality. Calibrated computer models were used with statistically generated rainfall estimates to represent possible future flood scenarios and their likelihoods (such as a 1 in 100 annual chance flood). These design flood events were simulated and mapped.

On the Queens Birthday long weekend in 2007 the Newcastle district experienced a devastating flood. Heavy rainfall was experienced on the afternoon and evening of the 8/6/2007. This resulted in severe flooding within the Newcastle area, including the Throsby, Cottage and CBD catchments. This flood occurred towards the end of the study, after the computer models had been calibrated and design flood modelling completed.

After the 2007 flood a major data collection exercise was conducted by Newcastle City Council and BMT WBM staff, providing the opportunity for further validation of the computer models. Due to the near completion status of this study, it was decided to incorporate the June 207 flood validation of the models into the early stages of the flood risk management investigations rather than this present study.

A Flood Risk Management Study is scheduled to start in 2008. This risk management study will investigate measures to reduce the flood risk. Possible measures vary from community education to building modifications to voluntary house raising and voluntary purchase schemes. The computer models will be verified to the data collected from the June 2007 flood events as part of the study.

The sensitivity of model results to a number of factors such as blockages to pipes and structures, increased rainfalls, structure losses and roughness will also be investigated as part of the floodplain risk management study.

1.2 Funding

This study is being carried out under the State Government's flood programme, with State and Commonwealth Grant assistance for flood investigations and implementation of flood risk management measures. To receive implementation funding, the State Government requires councils to carry out the necessary studies so that informed decisions are made in consultation with the community.

1.3 Previous Studies

A number of investigations have addressed the issues of flooding in the catchment and/or elevated ocean levels. Studies relevant to the current flood study are:

- Lawson and Treloar (1994), *Lower hunter River Flood Study (Green Rocks to Newcastle)*
- Newcastle City Council (1997), *Brief: Cottage Creek Flood Study*
- Newcastle City Council (1997), *Brief: Newcastle City Wide – Historic Flood Date Collection Study*
- Newcastle City Council (1997), *Brief: Newcastle City Wide – Design of Flood Data Collection System*
- Lawson and Treloar (1999), *Design Water Levels in Newcastle Harbour – Joint Probability Study*
- Lawson and Treloar (2000), *Design of a City-Wide Flood Data Collection System*
- WBM Oceanics Australia (2000), *Newcastle City Wide Flood Studies – Data Collection Study*
- WBM Oceanics Australia (2004), *Cottage Creek Flood Study – Final Report*

1.4 About This Report

This report documents the Throsby, Cottage and CBD Flood Study objectives, results and conclusions. All A3 drawings are included in a separate volume. The report consists of the following sections:

Volume 1 of 2: Main Body of Report

1 Introduction

Introduces the background of the study.

2 Methodology Overview

Presents a general discussion on the study methodology.

3 Available Data

Details of the topographic, hydrographic and GIS data available for the flood study.

4 Computer Model Development

Details the hydrologic and hydraulic models developed for the flood study.

5 Model Calibration

Discusses the calibration of the hydrologic and hydraulic models.

6 Design Floods

Presents the derivation of design floods and discusses design flood results.

7 Conclusions and Recommendations

Presents the general conclusions and recommendations of the study.

8 References

Reference list

Volume 2 of 2: A3 Drawing Addendum

Volume 2 is an addendum of A3 drawings which accompanies this report.

1.5 Provision of Electronic Data

Hydraulic modelling results have been provided to Newcastle City Council in WaterRIDE format. Both time-varying and peak results have been provided.

Modelling files in MapInfo and TUFLOW format are provided on DVD to accompany this report.

Newcastle City Council has been provided with a location specific version of TUFLOW. This allows Newcastle City Council to use the hydraulic model, developed as part of the Throsby, Cottage and CBD Flood Study.

2 METHODOLOGY OVERVIEW

The general approach and method employed to achieve the study objectives involved the following steps (as shown in Figure 2-1).

- Compilation and review of available information
- Acquisition of additional data required for flood study
- Development of hydrological and hydraulic models
- Calibration and verification of models
- Selection of design event combinations
- Modelling of design events under existing conditions
- Reporting and mapping

Selection of calibration events was based on the availability of historic rainfall, river and flood level data. This is discussed in more detail in Section 5.1.

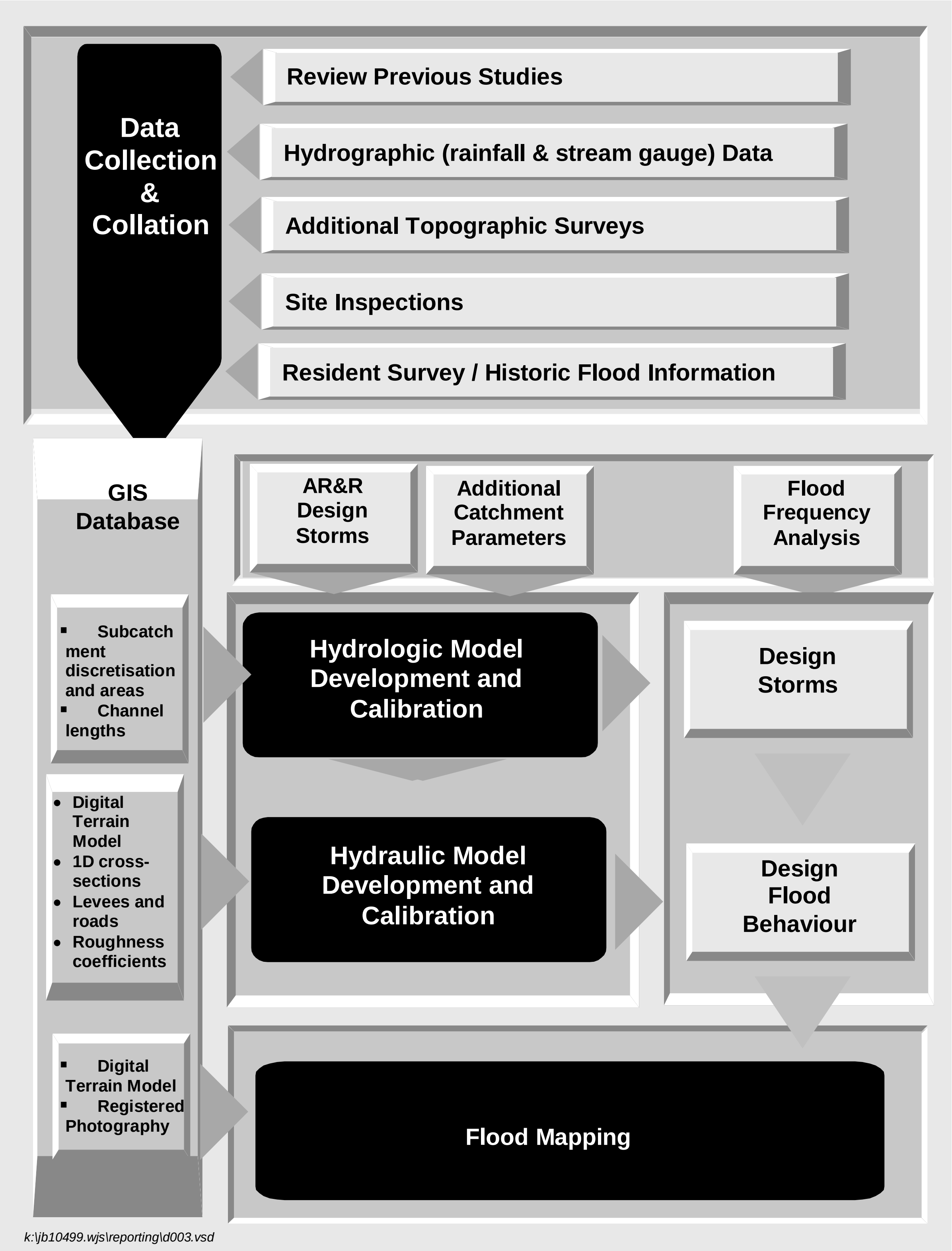

Figure 2-1 Study Approach

3 AVAILABLE DATA

3.1 Topographic Data

This section of the report details the topographical, hydrographic and GIS data used as part of the flood study.

3.1.1 Photogrammetry

Photogrammetry was collected by QASCO in 2000. It covers the majority of the study area and has a vertical accuracy ±0.2m.

2004 photogrammetry is of lower vertical accuracy (higher plane flying level) than 2000 photogrammetry. The vertical accuracy of the 2004 photogrammetry is ± 0.5m.

The photogrammetry extents are presented in Drawing 3-1.

3.1.2 Bathymetry

Current bathymetric survey of the tidal areas was provided by Newcastle Port Corporation. The data was provided as points with easting, northing and levels, and is a compilation of surveys over various years.

3.1.3 Ground Surveys

A number of different surveys using ground based techniques were utilised to supplement the DEM data due to civil works since 2000, where an improved vertical accuracy was beneficial (eg. along the creeks and concrete lined drains) or the aerial survey was inadequate (eg. through the Kotara shopping centre carpark). Ground survey is used in both the calibration and design modelling. Details of ground survey used in modelling are presented in Table 3-1 and their locations are presented in Drawing 3-1.

Table 3-1 Ground Survey Details

Area	Year	Source
Stewart Avenue	2005	NCC
Linwood St	2005	NCC
Carrington	2005	NCC
Honeysuckle	2005	NCC
Wickham	2005	NCC
Kotara	2005	NCC
Waratah Rail	2005	NCC
Glebe Road	2005	NCC
Kotara	1998	NCC
Maryville Pre Subdivision	1990	NCC
Broadmeadow Soccer Fields	1990	NCC

I:\B15058_I_BRH_ Throsby Cottage_WJS\MPI\[Topography_Sources_TUFLOW.xls]Ground_Survey

3.1.4 Structure Data

Structure details were provided by Newcastle City Council. These included a comprehensive database of photographs, each annotated with field measurements of the structure's openings, deck and handrails. Examples of the structure details are provided in Figure 3-1. Drawing 3-3 illustrates the location of the structures measured and photographed.

3.2 Hydrographic Data

3.2.1 Rainfall

Historic rainfall data was primarily obtained from data collected by Hunter Water Corporation (HWC) during the 1980s and early 1990s. In addition to these data, Bureau of Meteorology data was available from the Nobby's Head gauge. Locations of rainfall pluviograph data are presented in Drawing 3-3.

For design flood events, the estimated rainfall volumes and distribution were based on Australian Rainfall and Runoff, 1987.

3.2.2 Streamflow Gauging

HWC also operated a number of stream gauging stations during the same period as the rainfall monitoring. This data was also extracted from data collected by Hunter Water Corporation. The locations of the stream flow gauges are presented in Drawing 3-3.

3.2.3 Tidal

Recorded tidal data was available from a tidal gauge at Dyke Point in Throsby Basin. This gauge data is provided by the National Tidal Facility. Recordings are taken on an hourly basis.

3.3 GIS Data

3.3.1 Aerial Photos

Three aerial photo sets were available. These are all geographically registered.

- 1983 aerial photography
- 1990 aerial photography
- 2004 aerial photography

The 1990 aerial photography is presented in Drawing 3-4, and the 2004 photography in Drawing 3-5.

3.3.2 Cadastre

Newcastle City Council provided cadastral data to BMT WBM in GIS format (MapInfo). Newcastle City Council also provided GIS format data of suburb boundaries, street names and house numbers.

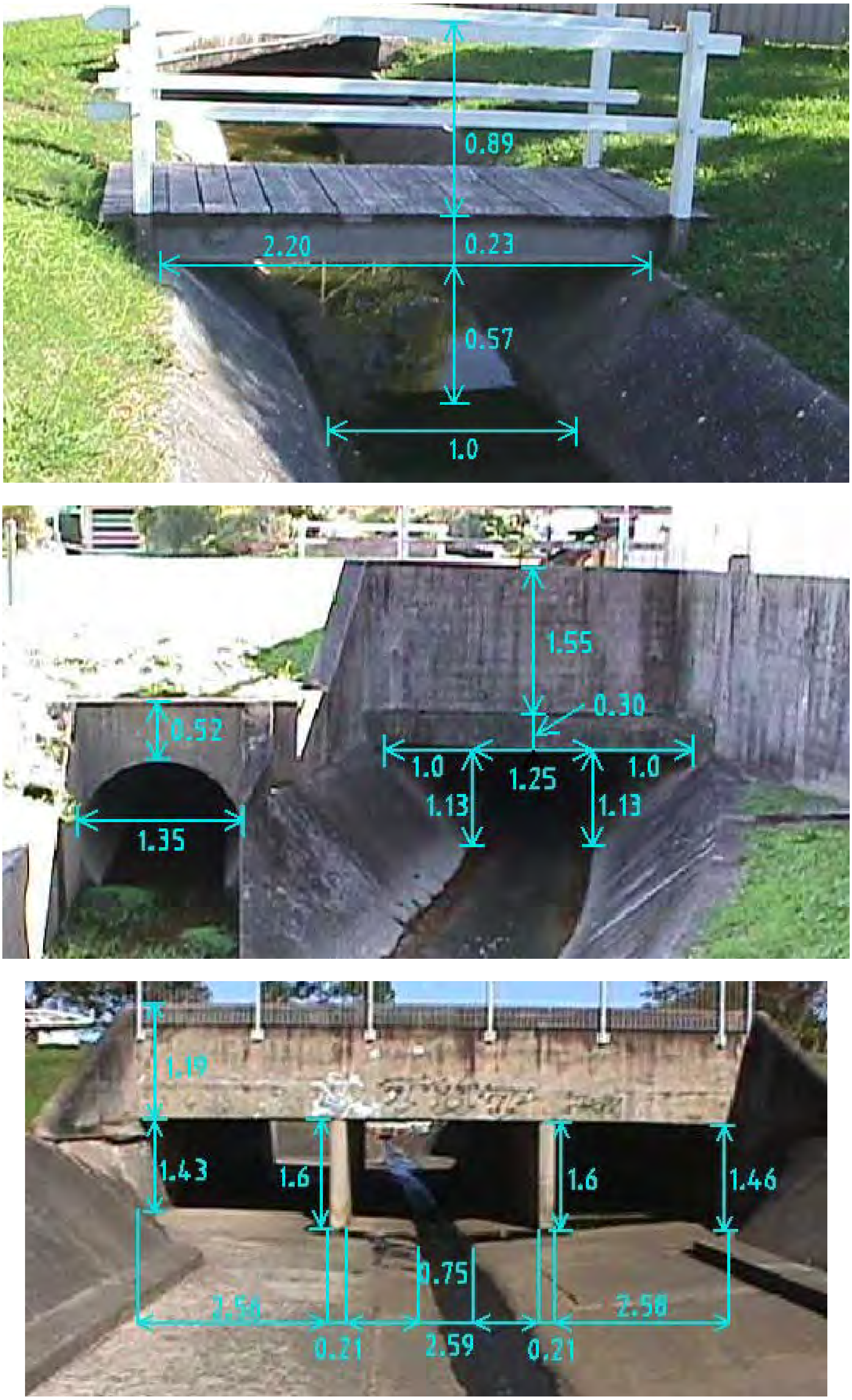

Figure 3-1 Example Structure Details

4 COMPUTER MODEL DEVELOPMENT

4.1 DEMs

A digital elevation model (DEM) is a three dimensional (3D) representation of the ground surface. A number of different DEMs were utilised in the current flood study. These were derived from various topographical data sources and have varying accuracies. The DEMs utilised in the Throsby, Cottage and CBD flood study are listed and described below.

4.1.1 DEM 2000

The DEM of conditions in the year 2000 was prepared by WBM for the purpose of this flood study. The DEM is based on various data sources including low level (higher accuracy) photogrammetry, ground survey and bathymetry. Of note is the use of ground survey to accurately define concrete lined drains using surveyed breaklines along the channel (eg. top of bank, toe, low flow drains). The ground surveys were merged with the photogrammetry to produce a high quality DEM. It was decided that the DEM should include bridge decks and other obstructions picked up by the aerial survey so as to aid in identifying evacuation routes, rather than replace the decks with the ground surveys.

This is the most accurate representation of the topography of the Throsby, Cottage and CBD catchments. The DEM of 2000 conditions is presented in Drawing 4-1.

For more information on this DEM see Appendix A.

4.1.2 DEM Modified for hydrology

An automated process of delineating the sub-catchments for the hydrologic was used. This process required that the DEM did not include obstructions across flow paths, such as bridge decks, and that major culverts (eg. the 1.6km racecourse culvert) be incised so as to delineate the low flow paths. Therefore, the DEM was artificially incised to create low flow paths, allowing automated delineation of these low flow routes and sub-catchments emanating from them.

The 2000 DEM also does not cover the whole of the Throsby, Cottage and CBD catchments. This is also necessary for sub-catchment delineation, so the 2000 DEM was extended to the catchment boundaries using a DEM created from 2m contour data.

The catchment delineation process is further described in Section 4.2.1. The modified DEM used for sub-catchment delineation is presented in Drawing 4-2.

4.1.3 DEM 2004

This DEM was created from the photogrammetry flown in 2004. This photogrammetry is of lower vertical accuracy than the 2000 photogrammetry, hence, the 2000 DEM is preferred for flood modelling. A section of this DEM was used in Hamilton South, where major changes have occurred to the topography between 2000 and 2004 due to a residential estate that was previously a dog racing track.

4.2 WBNM Hydrologic Model

Hydrologic modelling calculates the quantity and rate of catchment runoff from rainfall during a flood event. The model produces estimates of the discharges in the creeks and tributaries during the course of a flood. The Watershed Bounded Network Model (WBNM) software was utilised for the hydrological modelling. WBNM is distributed by the University of Wollongong.

WBNM requires input for each subcatchment of:

- Catchment area
- Percentage impervious

Calibration parameters within the WBNM model are:

- Initial loss
- Continuing loss
- Stream Lag Factor

4.2.1 Sub-Catchment Delineation

The hydrological model was split into 198 subcatchments. The sub-catchments are delineated using an automated process. The software package Streambuilder (Avantra Geosystems Pty Ltd) was used for the catchment delineation. A modified version of the DEM of 2000 conditions was used for the catchment delineation. Section 4.1.2 describes the modifications the 2000 DEM for hydrological modelling.

The modified DEM and catchment delineation are presented in Drawing 4-2.

4.2.2 Land-Use Types

Land use types were digitised from aerial photos, and a percentage impervious for each land use type was assigned. The average percentage impervious for each subcatchment was based on field inspections and the aerial photography. Percentage impervious is used as an input to the WBNM model.

4.3 TUFLOW Hydraulic Model

4.3.1 Model Extent

The complicated nature of flow patterns in the urban study area required the use of advanced modelling techniques and software. During low flows, stormwater is mostly restricted to the underground piped drainage and concrete lined drains, and is relatively simple to model. However, once the capacity of these conduits are exceeded, as amply demonstrated in April 1988, February 1990 and June 2007, the flow patterns become highly complex with flow into and out of drains, surcharging of manholes, along streets, and through houses, gardens and commercial properties. This requires a more advanced modelling approach to simulate the flow interaction between pipes, open channels and overland areas. As such, TUFLOW (www.tuflow.com), a fully 2D/1D dynamically linked hydraulic modelling system was used to model flooding behaviour in the Throsby/Cottage Creek catchments.

Pipes smaller than 900mm in diameter were generally excluded from the model to keep the model simulation times manageable and pipe survey costs within budget. Similarly, broad assumptions on gully traps and manholes were assumed as data on these were not available. This does not significantly reduce the accuracy of the hydraulic model for the study objectives, because in large flood events the majority of flow is carried in overland areas, open channels or larger conduits. It is noted however, that for detailed local drainage assessments into the future, that the sub-900mm pipe drainage and surface/pipe flow exchange via gully-traps may need to be added to the model for a more accurate representation.

The hydraulic model covers an extent of 28.2km^2. The extent of hydraulic modelling is shown in Drawing 4-3.

There may be areas subject to flooding that are outside the extent of the hydraulic modelling. This may occur for a variety of reasons, including:

- The area is outside the extent of the 2000 photogrammetry.
- Pipe sizes less than 900mm need to be included.
- Broad assumptions associated with gully traps.
- Blockages in drains and culverts due to debris and other obstructions.
- Vertical inaccuracies associated with DEM data.
- Uncertainties associated with data inputs, modelling and rainfall estimates.

4.3.2 2D Grid Dimensions and Cell Size

The 2D domain of the hydraulic model is based on a 10m square grid. This results in approximately 280,000 2D cells over the hydraulic model. Approximately 195,000 2D cells are active or wet near the peak of a large flood (PMF).

4.3.3 Topography in Hydraulic Model

TUFLOW allows topographic data to be inputted sequentially. This facilitates changes to be made easily, for example, ground survey data can be inputted to overwrite the DEM data. This is particularly useful to model changes in the floodplain, where development has occurred after the photogrammetry.

The base data for the hydraulic model is the DEM of 2000 conditions. Changes are made to this topography to represent the calibration (1988/1990) and existing (2005) conditions. Topographic changes for the calibration and design are discussed in Section 5.2.1 and 6.1 respectively.

4.3.4 1D Domains

The 10m cell size of the 2D model is too coarse to accurately model some sections of the drainage network, particularly the open drains. These and the underground pipe drainage network are modelled as 1D elements. Cross-sections were used to define the geometry of the open channel 1D elements, and measured dimensions of bridges, culverts and pipes were used for 1D hydraulic structure elements. The model includes over 2,000 1D elements. The three main types of 1D elements are described below.

4.3.4.1 Open Stormwater Channels

Open stormwater channels are modelled as 1D elements. The geometry of these open channels is defined by assigning a cross-section to each channel. Bed resistance is varied across the section based on land-use mapping to allow for changes in construction type and vegetation to be represented.

The DEM of the open channels is based on ground survey break lines along the channels at key points in the section. The survey, which consists of break-lines along the top of bank, toe of batter, low flow channels, etc, was built into the 2000 DEM, and is sufficiently detailed to allow cross-sections to be extracted from the DEM.

4.3.4.2 Underground Conduits

Underground conduits of greater than 900mm in size were included in the hydraulic model based on surveys carried out by Newcastle City Council. Details required for accurate representation include:

- Size
- Shape
- Inverts
- Number of barrels

The underground pipe network is connected to the surface via pits, which are modelled as an upright rectangular channel. The pit inlet is dynamically connected to the 2D model, see Section 4.3.5.

4.3.4.3 Bridges, Culverts and Weirs

The many structures play a major role in determining flood behaviour in the study area. It is important to represent these structures correctly in the hydraulic model. These structures were typically modelled as 1D elements.

Bridges are modelled using depth varying energy losses to simulate extra losses associated with piers and the bridge deck. Losses were calculated using the standard techniques outlined in AustRoads (1994).

Culverts can be either rectangular or circular in shape, and can accommodate all inlet and outlet controlled flow regimes including uni-directional flow due to flap-gates.

Flow over structures are modelled as 1D weir channels. Cross-sections were used to define the shape of the 1D weirs.

4.3.5 1D / 2D Dynamic Linking

1D elements are dynamically linked to the 2D model. The 2D/1D hydraulic model layout is shown in Drawing 4-3.

The underground pipe network is linked to the 2D model via a pit inlet, allowing flow in both directions. A schematic diagram of this linkage is presented in Figure 4-1.

1D open channels are linked to the 2D domain, usually along the top of bank of the open channel to ensure the exchange of water between open channel and overland area occurs at the correct height. The arrangement allows for both flows into and out of the open channel. The 2D cells within the open channel are deactivated, to prevent conveyance being duplicated. A schematic diagram for this type of linkage is presented in Figure 4-2. An example of the linkages utilised in the hydraulic model are presented in Drawing 4-4.

4.4 Hydrologic / Hydraulic Model Linkage

Flows into the hydraulic model are generated using the hydrological model. At the upstream of the hydraulic model cumulative flows (from multiple subcatchments) are added to the 1D pipe/open channel model. For subcatchments within the hydraulic model extent, flows are either added directly to 2D cells or split evenly between 1D nodes within the subcatchment. Hydrological inflow boundaries for the hydraulic model are presented in Drawing 4-5.

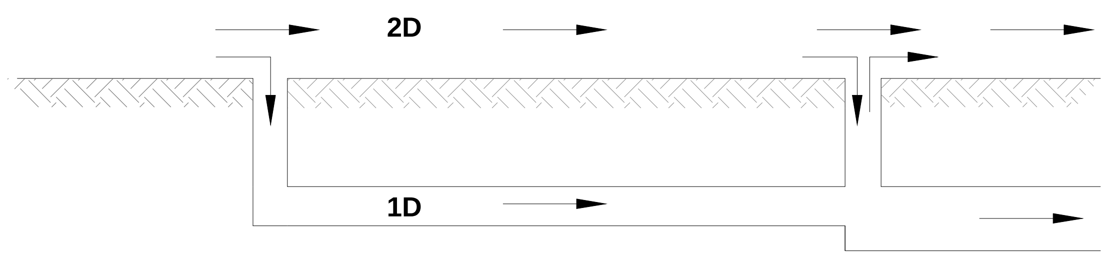

Figure 4-1 Schematic TUFLOW 2D / 1D Link in Urban Pipe Networks

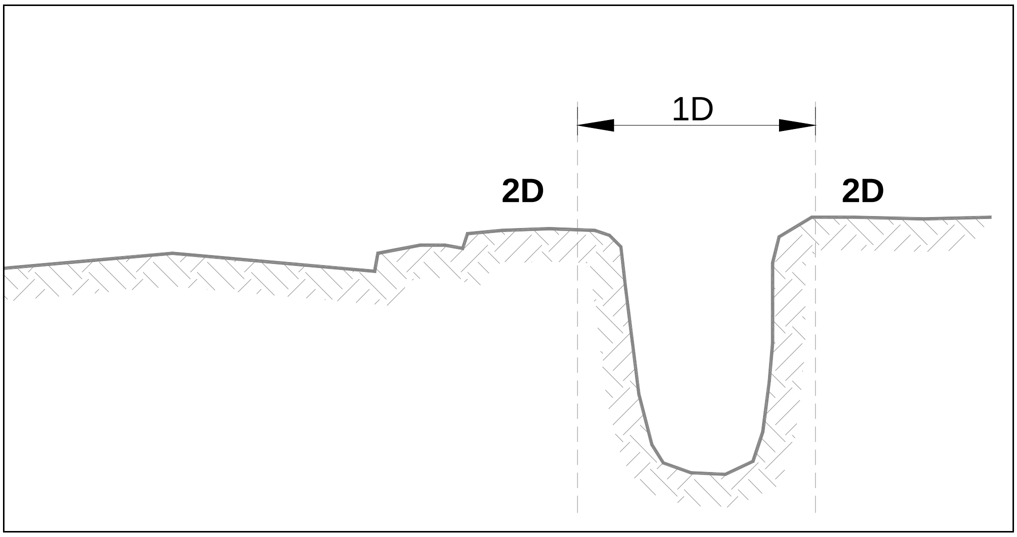

Figure 4-2 Modelling an Open Channel in 1D and Floodplain in 2D

5 MODEL CALIBRATION

5.1 Selection of Calibration/Verification Events

Data from known flood events were collated and reviewed to select events from which to calibrate and verify the computer models. The main criteria for a flood event to be a useful calibration/verification event are:

- pluviograph (a recorder that records rainfall over short time intervals) data are available in or close to the study area;
- preferably daily rainfall totals from other gauges within and/or close to the study area; and
- recorded flood levels are available.

Two floods, those in April 1988 and February 1990, stand out from other floods based on the criteria above. Two minor floods in 1992 in the Cottage Creek area are also potentially useful should further model verification be required.

The June 2007 flood, which occurred after the hydraulic model was calibrated, also has the potential to be an excellent calibration or verification event due to the large volume of flood marks that have been recorded and available for survey. Unfortunately the HWC rain and streamflow gauges were decommissioned in the 1990s, so there will be much greater uncertainty over the rainfall timing, depths and distribution for this flood compared with the 1988 and 1990 events. It is planned to validate the computer models to the June 2007 event during the following flood risk management study.

5.1.1 February 1990 Flood

Around 300 mm in a 48 hour period fell over the study area on the 2nd and 3rd of February 1990 in several bursts. The rainfall records show that the rainfall across the catchments was relatively uniform varying from around 316 mm in the west to 250 mm in the east. Six pluviograph recordings within the study area were available, of which one was discarded due to suspected malfunctioning.

Five flood height gauges recorded the rises and falls of the flood within the stormwater channels. There is some doubt over the actual water level heights for one or two of these gauges, however, the gauges clearly show the timing of when the flood peaks occurred. The first and largest peak, which caused the worst overland flooding, occurred around 3pm on the 2nd of February, 1990.

From previous investigations commissioned by Council, around 160 sites within the study area provided information on flooding. Of these, around 70 have identified a potential flood height to assist in the model calibration. These flood marks provide valuable information on flood levels away from the stormwater channels. In addition, there are a number of photographs and recollections that also assist in the model calibration process.

Drawing 5-1 shows the rainfall totals recorded and the location of the flood height information. Due to the comprehensive data set available for the February 1990 flood, it was selected as the primary calibration event.

5.1.2 April 1988 Flood

Unlike the February 1990 flood, the April 1988 flood rainfall was extremely varied over the study area. For the 48 hour period from 9:00am, 27th April, 141 mm of rain fell at Rankin Park Hospital, 101 mm to the south at Kotara Bowling Club, 44 mm in Waratah, 22 mm in Merewether and just 8 mm at Nobbys Head. At Rankin Park Hospital 75 mm (3 inches) of rain fell in just one hour from 9:30pm to 10:30pm on the 27th causing flash flooding in nearby creeks.

Only one of the Hunter Water Cooperation flood height gauges at Jellicoe Parade recorded the rise and fall of the flood within the stormwater channels. The second flood peak, which occurred around 11:00pm on the 27th, caused the worst overland flooding.

From previous investigations commissioned by Council, around 180 sites provided information on flooding. Of these, around 80 have identified a potential flood height to assist in the model calibration. These flood marks provide valuable information on flood levels away from the stormwater channels. In addition, there are a number of photographs and recollections that also assist in the model verification process.

Drawing 5-2 shows the rainfall totals recorded and the location of the flood height information. Due to the less comprehensive data set and greater uncertainty associated with the high variation in rainfall over the catchments, the April 1988 flood was selected as a verification event.

5.2 Model Calibration and Verification

5.2.1 Changes to 2000 Topography

A number of changes have occurred in the catchment since the calibration events. As the DEM is based on the conditions as of 2000, a number of layers were added (overwriting the 2000 topography) to adjust the calibration model so as to reflect conditions in 1988/1990. Layers added to modify the elevations sampled from the 2000 DEM are listed below in Table 5-1. The location of these modifications is presented in Drawing 5-3.

Table 5-1 Modifications to 2000 Topography for Calibration Modelling

Description/Source	Area	Change
DEM 2000	Hydraulic Modelling Area	Base
Harbour Data	Harbour	Missing in DEM 2000
Harbour Data	Harbour	Missing in DEM 2000
Harbour Data	Harbour	Missing in DEM 2000
Allworth St DEM (NCC)	Glebe Road	Missing in DEM 2000
Based on 1998 Ground Survey	Kotara	Changes to Homemaker Centre
DEM (NCC)	Maryville	Pre Subdivision
DEM (NCC)	Broadmeadow Soccer Fields	Pre Soccer Fields
Cowper St Bridge pre 1993	Harbour	Changes to bridge arrangement and isthmus
Elevations of Cycleway along Throsby Ck	Cycleway Maryville	No bund along cycleway
Harbour area pre-fill	Edges of Harbour	Pre-fill conditions
RTA Carpark above Cottage Ck	Newcastle West	DEM picks up channel
Ground Survey	Waratah Rail	More Accurate Ground Survey
Ground Survey	Glebe Road	More Accurate Ground Survey

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5.2.2 Interpretation of Calibration Data and Model Predictions

Calibration of computer models involves the adjustment of model parameters within industry-accepted ranges. It also requires having an understanding of uncertainties in the data sets used to build the model.

Reasons for differences between model results and recorded information are important to understand and appreciate when reviewing comparisons between the model and historical observations. Key areas of uncertainty are:

- Rainfall recorders (pluviographs) only represent a record of the rainfall at their exact location. Therefore, the rainfall used in the modelling away from the pluviograph sites is an estimate using interpolation or extrapolation techniques. A good example of a difficult rainfall event is the 1988 flood, where there are major variations in rainfall over relatively short distances, making it difficult to confidently estimate the rainfall at locations away from the pluviographs.

  It is noted that the New Lambton pluviograph was not used for modelling the 1988 and 1990 events on the basis that it's recordings were not consistent with the other pluviographs (this could be due to malfunctioning, an error in storing the data or other reason).

- Flood marks vary greatly in quality depending on how they are recorded (or recollected). Most of the flood marks available were derived and documented in previous studies, during which they were graded from 1 to 5 in terms of their reliability (i.e. accuracy). A Grade 1 level is one that is considered to be well defined (eg. a watermark on a wall) and should be representative of the flood peak. A Grade 4 level is considered to have considerable uncertainty associated with it. A Grade 5 has no level associated with it, but some recollections or observations of flooding were noted.

The general approach to calibrating the model is that the model's predicted levels are at or around Grade 1 levels (preferably within +/- 0.2m, i.e. 20cm). For lesser grades, the flood model should be predicting levels at or above these levels as the recorded levels are not necessarily indicative of the flood peak.

- The flood gauges in the open stormwater channels not only provide information on the flood peak, but also the rate of rise and fall of the floodwaters. The gauges record the depth of water over time in the stormwater channel, however, the datum (the height of the gauges relative to a fixed survey mark) is not known, so there is some uncertainty over the level of the gauges. There is also believed to be considerable uncertainty of the Bates St gauge (see Figure 5-1) as desktop analyses have shown that the gauge was underestimating the depth of water. However, the gauge clearly shows the rise and fall of the floodwaters which is still of considerable use. The average speed of the water in the channel at Bates St gauge is very high at around 6 m/s (over 20 km/h), which may cause problems with the gauge's performance.
- As discussed previously, the hydraulic model only includes the underground pipe drainage system for pipes 900 mm diameter or larger. Consequently, some areas are modelled as having no underground drainage and may show considerable extents of quite shallow inundation that may not have occurred.
- The ground level data over the floodplain is from photogrammetry (a technique that uses aerial photography to determine the level of the ground surface). The vertical accuracy of the photogrammetric ground levels on clearly visible surfaces is as a rule no more than 0.1 metres (about 4 inches) higher or lower than the real ground level. This is a very high accuracy that was needed to support the prediction of past and future flood levels. In some areas, such as under vegetation and other obstructions, the accuracy can be considerably less. This uncertainty affects the extent of flooding predicted, particularly where wide shallow inundation is displayed.

  Also of note, is that photogrammetry cannot "see" underneath building roofs, therefore, if the building is on a built up pad or the floor is elevated above the ground, the information on the floor level is not known. This means that buildings may appear as flooded, when they may not have experienced flooding above the floor. Conversely, some larger buildings have been modelled as a total blockage to floodwaters, and therefore appear not to have been flooded when they may have experienced inundation above their floors.
- Any debris build-up and partial blockage of bridges, culverts and pipes, which maybe the cause of more extensive flooding, were not included in the computer model simulations.
- The computer models themselves have uncertainties, as no computer model can be a perfect representation of reality. The hydraulic model presented in this report simulates flooding down to a resolution of 10 metres. Therefore, fine-scale obstructions to floodwaters such as fences, small buildings, etc are only roughly represented, and any localised flood affects (eg. water surcharging against a wall) are not necessarily depicted.

5.2.3 Presentation Formats of Model Calibration

The performance of the computer models to reproduce the 1988 and 1990 floods are presented in several formats as follows:

- Maps showing information at the flood peak including:
  - Predicted maximum extent and depths of inundation (the darker blue shades indicate greater depths of inundation – refer to the legend on the map).
  - Small coloured circles indicating the location of a recorded flood mark. Next to some circles is a number representing the difference in metres between the model's prediction and the flood mark. The circles and numbers are colour coded according to their grade (Magenta for Grade 1, Orange for Grade 2, Yellow for 3 and Green for 4 – no recorded flood marks are available for Grade 5 sites). A positive number indicates the model is above the recorded level, while a negative number indicates the model is below the recorded level. Refer to the discussion in Section 5.2.2 on reasons why there may be a difference. If no number appears next to the flood mark, the flood mark is located outside the area covered by the model, or the model did not predict any inundation at that site.
  - The predicted speed and direction of the water illustrated by the size and direction of the red arrows.
  - Predicted water level contours, shown as blue lines, on a half metre interval.
- Graphs showing a comparison between the recorded levels at the Hunter Water Cooperation gauges and the model's predictions. These show the rise and fall of the flood. Of particular interest here is the timing of the flood rise and fall, and whether the model is reproducing this.
- A profile of the peak water level down Throsby Creek is provided along with any recorded flood marks within 100 m of the creek centreline.
- Profiles down the major tributaries are presented with the design modelling results. This has been done to avoid replication and wastage. See Section 6.4 for detail on long sections.

Calibration to February 1990 Flood

The adopted rainfall isohyets for the February 1990 event are presented in Drawing 5-7.

Five maps, as described in Section 5.2.3, are provided in Drawing 5-8 to Drawing 5-12, to illustrate the predicted flood extent, depths and flow patterns. The first map is a key map showing the locations of the local map sheets. The local map sheets present the difference between the model's predicted level and the recorded level.

Figure 5-1 shows the model predictions at the five HWC gauges. Figure 5-2 presents the profile of peak water levels along Throsby Creek along with the recorded levels within 100 m of the creek centreline.

Observed and predicted flood levels for the 1990 calibration are presented in Table 5-2. A statistical analysis of flood marks by region is presented in Table 5-3.

Table 5-2 Feb 1990 Calibration to Flood Marks

Flood ID	Recorded Flood Level (mAHD)	Modelled Level (mAHD)	Difference [Modelled - Recorded] (m)	Data Grade
tc008a	12.70	12.88	0.18	1
tc207b	8.03	8.28	0.25	1
tc214	8.61	8.29	-0.32	1
tc404b	8.31	8.28	-0.03	1
tc601	15.73	15.65	-0.08	1
tc604	13.83	13.68	-0.15	1
tc702a	5.71	5.91	0.19	1
tc707	5.80	5.85	0.05	1
tc707b	5.68	5.84	0.16	1
tc708a	5.52	5.57	0.05	1
tc713	12.47	12.61	0.14	1
tc725c	17.39	17.55	0.15	1
tc743	9.34	9.30	-0.04	1
tc799b	12.06	12.13	0.06	1
tc804a	5.25	5.25	0.00	1
tc1207a	8.51	8.27	-0.24	1
tc1210	12.62	12.61	-0.01	1
tc1303	13.86	13.69	-0.17	1
tc1304b	13.15	13.04	-0.12	1
tc1306	12.68	12.80	0.12	1
tc1306a	12.69	12.65	-0.04	1
tc1307	14.62	14.64	0.02	1
tc1308	12.89	12.81	-0.08	1
cc3010	19.32	19.75	0.43	1
tc203	8.15	8.38	0.22	2
tc707a	5.87	5.64	-0.23	2
tc1304a	12.97	12.79	-0.18	2
tc1521	5.64	6.03	0.39	2
tc1604	2.58	3.04	0.46	2
tc1702	23.53	23.51	-0.02	2
cc011	9.83	9.59	-0.24	2
cc021	3.59	3.52	-0.07	2
cc058a	5.24	5.65	0.41	2
cc076	6.74	6.59	-0.15	2
tc218	7.98	8.32	0.34	3
tc219	7.79	8.29	0.5	3
tc717	13.60	13.65	0.05	3
tc725	16.83	16.99	0.16	3
tc725a	16.68	16.80	0.12	3
tc729	15.87	16.00	0.13	3
tc748	8.96	9.19	0.24	3
tc750	10.72	11.00	0.28	3
tc767	29.44	29.64	0.2	3
tc768	23.03	23.10	0.07	3
tc771	29.65	29.64	-0.01	3
tc772	30.29	30.40	0.11	3
tc774	32.41	32.43	0.02	3

tc781	32.28	32.31	0.03	3
tc782	8.10	8.41	0.31	3
tc787	11.55	11.50	-0.05	3
tc1014	18.68	19.08	0.4	3
tc1101	5.42	13.08	7.66	3
tc769	22.88	23.75	0.87	4
tc1526	11.28	11.50	0.22	4
cc012	8.56	8.65	0.09	4
cc016	8.56	8.71	0.15	4
cc1040	4.79	5.58	0.79	4

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Table 5-3 Regional Statistical Analysis of Feb 1990 Flood Marks

Region/Grade	% Levels Within ±0.1m	% Levels Within ±0.2m	Average Deviation (m)	Total Number of Levels
Total				
Grade 1	46%	83%	0.02	24
Grade 2	20%	40%	0.06	10
Grade 3	33%	56%	0.59	18
Grade 4	20%	40%	0.42	5
All Grades	33%	61%	0.24	57
Merewether				
Grade 1	0%	0%	0.43	1
Grade 2	25%	50%	-0.01	4
Grade 3	N/A	N/A	N/A	0
Grade 4	50%	100%	0.12	2
All Grades	29%	57%	0.09	7
Kotara				
Grade 1	N/A	N/A	N/A	0
Grade 2	100%	100%	-0.02	1
Grade 3	57%	71%	0.12	7
Grade 4	0%	0%	0.87	1
All Grades	56%	67%	0.19	9
Mayfield				
Grade 1	50%	100%	0.11	4
Grade 2	0%	0%	0.12	2
Grade 3	N/A	N/A	N/A	0
Grade 4	N/A	N/A	N/A	0
All Grades	33%	67%	0.11	6
ISC				
Grade 1	25%	25%	-0.09	4
Grade 2	0%	0%	0.22	1
Grade 3	0%	0%	0.42	2
Grade 4	N/A	N/A	N/A	0
All Grades	14%	14%	0.10	7
Lambton				
Grade 1	50%	100%	0.00	14
Grade 2	0%	100%	-0.18	1
Grade 3	14%	57%	0.18	7
Grade 4	N/A	N/A	N/A	0
All Grades	36%	86%	0.05	22

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5.2.4 April 1988 Verification

The April 1988 flood event was simulated through the model as a verification of the 1990 flood calibration. As discussed previously, the 1988 event is more problematic given the large variation and uncertainty in the rainfall that fell over the catchment, and was therefore selected for verification purposes. The objective of the verification stage is to check the model performs satisfactorily to another flood event, using the same parameters as adopted for the calibration stage. The same level of agreement as achieved during the model calibration stage is not necessarily expected for the verification stage.

The adopted rainfall isohyets for the April 1988 calibration are presented in Drawing 5-13.

As for the 1990 flood calibration, the 1988 verification is presented using the same map arrangement. These maps are presented in (Drawing 5-14 to Drawing 5-18).

Figure 5-3 shows the model predictions at the Jellicoe Parade HWC gauge, the only gauge for which information was available. Figure 5-4 presents the profile of peak water levels along Throsby Creek, along with the recorded levels within 100 m of the creek centreline.

Observed and predicted flood levels for the 1988 verification are presented in Table 5-4. A statistical analysis of flood marks by region is presented in Table 5-4.

Table 5-4 Apr 1988 Calibration to Flood Marks

Flood ID	Recorded Flood Level (mAHD)	Modelled Level (mAHD)	Difference [Modelled - Recorded] (m)	Data Grade
tc006	8.34	8.21	-0.13	1
tc006a	8.28	8.24	-0.04	1
tc010	10.21	10.22	0.01	1
tc017	14.65	14.19	-0.46	1
tc765	12.21	11.84	-0.37	1
tc765a	11.80	11.84	0.05	1
tc1017	20.80	20.40	-0.4	1
tc1308b	12.31	12.29	-0.02	1
tc021	8.62	8.06	-0.55	2
tc776	29.59	29.39	-0.2	2
tc1308a	12.39	12.39	0.01	2
tc1018	8.11	8.08	-0.03	3

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Table 5-5 Regional Statistical Analysis of Apr 1988 Flood Marks

Region/Grade	% Levels Within ±0.1m	% Levels Within ±0.2m	Average Deviation (m)	Total Number of Levels
Total				
Grade 1	50%	63%	-0.17	8
Grade 2	33%	33%	-0.25	3
Grade 3	100%	100%	-0.03	1
Grade 4	N/A	N/A	N/A	0
All Grades	50%	58%	-0.18	12
Merewether				
Grade 1	N/A	N/A	N/A	0
Grade 2	N/A	N/A	N/A	0
Grade 3	N/A	N/A	N/A	0
Grade 4	N/A	N/A	N/A	0
All Grades	N/A	N/A	N/A	0
Kotara				
Grade 1	N/A	N/A	N/A	0
Grade 2	0%	0%	-0.20	1
Grade 3	N/A	N/A	N/A	0
Grade 4	N/A	N/A	N/A	0
All Grades	0%	0%	-0.20	1
Mayfield				
Grade 1	N/A	N/A	N/A	0
Grade 2	N/A	N/A	N/A	0
Grade 3	N/A	N/A	N/A	0
Grade 4	N/A	N/A	N/A	0
All Grades	N/A	N/A	N/A	0
ISC				
Grade 1	50%	75%	-0.12	4
Grade 2	0%	0%	-0.55	1
Grade 3	100%	100%	-0.03	1
Grade 4	N/A	N/A	N/A	0
All Grades	50%	67%	-0.18	6
Lambton				
Grade 1	50%	50%	-0.22	4
Grade 2	100%	100%	0.01	1
Grade 3	N/A	N/A	N/A	0
Grade 4	N/A	N/A	N/A	0
All Grades	60%	60%	-0.17	5

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Statistics_Summary

5.2.5 Public Exhibition and Fine-Tuning

The calibration/verification of the computer models was placed on public exhibition and presented at community workshops. No negative feedback or changes in the models' calibration/verification resulted from the community feedback, although on-going investigation and fine-tuning occurred in localised areas (Broadmeadow/Adamstown area at start of racecourse culvert, Waratah Railway Station, Glebe Road, and upper areas of New Lambton) based on feedback from committee meetings.

5.3 Calibrated Model Parameters

5.3.1 Hydrological Parameters

The main calibration parameters in the WBNM hydrological model are the lag parameter, the initial rainfall loss and the continuing rainfall losses.

A number of other parameters in WBNM can be changed if justification for modifying these exist. For the Throsby, Cottage and CBD hydrological model these remained at the recommended default values. The calibrated model parameters are presented in Table 5-6.

Table 5-6 Calibrated Hydrologic Parameters

Parameter	1988 Calibration	1990 Calibration
Initial Loss (mm)	5.0	10.0
Continuing Losses (mm/hr)	2.0	2.0
Lag Parameter	1.3	1.3

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5.3.2 Hydraulic Model Parameters

The focus of the hydraulic model calibration was on varying hydraulic roughness (Manning's n). The calibrated Manning's n values are listed in Table 5-7.

Table 5-7 Calibrated Manning's n Values

Land Use	Manning's n Value
2D Areas	
Grass (maintained)	0.030
Parkland	0.040
Roads / Railway	0.020
Open Concrete/Asphalt	0.020
Riparian Vegetation	0.100
Dense Land Vegetation / Forest	0.090
Building	1.000
Urban Block	0.300
Concrete Lined Channel	0.018
Bare Earth / unkempt low-level foliage	0.045
Harbour, dams, water	0.022
1D Areas	
Channel overbank	0.030
Parkland	0.040
Roads	0.020
Open Concrete/Asphalt	0.020
Riparian Vegetation	0.100
Dense Land Vegetation / Forest	0.090
Building	1.000
Urban Block	0.300
Concrete Lined Channels	0.018
Tidal Creek Bed	0.022
Fences	0.300
Bare Earth / unkempt low-level foliage	0.045

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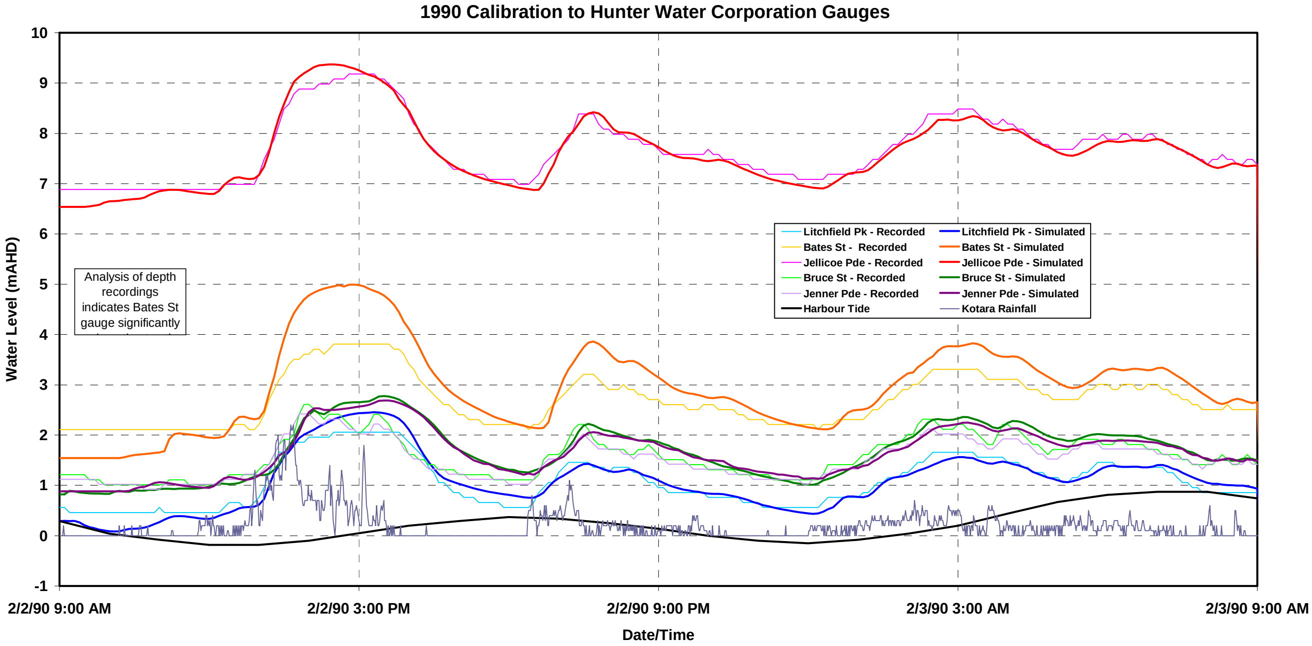

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Figure 5-1 1990 Calibration to Flood Level Gauges

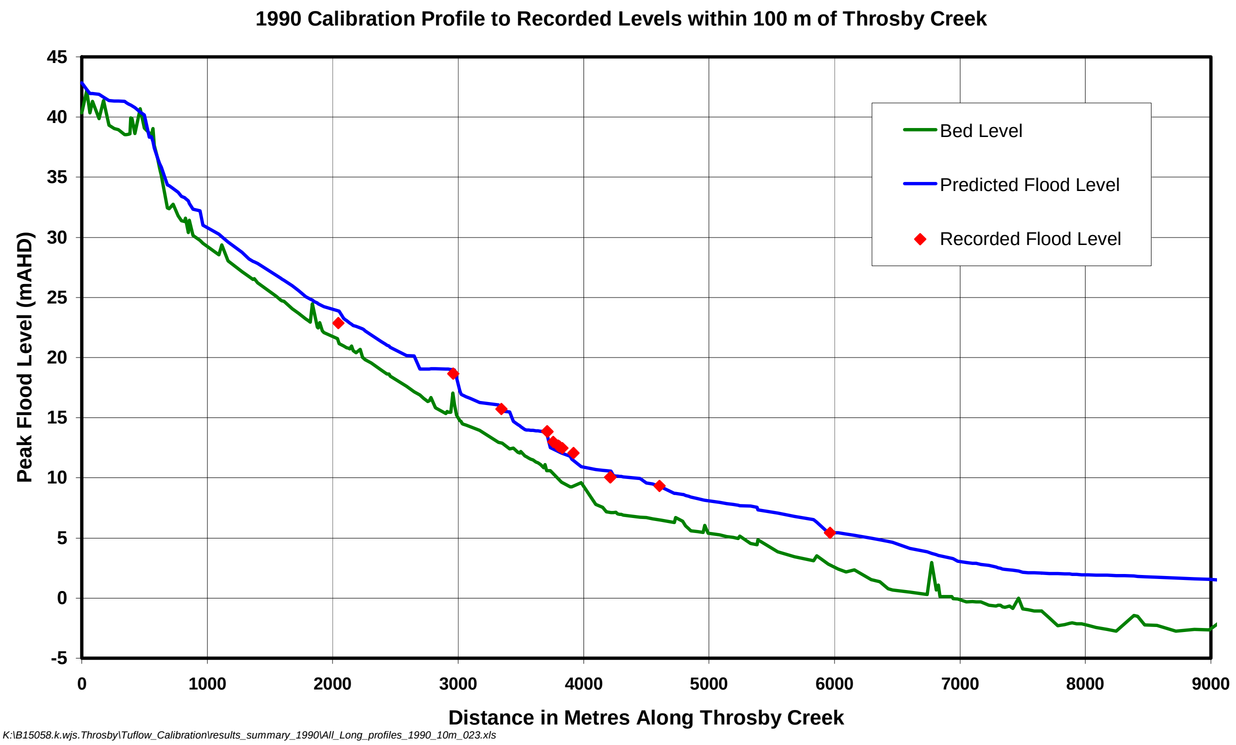

Figure 5-2 1990 – Calibration Profile to Recorded Levels with 100m of Throsby Creek

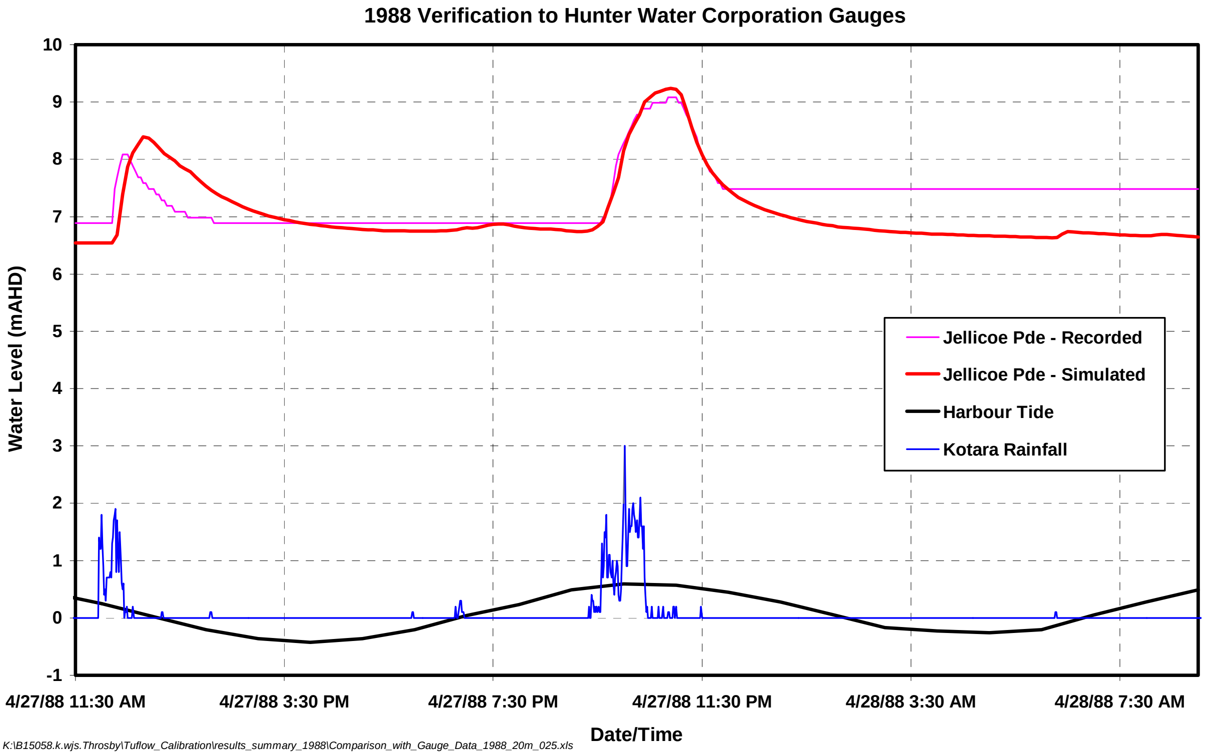

Figure 5-3 1988 Verification to Flood Level Gauges

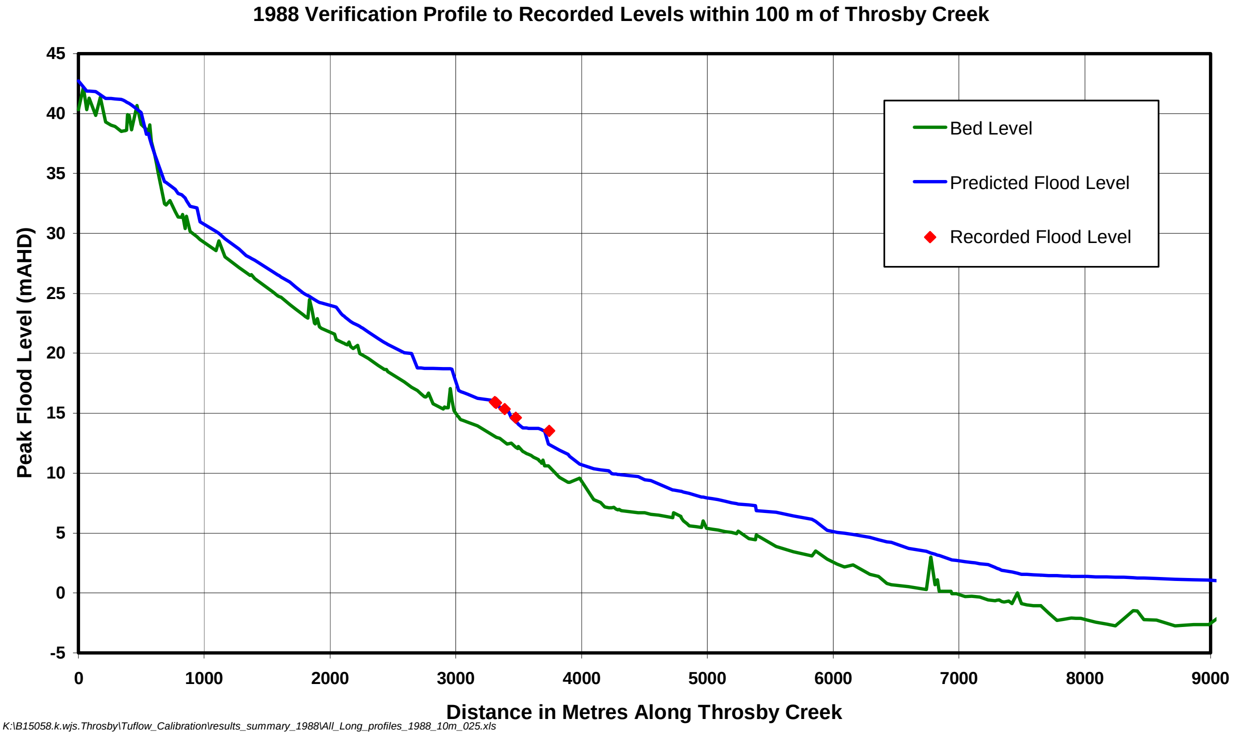

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Figure 5-4 1988 Verification Profile to Recorded Levels within 100m of Throsby Creek

6 DESIGN FLOODS

6.1 Topography Adjustments (1990 to 2005)

There have been a number of changes to the catchment since the 1990 calibration event that need to be incorporated as the design modelling is based on existing (2005) topography. The topography of the calibrated model was updated to ensure that the design model was reflective of the existing topography.

6.1.1 DEM and Bathymetry

The primary DEM is based on the conditions as of 2000. Changes made to reflect conditions as of 1988/1990 were removed from the design model, and changes to the topography between 2000 and 2005 included. Layers added to modify the DEM of 2000 are listed below in Table 6-1. The locations of these modifications are presented in Drawing 6-1.

Table 6-1 Modifications to 2000 Topography for Design Modelling

Description	Area	Change
DEM 2000	Hydraulic Modelling Area	Base
Bathymetry	Harbour	Missing in DEM 2000
Bathymetry	Harbour	Missing in DEM 2000
Bathymetry	Harbour	Missing in DEM 2000
Allworth St DEM (NCC)	Glebe Road	Missing in DEM 2000
2005 Ground Survey	Stewart Avenue	Development Since DEM 2000
2005 Ground Survey	Linwood St	Development Since DEM 2000
2005 Ground Survey	Carrington	Development Since DEM 2000
2005 Ground Survey	Honeysuckle	Development Since DEM 2000
2005 Ground Survey	Wickham	Development Since DEM 2000
2005 Ground Survey	Kotara	Development Since DEM 2000
DEM 2004 Photogrammetry	Hamilton South	Development Since DEM 2000
Ground Survey	Waratah Railway	More Accurate Ground Survey
Ground Survey	Glebe Road	More Accurate Ground Survey

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6.1.2 Cross-Sections

The lower sections of Throsby Creek and the harbour are modelled in 2D. Changes to topography caused by dredging and development in these areas are represented.

6.1.3 Land-Use

The 2004 aerial photographs were used to digitise the current land uses in areas that have changed since the calibration events. The land uses used in the design modelling are presented in Drawing 6-2.

6.1.4 Hydraulic Structures

The rail bridge over Styx Creek was replaced in 2004. Newcastle City Council provided details of both bridges. The model was updated to reflect the current arrangement.

Details for the hydraulic structures are based on the drawings provided by Newcastle City Council. These structures were surveyed / measured in the years 2000 and 2001. It is assumed that these are reflective of the current structures.

6.2 Design Flood Behaviour

6.2.1 Flood Mechanisms

In general, the flooding behaviour in the Throsby, Cottage and CBD areas in its current developed state can be summarised as follows:

- Rainfall on the catchment initially drains via the underground drainage network to the network of concrete lined open channels that discharge to the harbour.
- When runoff exceeds the capacity of the underground drainage and open channel network, floodwaters primarily travel along the road system as a network of flowpaths draining the catchment into the open channels or parallel to open channels.
- In some areas, the major overland flowpaths are through residential/commercial buildings and grounds and parkland.
- Flooding in the lower areas (Carrington in particular) can result as a back up from Throsby Basin either from a Hunter River flood, an elevated ocean level (eg storm surge) or from a combination of both.

6.2.2 Critical Duration Analysis

The hydrological model was used to simulate 11 rainfall durations for the 1% AEP event to ascertain the critical duration storm periods. Flows generated were input to the hydraulics model to determine the design rainfall durations that result in the highest modelled water level at locations throughout the study area.

To ensure that the timing of the tide in the harbour did not influence the critical duration analysis, the downstream water level for the critical duration simulations was held constant at 0.0mAHD. Results of the critical duration analysis are presented in Drawing 6-3. This figure shows where the various rainfall durations yield the highest predicted water level.

The rainfall durations used in the critical duration and the area that each of these is critical is presented in Table 6-2. It should be noted that while the 1 and 1.5 hour durations have a greater percentage than the 9 hour, the depth is generally very close in value to the 2 hour duration. In lower areas, the longer durations are critical and these are significantly deeper than the 2 hour duration.

The locations where the depth of the 2 and 9 hour durations is within 50mm of the critical depth was calculated. Drawing 6-5 shows areas where the 2 and 9 hour events are within 50mm of the critical duration. This drawing shows that over the extent of the model the 2 and 9 hour events are generally either critical or within 50mm of the critical depth.

In consultation with the flood study technical committee it was decided that two and nine hour rainfall durations would be used for design flood simulations.

Table 6-2 Results Critical Duration Analysis of 1% AEP

Duration	Area km^2	Percentage of Area Critical
0.5 hour	0.28	3.0%
1 hour	1.25	13.5%
1.5 hour	1.53	16.5%
2 hour	**3.97**	**42.9%**
3 hour	0.32	3.5%
4.5 hour	0.22	2.4%
6 hour	0.22	2.4%
9 hour	**0.71**	**7.6%**
12 hour	0.26	2.8%
18 hour	0.16	1.7%
24 hour	0.35	3.8%
Total	**9.26**	**100.0%**

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[TCC_Q100_Critical_Duration_Statistics.xls]Crit_Dur_Stat

6.3 Design Flood Combinations

6.3.1 Design Event Abbreviations

The following abbreviations are used for the design event section of the Throsby, Cottage and CBD Flood study:

Table 6-3 Design Event Abbreviations

Abbreviation	Description
Topography	
TEX	Topography as at 2005 (ie. existing conditions)
TFD	Fully developed topography
Event Probability	
QPMF	PMF Flood Event
Q200	200 year ARI or 0.5% AEP Event
Q100	100 year ARI or 1% AEP Event
Q050	50 year ARI or 2% AEP Event
Q020	20 year ARI or 5% AEP Event
Q010	10 year ARI or 10% AEP Event
Q005	5 year ARI or 20% AEP Event
Q002	2 year ARI or 50% AEP Event
Duration	
D0030m	30 minute critical duration
D01.0h	1 hour critical duration
D01.5h	90 minute critical duration
D02.0h	2 hour critical duration
D03.0h	3 hour critical duration
D04.5h	4.5 hour critical duration
D06.0h	6 hour critical duration
D09.0h	9 hour critical duration
D12.0h	12 hour critical duration
D18.0h	18 hour critical duration
D24.0h	24 hour critical duration
Harbour Conditions (Hunter River / Ocean Combinations)	
RPMF	Hunter River PMF flood event with a 1.3m ocean storm tide. The two peaks are timed to coincide within the harbour.
H0.5e	0.5% exceedance for any given hour harbour boundary from L&T joint probability study.
H01e	1% exceedance for any given hour harbour boundary from L&T joint probability study.
H02e	2% exceedance for any given hour harbour boundary from L&T joint probability study.

H05e	5% exceedance for any given hour harbour boundary from L&T joint probability study.
H10e	10% exceedance for any given hour harbour boundary from L&T joint probability study.
H20e	20% exceedance for any given hour harbour boundary from L&T joint probability study.
H50e	50% exceedance for any given hour harbour boundary from L&T joint probability study.
Climate Change	
C01	Climate Change Scenario 01: 0.4m sea level rise.

6.3.2 Design Event Probabilities

Flooding was simulated using the hydraulic model for eleven combinations of design event probabilities for the TEX (Existing) and TFD (Future) topographic scenarios as follows.

- Existing (TEX) conditions: PMF, Q200, Q100, Q50, Q20, Q10, Q5 and Q2.
- Future (TFD) conditions: PMF, Q100 and Q10.

6.3.3 Design Event Combinations

The selection of rainfall event durations (two and nine hour) was based on the critical duration analysis, see Section 6.2.2. The following combinations were simulated for the design probabilities listed in Table 6-4.

All design events have a 1 hour, 1% AEP time varying tailwater condition, based on the joint probability study of water levels in Newcastle Harbour (Lawson and Treloar, 1999). The fully developed condition simulations have an allowance of 0.4m on tailwater levels to account for possible sea level rise in the future.

Table 6-4 Design Flood Combinations

Design Flood Probability	Combinations
Existing Condition (TEX) Combinations	
PMF	1. TEX_QPMF_D02.0h_ H01e
Q200	2. TEX_Q200_D02.0h_H01e 3. TEX_Q200_D09.0h_H01e
Q100	4. TEX_Q100_D02.0h_H01e 5. TEX_Q100_D09.0h_H01e
Q050	6. TEX_Q050_D02.0h_H01e 7. TEX_Q050_D09.0h_H01e
Q020	8. TEX_Q020_D02.0h_H01e 9. TEX_Q020_D09.0h_H01e
Q010	10. TEX_Q010_D02.0h_H10e 11. TEX_Q010_D09.0h_H10e
Q005	12. TEX_Q005_ D02.0h _H01e 13. TEX_Q005_ D09.0h _H01e
Q002	14. TEX_Q002_ D02.0h _H01e 15. TEX_Q002_ D09.0h _H01e
Fully Developed Condition (TFD) Combinations	
PMF	16. TFD_QPMF_ D02.0h _H01e_C01
Q100	17. TFD_Q100_D02.0h_H01e_C01 18. TFD_Q100_D02.0h_H01e_C01
Q010	19. TFD_Q010_D02.0h _H01e_C01 20. TFD_Q010_D09.0h_H01e_C01

6.4 Presentation of Results

Design flood levels and depths are presented for the eight existing design event probabilities. The results for each design probability are the maximum envelope of two critical durations (two and nine hour durations).

The peak water level does not occur everywhere at the same time, therefore, values presented are based on the maximum that occurred at each computational point in the model during a combination of event durations. Hence, results do not represent an instantaneous point in time, but rather an envelope of the maximum values that have occurred.

Unless otherwise stated, presentations in this report are based on peak values, not at an instant in time. Peak velocity and peak velocity-depth products are those that occur at the time of the peak water level.

Long sections down each of the major tributaries are presented for all the design and calibration events. An index of the long profiles is presented in Table 6-5. A map of the location of profiles is presented in Drawing 6-5.

Table 6-5 Index Of Long Profiles

Branch	Drawing Number
Location Plan	Drawing 6-4
Adamstown	Drawing 6-5
Broadmeadow East	Drawing 6-6
Broadmeadow	Drawing 6-7
Cottage Creek	Drawing 6-8
Georgetown	Drawing 6-9
Griffiths Flat	Drawing 6-10
Kotara	Drawing 6-11
Lambton	Drawing 6-12
Mayfield	Drawing 6-13
New Lambton	Drawing 6-14
Orchardtown	Drawing 6-15
Racecourse	Drawing 6-16
Throsby Upper	Drawing 6-17
Throsby Lower	Drawing 6-18
Waratah	Drawing 6-19

K:\B15058.k.wjs.Throsby\Tuflow_Design\results_summary\Long_Profiles_123\Excel\[Index_of_LPs.xls]Index_Table

Five drawings are presented for each design event probability and output type, as a keysheet (A3) and four A3 maps. An index of the design mapping is presented in Table 6-6.

Table 6-6 Index of Design Flood Maps

Event	Levels	Depths
Q002_TEX	Drawing 6-20 to Drawing 6-24	Drawing 6-25 to Drawing 6-29
Q005_TEX	Drawing 6-30 to Drawing 6-34	Drawing 6-35 to Drawing 6-39
Q010_TEX	Drawing 6-40 to Drawing 6-44	Drawing 6-45 to Drawing 6-49
Q020_TEX	Drawing 6-50 to Drawing 6-54	Drawing 6-55 to Drawing 6-59
Q050_TEX	Drawing 6-60 to Drawing 6-64	Drawing 6-65 to Drawing 6-69
Q100_TEX	Drawing 6-70 to Drawing 6-74	Drawing 6-75 to Drawing 6-79
Q200_TEX	Drawing 6-80 to Drawing 6-84	Drawing 6-85 to Drawing 6-89
QPMF_TEX	Drawing 6-90 to Drawing 6-94	Drawing 6-95 to Drawing 6-99

I:\B15058_I_BRH_ Throsby Cottage_WJS\DRG\Design_Mapping\[A3_Drawing_Addendum.xls]Table

6.5 Design Flood Peak Envelopes

6.5.1 2 year ARI Event

The following comments are made with respect to the 50% AEP (2 year ARI) flood probability combination:

- There are significant areas predicted to experience shallow flooding, these include New Lambton, The Junction, Hamilton North and Carrington. Many of these are likely to be as a result of the sub-900mm pipes not being included.

- Velocity and velocity-depth products are typically low for overland areas, the exception being Merewether.
- The railway embankment at Kotara acts as a significant restriction to flow with a head drop of approximately 1.5m at the culverts.
- There is no interaction between the Throsby and Cottage Creek catchments.
- Predicted area inundated is 5.9km^2.

6.5.2 5 year ARI Event

The following comments are made with respect to the 5 year ARI (20% AEP) probability design event combination:

- Significant increases to flood extent (compared with the 2 year ARI event) occur in New Lambton (Bridges Road and Errington Ave / Mackie Ave) and the CBD (Hunter and King Streets).
- A flow path is created along Bridges Road, New Lambton (between Longworth Ave and Russell Rd).
- A small interaction between the Throsby and Cottage Creek catchments occurs. A peak flow of approximately 0.5m^3/s from the Cottage Creek catchment to the Throsby Creek occurs in the nine hour event. The flow occurs along Fowler and Coady Streets in Hamilton South.
- Predicted area inundated is 7.3km^2.

6.5.3 10 year ARI Event

The following comments are made with respect to the 10 year ARI (10% AEP) probability design event combination:

- Significant increases to flood extent (compared to the 5 year ARI event) occur in Mayfield and New Lambton.
- Proportion of flow along Bridges Road / Penman Avenue / Fairfield Avenue increases. Velocities of greater than 1m/s are predicted.
- Approximately 40% of flow in overland areas along Selwyn and Wilton Streets (Merewether).
- Predicted area inundated is 7.9km^2.

6.5.4 20 year ARI Event

The following comments are made with respect to the 20 year ARI (5% AEP) probability design event combination:

- Increases in flood extent and overland flow.
- Flowpath along Silsoe Street / Dangar Park in Mayfield develops.
- Overland flow path along Dawson, Queen and Darby Streets in Cooks Hill develops.
- Overland flow path along Mitchell St (between Llewellyn and Robert Streets) in Merewether develops.
- Predicted area inundated is 8.7km^2.

6.5.5 50 year ARI Event

The following comments are made with respect to the 50 year ARI (2% AEP) probability design event combination:

- General increases in flood extent and overland flow, notably in Hamilton North, Broadmeadow, Adamstown and Cooks Hill.
- Overland flowpath along Griffiths Road and Broadmeadow Road into Hamilton North develops.
- Overland flowpath north along Brunker, Chatham and Broadmeadow Roads develops.
- Overland flowpath along Mowbray and Wood Streets Adamstown develops.
- Overland flowpath along St James Road (east of Evenscourt Road) develops.
- Peak flow between the Throsby and Cottage Creek catchments is 2.6m^3/s from Throsby Creek to Cottage Creek catchment.
- Predicted area inundated is 9.6km^2.

6.5.6 100 year ARI Event

The following comments are made with respect to the 100 year ARI (1% AEP) probability design event combination:

- General increases in flood extent and overland flow, notably in New Lambton, Hamilton, Hamilton South and Newcastle West.
- Overland flow occurs north along Orchardtown Road, Birdwood Street and Knight Street.
- 75% of flow occurs in overland areas (as opposed to underground conduits) along Selwyn and Wilton Streets (Merewether).
- Predicted area inundated is 10.2km^2.

6.5.7 200 year ARI Event

The following comments are made with respect to the 200 year ARI (0.5% AEP) probability design event combination:

- General increases in flood extent and overland flow.
- A significant number of streets have velocities of greater than 1m/s, particularly in Merewether and New Lambton.
- Predicted area inundated is 10.8km^2.

6.5.8 PMF Event

The following comments are made with respect to the Probable Maximum Flood (PMF) event combination:

- The PMF event combination results in very large areas being inundated.

- Large portions of Broadmeadow, Hamilton, Hamilton North, Hamilton South, Hamilton East, The Junction, Wickham, Islington, Maryville, Carrington and New Lambton are predicted to experience flooding.
- Numerous roads have peak velocities of greater then 1m/s and a significant number have predicted velocities greater than 2m/s.
- Predicted area inundated is 19.3km^2.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following points summarise the findings for the Throsby, Cottage and CBD Flood Study:

- A hydrological model of the Throsby, Cottage and CBD catchments has been developed. The model uses industry standard parameters.
- A dynamically linked two-dimensional/one-dimensional (2D/1D) TUFLOW hydraulic model of the Throsby, Cottage and CBD areas was developed and calibrated/verified to the 1988 and 1990 flood events
- The models have successfully been used to derive a detailed representation of flooding in creek/channel and urban areas for the 50%, 20%, 10%, 5%, 2%, 1% and 0.5% AEP design flood events as well as the probable maximum flood.
- The models are considered to form a reliable and representative base from which to carry out flood risk management investigations and quantitatively assess impacts of flood mitigation options.

7.2 Recommendations

The following recommendations are made with respect to the Throsby, Cottage and CBD flood study:

- The computer models developed of the Throsby, Cottage and CBD catchments should be verified against the June 2007 flood event.
- The computer models should form the basis of all future floodplain risk management investigations for the study area.

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