WOOLLAHRA MUNICIPAL COUNCIL

DOUBLE BAY CATCHMENT FLOOD STUDY

JUNE 2008

Bewsher Consulting Pty Ltd

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June 2008

Prepared by:

BEWSHER CONSULTING PTY LTD
P O BOX 352 EPPING NSW 1710
Telephone (02) 9868 1966
Facsimile (02) 9868 5759
E-mail: postmaster@bewsher.com.au
ACN 003137068. ABN 24 312 540 210

in association with

BROWN CONSULTING (NSW) PTY LTD
P O BOX 1484 MACQUARIE CENTRE, NORTH RYDE NSW 2113
Telephone (02) 9900 1000
Facsimile (02) 9900 1099
E-mail: macquarie@brownconsulting.com.au
ABN 30109 434 513

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FOREWORD

The NSW Government's Flood Policy is directed at providing solutions to existing flooding problems in developed areas, and ensuring that new developments are compatible with the flood hazard and do not create additional flooding problems in other areas. Under the Policy, the management of flood prone land remains the responsibility of local government.

The policy provides for a floodplain management system comprising the following four sequential stages:

1. Flood Study	Determines the nature and extent of the flood problem.
2. Floodplain Risk Management Study	Evaluates management options for the floodplain with respect to both existing and future development.
3. Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4. Implementation of the Plan	Involves construction of flood mitigation works, where viable, to protect existing development. Uses planning controls to ensure that future development is compatible with flood hazards.

Woollahra Municipal Council is responsible for local planning and land management in the Woollahra Local Government Area (LGA) including the management of flood prone areas in the Double Bay catchment. Through its Floodplain Management Committee, Woollahra Municipal Council proposes to prepare a comprehensive Floodplain Risk Management Plan for the catchment in accordance with the NSW Government's 2005 Floodplain Development Manual.

This report is part of the first stage of the management process for the Double Bay catchment and has been prepared for Woollahra Municipal Council by Bewsher Consulting Pty Ltd. It documents the nature and extent of flooding throughout the catchment and will enable Council to proceed to the next steps of undertaking a Floodplain Risk Management Study of the catchment where detailed assessment of the flood mitigation options and floodplain management measures would be undertaken and then developing a Floodplain Risk Management Plan for the catchment.

GLOSSARY

Note that terms shown in bold are described elsewhere in this Glossary.

100 year flood	A **flood** that occurs on average once every 100 years. Also known as a 1% flood. See **annual exceedence probability (AEP)** and **average recurrence interval (ARI)**.
20 year flood	A **flood** that occurs on average once every 20 years. Also known as a 5% flood. See **annual exceedance probability (AEP)** and **average recurrence interval (ARI)**.
5 year flood	A **flood** that occurs on average once every 5 years. Also known as a 20% flood. See **annual exceedance probability (AEP)** and **average recurrence interval (ARI)**.
afflux	The increase in flood level upstream of a constriction of flood flows. A road culvert, a pipe or a narrowing of the stream channel could cause the constriction.
annual exceedance probability (AEP)	AEP (measured as a percentage) is a term used to describe **flood** size. AEP is the long-term probability between floods of a certain magnitude. For example, a 1% AEP flood is a **flood** that occurs on average once every 100 years. It is also referred to as the '100 year flood' or 1 in 100 year flood'. The terms **100 year flood**, **20 year flood**, **5 year flood** etc, have been used in this study. See also **average recurrence interval (ARI)**.
Australian Height Datum (AHD)	A common national plane of level approximately equivalent to the height above sea level. All **flood levels**, floor levels and ground levels in this study have been provided in metres AHWD
average recurrence interval (ARI)	ARI (measured in years) is a term used to describe **flood** size. It is a means of describing how likely a flood is to occur in a given year. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The terms **100 year flood**, **20 year flood** etc, have been used in this study. See also **annual exceedance probability (AEP)**.
catchment	The land draining through the main stream, as well as tributary streams.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, **cubic metres per second (m^3/s)**. Discharge is different from the speed or **velocity** of flow, which is a measure of how fast the water is moving.
flood	A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
DRAINS	The software program used to develop a computer model that analyses the **hydrology** (rainfall–**runoff** processes) of the **catchment** and calculates hydrographs and **peak discharges**. Known as a hydrological model.

flood hazard	The potential for damage to property or risk to persons during a **flood**. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.
flood level	The height of the **flood** described either as a depth of water above a particular location (e.g. 1m above a floor, yard or road) or as a depth of water related to a standard level such as **Australian Height Datum** (e.g. the flood level was 7.8m AHD). Terms also used include **flood stage** and **water level**.
flood liable land	Land susceptible to flooding up to the **probable maximum flood (PMF)**. Also called **flood prone land**.
flood prone land	Land susceptible to flooding up to the **probable maximum flood (PMF**). Also called **flood liable land**.
Flood Study	A study that investigates flood behaviour, including identification of flood extents, **flood levels** and flood velocities for a range of flood sizes.
floodplain	The area of land that is subject to inundation by floods up to and including the probable maximum flood event, that is, **flood prone land** or **flood liable land**.
Floodplain Risk Management Plan	The outcome of a **Floodplain Management Risk Study**.
Floodplain Risk Management Study	These studies are carried out in accordance with the *Floodplain Development Manual* (NSW Government, 2005) and assess options for minimising the danger to life and property during **floods**. These measures, referred to as 'floodplain management measures/options', aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. The outcome of a Floodplain Risk Management Study is a **Floodplain Risk Management Plan**.
floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels
flow	see **discharge**
HEC-RAS	A software program used to develop a computer model that analyses the **hydraulics** of the waterways within a **catchment** and calculates water levels (flood levels) and flow **velocities**. Known as a 1D hydraulic model.
high flood hazard	For a particular size **flood**, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and **velocity**.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of **peak discharges**, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood).

ILSAX	The software program used to develop a computer model that analyses the **hydrology** (rainfall–**runoff** processes) of the **catchment** and calculates hydrographs and **peak discharges**. Known as a hydrological model.
km	kilometres. 1km = 1,000m = 0.62 miles.
km^2	square kilometres. 1km^2 = 1,000,000m^2 = 100ha ≈ 250 acres.
low flood hazard	For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.
m	metres. All units used in this report are metric.
m AHD	metres **Australian Height Datum (AHD)**.
m/s	metres per second. Unit used to describe the **velocity** of floodwaters. 10km/h ≈ 2.8m/s.
m^3/s	Cubic metres per second or 'cumecs'. A unit of measurement for creek flows or **discharges**. It the rate of flow of water measured in terms of volume per unit time.
overland flow path	The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as ‘overland flows’, may or may not re-enter the main channel from which they left — they may be diverted to another water course.
peak discharge	The maximum **flow** or **discharge** during a flood.
probable maximum flood (PMF)	The largest flood likely to ever occur. The PMF defines the extent of **flood prone land** or **flood liable land**, that is, the **floodplain**. The extent, nature and potential consequences of flooding associated with the PMF event are addressed in the current study.
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall that ends up as flow in a stream, also known as rainfall excess.
THSM	The software program used to develop a computer model that analyses the **hydrology** (rainfall–**runoff** processes) of the **catchment** and calculates hydrographs and **peak discharges**. Known as a hydrological model.
TUFLOW	The software program used to develop a computer model that analyses the **hydraulics** of the waterways within a **catchment** and calculates water levels (flood levels) and flow **velocities**. Known as a 2D hydraulic model.
velocity	the term used to describe the speed of floodwaters, usually in **m/s** (metres per second). 10km/h = 2.7m/s.
water level	see **flood level**.

EXECUTIVE SUMMARY

In accordance with NSW Government policy, Woollahra Municipal Council is committed to preparing a Floodplain Risk Management Plan for the Double Bay catchment. This report documents the first stage of the process of preparing the Plan — that is, the preparation of a flood study report.

The mostly urban catchment totals 280 hectares and almost all of it lies within the Woollahra Council LGA. It includes Double Bay and parts of Edgecliff, Woollahra and Bellevue Hill. While the majority of the stormwater drainage infrastructure is owned by Council, the larger trunk drainage channels and conduits are mostly owned by Sydney Water Corporation.

The report compiles historical records about flood problems that have been experienced in the catchment and it was found that the worst flood was in November 1984. While the historical problems have been relatively limited in both extent and associated damages, it is considered more likely they reflect the fact that the storms themselves have been mostly minor, rather than the capacity of the stormwater systems to cope with the runoff.

Through the development of computer-based (DRAINS) hydrologic models and a (TUFLOW) hydraulic model, the report assesses catchment-wide flows and lower catchment flood behaviour for a range of design flood events including the 100 year and Probable Maximum floods. Flood inundation and risk mapping has been undertaken.

The modelling shows that the principal residential flood problem areas include Manning Road (near Lough Park), Bellevue Road (especially north of Yamba Road), Carlotta Road, Glendon Road, Kiaora Road and Guilfoyle Avenue, while there are Double Bay retail area problems in and north of New South Head Road.

The detailed DRAINS and TUFLOW models will provide a sound platform for the flood modeling tasks that will be undertaken during preparation of the Floodplain Risk Management Study and Plan.

1. INTRODUCTION

1.1 THE STUDY CATCHMENT

The overall study catchment has an area of approximately 280 hectares which drains to Sydney Harbour (**Figure 1**). It includes Double Bay and parts of Edgecliff, Woollahra and Bellevue Hill. Of the total area, 30 hectares represents the west Double Bay portion of the catchment which has separate pipelines conveying local runoff to the harbour. Apart from a very small area (of 14 hectares) at Bondi Junction which is within the Waverley Council area, the catchment lies wholly within the Woollahra local government area (LGA).

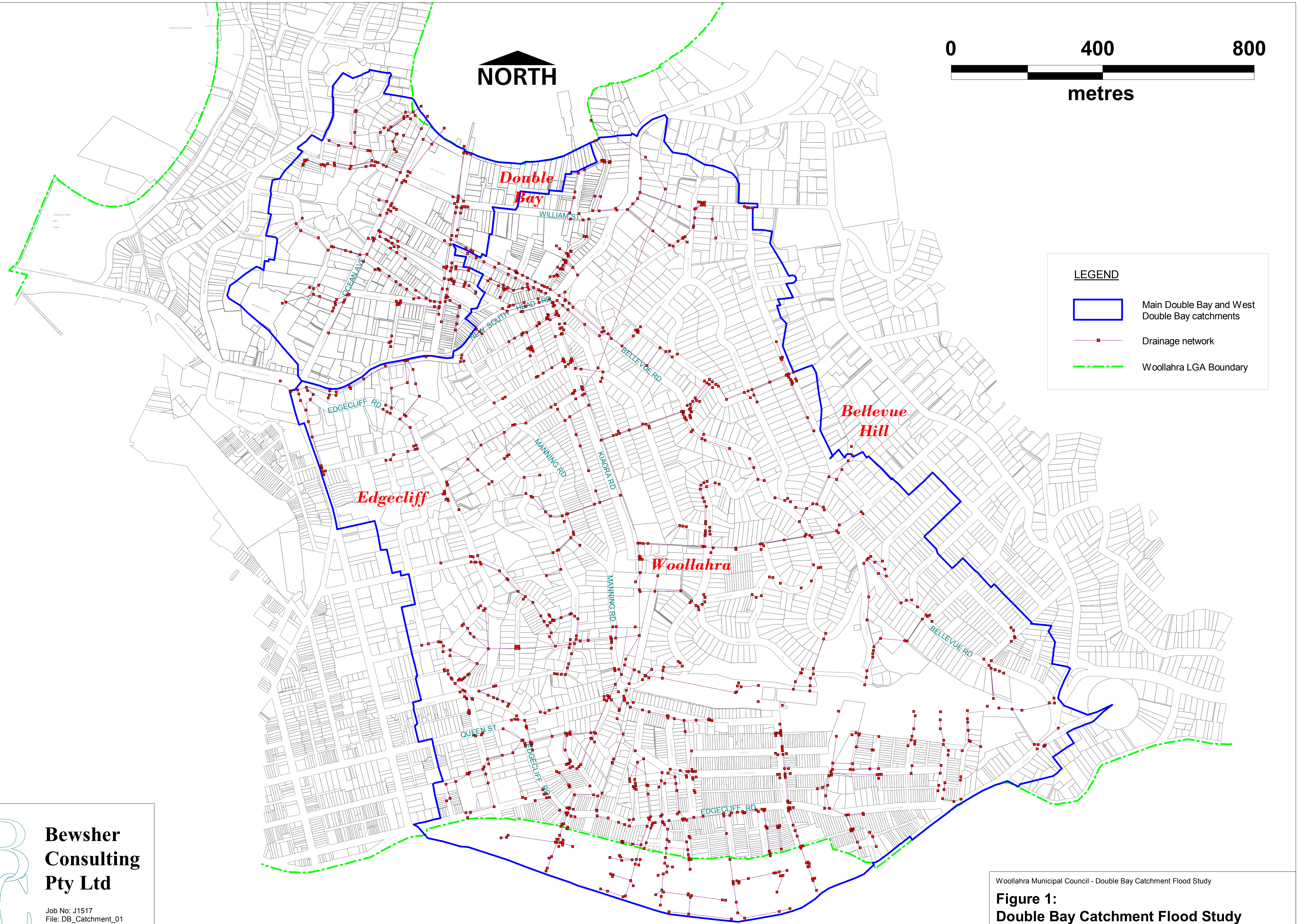
The upper section of the catchment comprises urban development, commercial and retail premises and limited areas of open space apart from Cooper Park. Stormwater within this section is carried within the underground piped network, or when this is exceeded, along roads or through private property. Most of the drainage infrastructure was built in the 1930s.

The lower section comprises the area where stormwater collects into the open channel downstream of Lough Park and the receiving covered channel which passes under New South Head Road and the Double Bay retail area. The major open and covered channels between Lough Park and the harbour are owned and maintained by the Sydney Water Corporation (SWC) while almost all the catchment stormwater pipes and pits are owned and maintained by Woollahra Council.

The original SWC system comprised a mostly open channel system which was constructed in about 1900. In 1938, the open channel downstream of New South Head Road was covered and effectively duplicated (and these works are known as referred to as the *1st amplification* by SWC). In 1968 an amplification tunnel was constructed from Carlotta Road to the harbour along an alignment which was east of the 1938 works (and is referred to as the *2nd amplification* by SWC). The main channel between Lough Park and Carlotta Road was widened in 1986 (and is referred to as the *3rd amplification* by SWC).

The Lough Park playing field area is of importance since it is located in the bottom of the main valley of the catchment and the principal SWC stormwater conduit passes under it. While the grassed embankment at its downslope end would result in floodwaters ponding in the park, there are no records of the embankment having been constructed as part of a purpose-built flood detention basin. We concur with the conclusion reached by Patterson Britton in their 2003 report (**Reference 3**) that there is no formal basin but rather the embankment exists as part of the works associated with the Bondi Ocean Outfall Sewer (BOOS) conduit.

At its lowest point in Double Bay, New South Head Road itself is slightly higher than adjoining southern and northern streets and therefore represents a potentially



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Date: 23 Aug 07

Woollahra Municipal Council - Double Bay Catchment Flood Study

Figure 1:
Double Bay Catchment Flood Study
Study Area

significant barrier to major flood flows which exceed the capacity of the SWC trunk drainage conduits. In these circumstances the resultant floodwaters will pond in the lower areas (centred on Kiaora Road) that lie immediately south of the road until such time as the adjacent SWC trunk drainage system can carry the floodwaters to the harbour.

There have been some instances of flooding of roads and property in the past and these are detailed later in the report.

1.2 STUDY OBJECTIVES

The key objectives of the Flood Study are to:

- define the flows throughout the whole catchment for a range of design events (being the 1 year, 2 year, 5 year, 10 year, 20 year and 100 year average recurrence interval events) and the largest possible event which is known as the Probable Maximum Flood or PMF,

- map the flood behaviour of the open and closed channel systems and the associated floodplain in the lower section of the catchment for the 5 year, 20 year and 100 year design events and the PMF, and

- identify the risk category (i.e. low, medium or high risk) for flood prone land within the lower section of the catchment.

Since the Flood Study provides a technical basis for the subsequent Floodplain Risk Management Study, it is important that the models developed during the study can be used to assess the impact of development and mitigation measures during the Floodplain Risk Management Study phase. This was a major consideration in the choice of hydrologic (DRAINS) and hydraulic (TUFLOW) model software which are described in **Chapters 6** and **7** respectively.

2. DATA BASE

2.1 EARLIER REPORTS

2.1.1 1998 Sydney Water Corporation Report

The SWC prepared a stormwater asset report in 1998 (**Reference 1**). Using basic Rational Method hydrologic calculations and 'uniform flow' conduit capacity calculations, the SWC concluded that their stormwater assets had flow capacities that were typically of the order of 2 year to 5 year ARI.

(Midway through this study, the initial 100 year flood modelling results were indicating that the SWC assets were performing much better in terms of their capacity. This led to a comparison of the DRAINS and TUFLOW model results and the published SWC findings. This comparison found the following:

- the TUFLOW and 1998 SWC conduit capacity values were very similar;
- the SWC analysis did not attempt to model the impact of Lough Park ponding. Therefore not only were their estimates of peak flows downstream of Lough Park conservatively high, but correspondingly their estimates of downstream trunk drainage asset ARI capacities were conservatively low;
- Brown Consulting's DRAINS modelling of ponding in Lough Park showed that the de-facto basin was very efficient in retarding flood hydrographs. That is, the results show that the 5 year peak overland flow was being reduced to virtually zero, while the 100 year peak overland flow was being reduced from about $23m^3/s$ to about $5m^3/s$.

It therefore follows that the detailed catchment-wide modelling that has been undertaken for this study — which specifically includes modelling of the Lough Park flow regime — provided a more accurate picture of both conduit and overland flow regimes.)

2.1.2 2002 & 2003 Patterson Britton Reports

These two reports (**References 2** & **3)** assessed potential flooding in Kiaora Road just south of New South Head Road as part of as proposed major re-development. 100 year ARI event flood levels were initially calculated using a hydrologic model approach which generated levels of RL 3.1/3.2m on the basis of 'level pool' flooding occurring in the low area adjacent to Kiaora Lane. In the 2003 report more specific hydraulic modelling was undertaken and the peak 100 year ARI flood level in Kiaora Road adjacent to Kiaora Lane was also found to be RL 3.1m.

(While the Patterson Britton modelling did include allowance for catchment features such as the ponding in the Lough Park playing fields, the detailed catchment-wide modelling undertaken as part of this study provides a more complete picture of (a) the pattern and volumes of overland flows that are being conveyed to Lough Park, the lower Kiaora Road area and spilling across New South Head Road (principally from the direction of Bellevue Road); (b) the impact of storage occurring at Lough Park; and (c) flood levels in lower Kiaora Road.)

2.1.3 2004 Patterson Britton Report

This report (**Reference 4**) examined local drainage issues in the Bellevue Hill portion of the study catchment and recommended short and long term stormwater works be considered in order to alleviate the identified problems. Hydrologic (DRAINS) modelling was undertaken as part of the investigation but that analysis has now been superseded by the up-to-date and detailed pit-by-pit DRAINS analysis which was undertaken by Brown Consulting for this study.

2.2 STORMWATER SYSTEMS

Council provided extensive details of its stormwater assets and a comprehensive picture of stormwater assets based on that data and supplementary field investigations was put together by Brown Consulting (as documented in **Chapter 6**).

2.3 FLOODPLAIN DEFINITION

Council provided very detailed ground truth and associated mapping data which had been collected under a separate aerial laser scanning contract.

Details of open and closed channels were obtained from the following sources:

- The earlier referenced 1998 SWC report titled *Double Bay SWC 32 Capacity Assessment* (**Reference 1**);
- *2nd Amplification* tunnel design plans provided by SWC; and
- Additional conduit, channel and private bridge information collected by Mr Warren Cole, registered surveyor, expressly for this study.

2.4 HARBOUR FLOOD LEVELS

Consistent with the recent Rushcutters Bay Flood Study (**Reference 6**), the design Sydney Harbour flood levels listed in **Table 1** were adopted for this study. A harbour level of RL 1.30m AHD was adopted for the 1 year, 2 year and 5 year ARI events.

TABLE 1: SYDNEY HARBOUR DESIGN FLOOD LEVELS

Design Flood Event	Sydney Harbour Level (metres AHD)
≤5 year ARI	1.30
20 year ARI	1.38
50 year ARI	1.42
100 year ARI	1.45
PMF	1.50

Note: Levels sourced from Table 9 of Reference 6

3. COMMUNITY CONSULTATION

At the commencement of the study, a community newsletter and accompanying flood questionnaire were prepared and sent to property owners whose properties were adjacent to the major open and closed channel systems.

A total of 219 questionnaires were mailed to owners and the coverage is shown in sheets 1 and 2 of **Figure 2**. A total of 51 questionnaires (or 23%) were returned and of those, 15 contained some information about property flooding problems. While the information was generally useful there was very little specific information about flood depths and flood dates. That this was the case was not surprising given that the last significant flood occurred in November 1984, more than two decades ago. Indeed of the 15 who reported problems at their own properties, the vast majority of those who responded to the question which asked the date of the worst flood thought that the 1984 flood was the biggest.

28 of the returned questionnaires provided information about past flood events — either at or near their property or elsewhere in the catchment.

Two questionnaire respondents from Glendon Road reported experiencing above floor level flooding in 1984. One property owner who experienced flooding from both the direction of Glendon Road and the SWC open channel reported that their above floor level flooding was a function of the former flow regime. The second owner identified that their flooding related to floodwaters overtopping the SWC channel (and it is noted that this event occurred prior to the channel's enlargement by the SWC.)

About thirty of the respondents referred to problems remote from their properties. Those recollections typically related to one or other of two locations; in Kiaora Road (principally near Kiaora Lane and New South Head Road) and in Manning Road (at two sag points adjacent to Lough Park).

It is also noted that three properties in Epping Road which back on to Kiaora Road just below Lough Park reported flood inundation problems in November 1984. Follow-up enquiries confirmed that the floodwaters related to surcharge occurring from the adjacent SWC channel (which as noted earlier has since been enlarged by the SWC).

Woollahra Municipal Council - Double Bay Catchment Flood Study

Figure 2: Targeted Properties for Questionnaire Survey (Sheet 1 of 2)

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Woollahra Municipal Council - Double Bay Catchment Flood Study

Figure 2:
Targeted Properties for Questionnaire Survey (Sheet 2 of 2)

4. HISTORIC FLOODING

4.1 SWC DATA

The Sydney Water Corporation provided historical flooding information and this is reproduced in **Table 2**. The table provides information for a number of storm events between 1943 and 1991.

Most of the information relates to their open channel system between Lough Park and New South Head Road but is only of limited use because there is very little information about flood depths.

The table refers to three occasions of flooding in New South Head Road itself — that is, in 1943, 1951 and 1983. On two of the occasions, shops were reportedly flooded by bow waves generated by buses travelling along New South Head Road.

The table includes only one reference to flooding between New South Head Road and the harbour (in a 1944 storm event) but this was attributed to inadequate stormwater inlet capacity in Cross Street.

4.2 COUNCIL DATA

The following information was gathered from interviews with Council staff and reviews of Council files:

Upstream of New South Head Road

The worst affected streets have been Kiaora Road, Epping Road, Manning Road (near Lough Park) and Glendon Road and the lower parts of Court Road and Forest Road but detailed descriptions of the problems were not available. With the exception of Epping Road and Manning Road, these localities are immediately adjacent to the main open channel. Most of the historic problems appear to be localised – indicating that either the problem was due to local catchment runoff and/or a lack of capacity in the pit and pipe network to convey the flows to the open channel rather than the open channel having insufficient capacity to carry the storm flows.

Several of the reports related to excessive overland flows passing along the drainage reserves that are adjacent to No. 26 Glendon Road and Nos. 47 and 50 Epping Road and there were numerous reports of problems at the two sag points in Manning Road (near Nos. 91 and 117) which are adjacent to Lough Park.

TABLE 2: SWC HISTORICAL FLOODING INFORMATION

DATA RATING: **1** - Well Defined Level and Location **2A** - Level Well Defined, Location Unsure **2B** - Level Unsure, Location Well Defined **3** - Approximate Only
SOURCE OF DATA: A - File No. 224152F9 **B** - File No. 225419F1 **C** - Double Bay SWC 32 General Flooding Folder **D** - File No. 224143F8 E - Flooding Reports Maintenance Bch

LOCATION	LOC. ON MAP	DATE FLOODED FROM	DATE FLOODED TO	DEPTH m	LEVEL ABOVE FLOOR m	LEVEL ABOVE COPING m	FLOOD LEVEL (AHD) m	FLOOR LEVEL (AHD) m	GUTTER LEVEL (AHD) m	REMARKS	DATA RATING	SOURCE OF DATA
Glendon Rd, Double Bay, Bowling Club		14/05/1943	21/05/1943							2 panels of fencing carried away from Bowling Green	2B	A
Epping Rd, Double Bay (D/S of BOOS - between BOOS and Leura Rd)		29/09/1943	29/09/1943							Channel overflowed. Floodwaters travelled down Kiaora Rd. Several garages and yards flooded adjoining Leura Rd.	2B	A
New South Head Road, Double Bay		29/09/1943	29/09/1943							Roadway flooded up to level of doorsteps of shops fronting road. Buses caused bow wave into some shops.	2B	A
Splash Car Wash, Cross Street, Double Bay		29/09/1943	29/09/1943							Several properties badly flooded.	2B	A
New South Head Road, Double Bay		19/02/1944	19/02/1944							Channel overflowed. No damage.	2B	A
Splash Car Wash, Cross Street, Double Bay		20/03/1944	20/03/1944							Some local flooding, due to inadequate inlets to channel	2B	A
Epping Road, Double Bay (D/S of BOOS)		22/04/1947	22/04/1947			0.56				Channel surcharged over coping.	2B	A
Epping Road, Double Bay (D/S of BOOS)		15/06/1949	15/06/1949			0.56				Surcharged over coping and flooded parts of adjacent properties, Double Bay Bowling Club.	2B	A
New South Head Road, Double Bay		25/09/1951	25/09/1951							Stormwater covered footpath and reached floor level	2B	A
Epping Road, Double Bay (D/S of BOOS)		25/09/1951	25/09/1951			0.56				Channel overflowed and flooded parts of adjacent properties.	2B	A
Upstream of New South Head Road, Double Bay		17/11/1961	24/11/1961							Channel overflowed flooding adjacent roadways.	2B	B
Kiaora Road, Double Bay		4/03/1977	4/03/1977							Water marks on walls 0.45m above footpath at B/L. Parked cars flooded half way up doors.	2B	C
New South Head Road, Double Bay		12/08/1983	12/08/1983							Floodwaters flooded shops. Buses caused bow wave 1m deep.	2B	C
Court Road, Double Bay (between Kiaora and Epping Roads, Double Bay)		8/11/1984	9/11/1984							Most properties suffered water damage. Floodwaters exceeded floor level in some cases.	2B	C and D
Kiaora Road, Double Bay (south of Forest Road)		8/11/1984	9/11/1984							Roadway awash up to 0.7m deep.	2B	C and D
Kiaora Road, Double Bay (north of Forest Rd intersection)		8/11/1984	9/11/1984							Flooding less severe, garden damage and roads awash only.	2B	C and D
Manning Road, Woollahra		1989								Waist high flooding in street, 2 cars severely damaged (File 296187FB)	2B	C
Manning Rd, Woollahra		26/01/1991	26/01/1991							Waist high flooding in street, 1 car severely damaged (File 296187FB)	2B	C

Other spots where occasional problems have been reported are:

- near the intersection of Yamba Road and Bellevue Road (where Council has undertaken some works to alleviate the problem);

- below the low point in Magney Street (where above floor level flooding has been experienced);

- at the low point in Nelson Street;

- at the low point in Small Street (and Council has undertaken works to alleviate that problem);

- along the low level footpaths in Edgecliff Road (where overtopping results in flows entering private property).

The 2004 Patterson Britton report commissioned by Council (**Reference 4**) also refers to historic problems in Bellevue Road and Arthur Street.

At New South Head Road

There was one report of the supermarket at Nos. 433-451 New South Head Road being inundated. The date was unknown and it was unclear whether it was due to floodwater overtopping the footpath or a wave created by vehicles negotiating floodwaters in the street.

Downstream of New South Head Road

Details were sketchy but there is a history of local ponding in the Guilfoyle Avenue Reserve.

Also there has been a history of local flooding issues at and near No. 1 Castra Place. (While in response to some of those problems Council has undertaken some stormwater works in adjacent Sherbrook Avenue, it is noted that the cul-de-sac end of Castra Place is lower than the adjacent surface levels on top of the SWC covered channel. This means that surface flows in this area would see the deepest ponding occurring in Castra Place.)

4.3 APRIL 2007 STORM

Midway through the study, there was a significant storm on 4 April. The Bureau of Meteorology reported that a total of 49mm was measured at Bondi Junction (just beyond the southern boundary of the catchment) and 82mm was measured over about two hours at Royal Sydney Golf Club in the neighbouring Rose Bay catchment.

The golf club recorder readings for the most intense 20 to 60 minute periods correspond to between 2 year and 5 year ARI design intensities while the 90 and 120 minute bursts correspond to about 10 year ARI design intensities.

As a result of runoff generated by the storm, a number of New South Head Road shops located between Knox Street and Cross Street experienced some above floor inundation, part of the westbound carriageway of New South Head Road was temporarily closed and the northern part of Kiaora Road was completely inundated (see Photographs 1, 2 and 3). While it is unclear whether those photographs were taken at the peak of the flooding it appears that Kiaora Road was still passable for light traffic.

Photograph No. 1: April 2007 flooding in Kiaora Road looking north towards the intersection with Kiaora Lane.

Photograph No. 2: April 2007 flooding in Kiaora Road looking south towards the intersection with Court Road.

Photograph 3: Vehicles negotiating April 2007 flood waters in the lowest part of Kiaora Road

4.4 SUMMARY

While the SWC and Council data refer to a number of occasions of catchment flooding, the data typically refers to only several ‘problem’ locations — i.e. at Kiaora Road, Glendon Road and Manning Road (near Lough Park) — and there is a lack of detailed information for any of the occasions. This is also mirrored in the comments made by this study’s questionnaire respondents.

Based on the compiled information, the worst flooding occurred early in the morning of 8 November 1984 (and further details regarding that flood are provided in **Section 5.3**). There were also several references to flooding in August 1983 and January 1991. It is noted that all three storms also impacted on the neighbouring Rushcutters Bay catchment (**References 5** and **6**).

The historical problems appear to have been relatively limited in both extent and associated damages. However it is more likely that they reflect the fact that the storms themselves have been mostly minor, rather than the capacity of the stormwater systems to cope with the runoff.

5. FLOOD STUDY METHODOLOGY

The Flood Study involves a comprehensive technical investigation of the nature and extent of flooding within the catchment and, as required, it includes the assessment of pipe and overland flows throughout the catchment and the calculation of flood levels in its lower section.

The computer-based modelling of the catchment-wide pipe and overland flows is known as *hydrologic modelling*. When these flow rates are combined with information defining the ground levels in the floodplain, the resulting water levels, velocities and flood extents are calculated by undertaking *hydraulic modelling*.

Wherever possible predicted flood behaviour from these models is calibrated and verified through the collection of historical flood data.

5.1 CHOICE OF HYDROLOGIC MODEL

At the time the flood study was commissioned DRAINS software was already being used to assess pipe network performance throughout the Woollahra LGA. This work was being undertaken by Brown Consulting under a commission from Council. Given that situation — and Council's preference for DRAINS to also be used for this study — Brown Consulting was engaged to undertake the modelling throughout the Double Bay study catchment to ensure consistency with the broader LGA hydrologic modelling.

5.2 CHOICE OF HYDRAULIC MODEL

Flood studies of catchments such as Double Bay's have typically seen the adoption of the widely-used (and one-dimensional) HEC-RAS modelling software. However at the beginning of this study it was appreciated that more powerful and sophisticated modelling software, which was now available for assessing the flood regimes in what are potentially complex urban overland flow situations, should be used.

The type of model chosen is a combined 2-dimensional/1-dimensional hydraulic model that can accurately define formal creek channels and stormwater pipe systems as 1D 'elements', while the overbank/overland flowpaths are explicitly modelled using a fine scale two-dimensional grid. In the particular software (TUFLOW) used in this study, the analysis is undertaken using a 2D solution algorithm which solves the full two dimensional, depth averaged, momentum and continuity equations for free-surface flow while ESTRY (a 1D or quasi-2D modelling system which is based on the full one-dimensional free surface flow equations) is used for modelling the 1D elements.

5.3 REVIEW OF HISTORIC FLOOD INFORMATION

As detailed earlier, the most serious flooding occurred on 8 November 1984.

Unfortunately there is no record of the amount of rainfall which fell in the Double Bay catchment. The two nearest recorders in November 1984 were at Paddington and Vaucluse. Information presented in a 1985 Bureau of Meteorology report (**Reference 7**) shows that the rainfall patterns recorded at those two locations were quite dissimilar. As can be seen in **Table 3**, the Vaucluse intensities were greater up to and including one hour but for all longer durations the Paddington intensities were greater.

TABLE 3: MAXIMUM NOVEMBER 1984 RAINFALL INTENSITIES (mm/h)

	Duration (hours)										
	0.1	0.2	0.3	0.4	0.5	1	2	3	6	12	24
Paddington	125	118	113	108	105	90.5	73.8	54.0	27.8	14.5	10.4
Approx. ARI	2y	5y	10y	10y	20y	50y	>100y	>100y	50y	20y	50y
Vaucluse	165	153	157	148	143	100	54.8	40.8	20.9	10.7	7.8
Approx. ARI	10y	20y	50y	<100y	>100y	>100y	50y	50y	10y	10y	10y

Note: Data sourced from **Reference 7**

Hence although the Vaucluse intensities are very high, the intense part of the storm was much shorter compared with Paddington. Given these differences in rainfall pattern and depth recorded either side of the Double Bay catchment, it is quite unclear what the rainfall pattern would have been in the study catchment.

While both the SWC data in **Table 2** and some of the respondents to this study's questionnaire provided an idea of how high the floodwater came in the flood there is no precise information which would provide a detailed and accurate picture of flooding.

Additionally it is important to note that the present day open channel between Lough Park and Carlotta Road represents the result of the 1986 SWC construction works which significantly increased the channel width that existed at the time of the November 1984 flood. This means that the 1984 flood observations made by people who live adjacent to that portion of the channel would not reflect the impact of a similar storm event being experienced today.

Given this combination of no within-catchment rainfall data and the lack of detailed flood levels, there is no clear picture of the Double Bay flood regime that occurred on 8 November 1984. Hence the flood could not be used for calibration purposes.

Since the information for other — and smaller — historic events was less than that which had been compiled for the November 1984 flood, those events were also not suitable for model calibration or verification purposes.

6. DRAINS MODELLING

6.1 INTRODUCTION

6.1.1 Overview

This chapter documents the hydrologic modelling of the study catchment which was undertaken by Brown Consulting. Initially the work was undertaken under a commission from Bewsher Consulting for the Double Bay catchment (see **Figure 3**). However, since the initial hydraulic modelling demonstrated the potential for floodwater to spill into the adjacent 'West Double Bay' catchment, the hydraulic modelling was extended to formally include the latter area. Hence as detailed in this chapter, the hydrologic modelling of the study catchment also needed to be extended and is therefore a combination of part of the "Darling Point and West Double Bay" model (see **Section 6.3**) which was modelled by Browns under a separate, and broader LGA-wide, commission from Council (**Reference 12**) and the "Main Double Bay" model (see **Section 6.4**).

The main thrust of the modelling was to model and to assess the capacity of the piped drainage systems using the DRAINS software (**Reference 10**) plus the estimation of flood flows in large storm events, both along streets and in private properties.

6.1.2 Objectives

The specific objectives related to the flood study were:

1. To review the existing GIS layers of pipes and pits, and define additional layers for sub-catchments and flowpaths taking account of the layers of parcels and contours,
2. To review the existing THSM hydrologic model and its data, and utilise this existing data whenever possible in developing DRAINS models, and
3. To develop DRAINS drainage models using the latest version of the DRAINS computer program. To run the DRAINS Model for 1, 2, 5, 10, 20 and 100 year ARI and PMF storm events and define additional layers in Council's GIS to present the results of DRAINS modelling.

6.1.3 Available Information

Considerable information was available from previous studies by Council and various consultants. The data provided included:

- GIS layers (ESRI shapefiles) that contained information on pits and pipes gathered during previous modelling by Council using the THSM program;

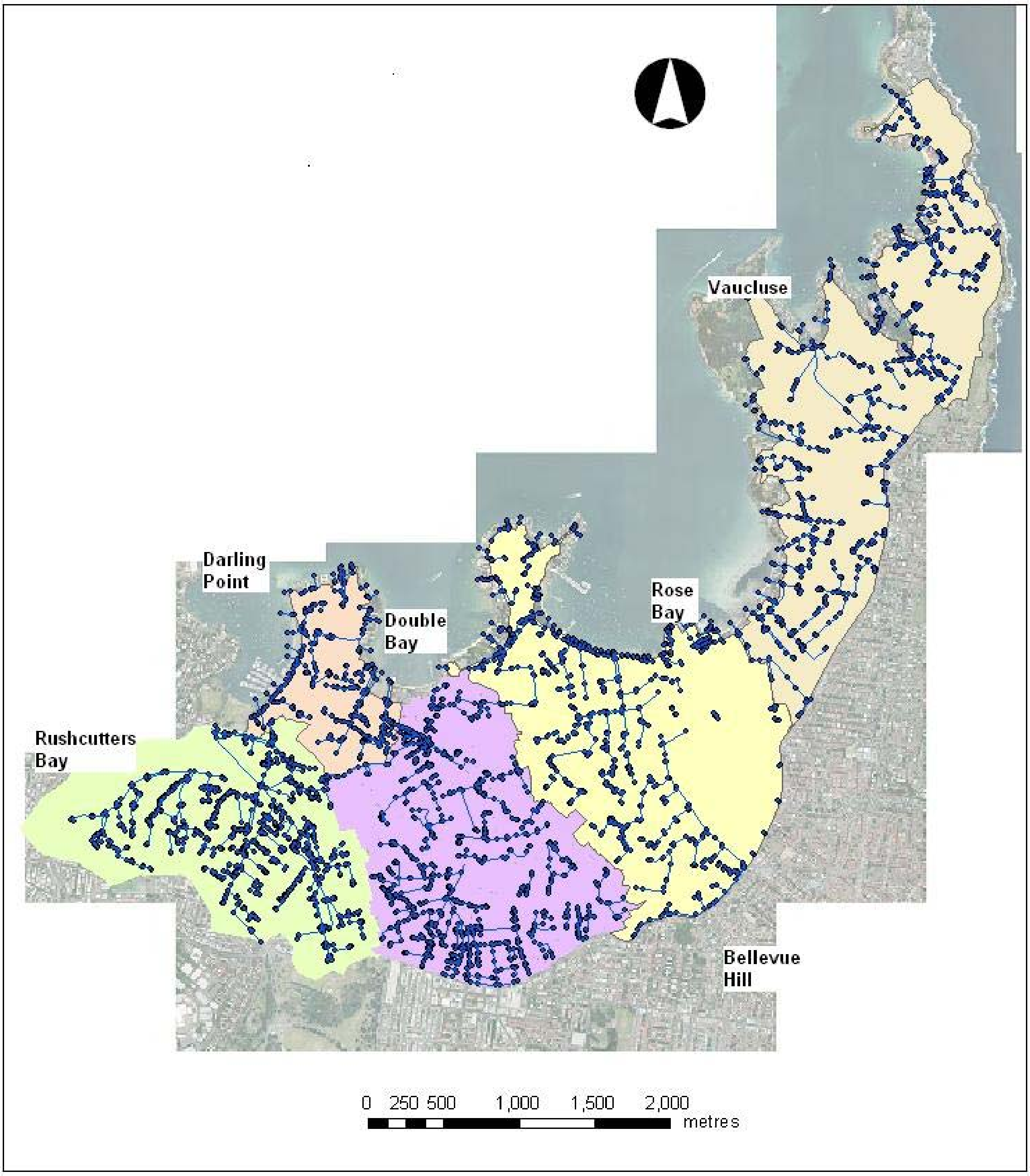

Figure 3: Location of individual DRAINS models throughout the Woollahra LGA

- other GIS information including land parcels, aerial photography and contours at 2m intervals;
- paper plans of the drainage system;
- sub-catchment diagrams from the THSM modelling;
- reports on parts of the system, e.g. by Sydney Water (**Reference 1**) and Patterson Britton (**Reference 4**).

During the study, Council provided aerial laser scanning (ALS) data and a set of 0.25m and 0.5m contours developed from this.

Little documentation of the THSM modelling and work-as-executed plans for drainage works carried out by Council was available. Information on flooding complaints was also limited.

All drainage systems were inspected by Brown Consulting staff and details of pit inlets were noted.

6.1.4 Methodology

The methodology had been previously defined in a pilot study carried out for Woollahra Municipal Council by Brown Consulting in August 2005 (**Reference 8**). This study involved the creation of a detailed model for drainage system BH9 on the eastern side of Double Bay, the assessment of available information and recommendations on procedures to be adopted by Council.

The steps proposed to be used in this study were broadly as follows:

(a) Gather available information from Council, including the GIS layers and paper plans available, including those from an internal modelling process carried out by Council using the now-obsolete THSM program.

(b) Carry out site inspections, viewing all pits and pipelines.

(c) Develop base-case DRAINS models, incorporating a cadastre base and the various components of the models, together with suitable design storms.

(d) Provide preliminary results in a draft report, and obtain comments from Council staff.

(e) Revise models where necessary and produce a final report, providing this to Council, together with the DRAINS models and related files such as GIS layers of sub-catchments.

There have been some changes to parts of the proposed methodology as complexities have been encountered. As expected from the pilot study, the THSM information was of limited use. DRAINS requires more information than THSM, and it was considered not worthwhile to convert THSM text files to DRAINS format. Instead, DRAINS models were developed from scratch, with pit and pipe locations being brought into the base model when the background was imported from GIS layers. The existing THSM information in the GIS files did prove useful in providing pipe diameters, lengths and depths at pits, information that appears to be generally reliable. Drawings of sub-catchments used in the previous modelling were informative when estimating sub-catchments in the present study.

As the study progressed, the need to model some parts of the system differently from the standard procedures became apparent. This was the case for sub-catchments containing large, undocumented property drainage systems leading to single street pits with low inlet capacity. A node and dummy pipe was used to model the effects of these property drainage systems.

Many situations proved to be difficult to assess given the number of old pipe systems and unknown alterations to these. Notes were made in the DRAINS model wherever there were uncertainties about particular components.

6.1.5 Final Product

A CD was provided to Council which contains ESRI shapefiles of the sub-catchments developed during this study and the shapefiles contain information on the results generated for pits (nodes), pipes, sub-catchments and overflow routes in the runs of the DRAINS models.

6.2 MODELLING PROCEDURES

6.2.1 General

Modelling followed the general methodology described in **Section 1.4** while specific guidelines were established at the start of the project so that all of the LGA-wide DRAINS models would be consistent. These have been adhered to with a few exceptions and are outlined below. Several issues mentioned relate to technical details of the DRAINS model which are not explained here but are covered in the DRAINS Manual (**Reference 10**).

6.2.2 Specific Assumptions

Locations and Details of Components

Generally Council's information was accurate, but there were several disparities between pit and pipe locations on Council's GIS layers, its paper plans and field observations. The greatest weight was given to inspections, then second to the paper plans and finally to GIS layer information.

DRAINS Version

The general practice when developing models was to use the latest version of DRAINS. Versions 2007.06 to 2007.08 were used to make the runs reported in this study, operating in basic hydraulic calculation mode.

Hydrological Model

The hydrological model applied in DRAINS was an ILSAX model with Soil Type 3 and antecedent moisture condition 3.

Rainfall Data

The models utilised the standard Woollahra data from Council's website. Design storms obtained from Chapter 3 of *Australian Rainfall and Runoff* (**Reference 11**) were run for ARIs of 1, 2, 5, 10, 20 and 100 years and for probable maximum storms. For ARIs up to 100 years, durations from 5 minutes to 3 hours were considered, and for PMP, durations of 0.25, 0.5, 1, 1.5 and 2 hours were considered.

Pits

Generally, the Hornsby pit capacity data set available in DRAINS were used to model kerb inlets with single grates. For kerb inlets alone, grates alone or other pit arrangements, relationships created from the DRAINS pit capacity spreadsheet were used. Pits without inlets were specified with bolt down lids.

All street pits were included and pit surface levels were obtained from ALS data. The pit types observed during field inspections are noted in the comment spaces in the Pit property sheets in DRAINS. The following codes were used in these notations:

G – standard 900 x 450 mm cast iron

1000G – 1000 x 450 mm galvanised steel grate

2500L – kerb inlet with 2500 mm lintel (taken to nearest size in the set of Hornsby pits)

S – sealed or bolted-down pit (junction pit).

Due to access problems, it was not possible to specify pits on private property accurately. These were usually modelled as sealed pits.

The Mills procedure in the DRAINS Run menu, implemented after performing a 100 year ARI run, was used to define pit pressure change factors for full pipe flow. For part-full pressure changes, the third option with the standard multiplier of 1.0 has been used in all cases.

Blockage factors were set to 0.5 for sag pits and 0.0 for on-grade pits.

Pipes

Standard concrete pipes can be specified in most cases. Where there are rectangular pipes these were set up as a pipe type in the DRAINS pipe data base. Where depths at pits were available from the GIS information these were used, but otherwise an assumed depth with 0.4 to 0.6m cover was assumed.

Converters (pipes ending in a surcharge pit) were modelled as a pipe ending at a node, with an overflow route leading to the downstream receiving pit.

Sub-Catchments

Proportions of paved, supplementary and grassed surfaces within sub-catchments were estimated from aerial photos.

Sub-catchments were generally provided with constant times of entry for sub-catchments of 0.1 ha and below, and with flow path information for kinematic wave calculations for larger sub-catchments. In some cases there was a constant time for the paved area flow path and a kinematic wave calculation plus a constant or a time lag for the grassed area.

Overflow Routes

A few representative cross-sections in the DRAINS overflow route data base were applied to overflow routes. Uncertain routes, such as those through private property were assumed to have a nominal 4m wide path. The assumed times were based on a speed of 1m/s but slower speeds were estimated where obstructions such as fences were present.

Lengths were scaled off plans. Slopes were usually set at 1%.

Outlets

Where these are to Sydney Harbour, a tailwater level of 1.0m AHD was adopted.

6.3 DARLING POINT AND WEST DOUBLE BAY MODEL

6.3.1 General

The areas modelled in the 70ha catchment shown in **Figure 4** have mainly residential land-use. The Double Bay area includes a school and part of the Double Bay commercial area.

The landform consists of a hill projecting into Sydney Harbour at Darling Point, and a flatter area, probably an infilled bay, to the east, at Double Bay. The study area has been modelled using 307 sub-catchments, with the average land-uses being 67.5% paved, 0.5% supplementary and 32% grassed. Areas that drain directly to Sydney Harbour are not included in the model.

6.3.2 Catchment Characteristics

This drainage system, shown in **Figure 4**, includes two major pipelines draining the western part of Double Bay. Only one section of open channel, near Spring Street, is involved. Areas that drain directly to the Harbour with no identifiable piped drainage system, such as Steyne Park, are not included in the model.

6.3.3 The DRAINS Model

The model developed, shown in **Figure 5**, contains 404 pits, and associated pipes, channels, sub-catchments and overflow routes. Of these, 180 of the pits are within the Double Bay study catchment.

The most critical part of the system is the depressed area at Guilfoyle Avenue in west Double Bay, which at one point has a surface level of 2.1m AHD, which is one metre below any possible overland drainage path out of this area. **Figure 6** shows this area. Two detention basins have been used to model this location, one for the areas south of the centreline of Guilfoyle Avenue (which incorporates a small park) and the other for the areas north of this line. Levels in the two basins are equalised using two opposing overflow routes between the basins. It was very difficult to establish a definite overflow path out of this area. A weir with a crest level of 3.25m and a 20m length was assumed to control overflows, with these being directed northwards to the corner of Ocean Avenue and Cross Street.

These basins have been modelled more closely than was originally intended due to a request from interests wishing to re-develop a property on Guilfoyle Avenue. With Council's concurrence, additional local investigations and modelling were performed, and some unsteady flow modelling was undertaken. The level finally set was slightly lower than that given by the current models, which use the basic hydraulics in DRAINS.

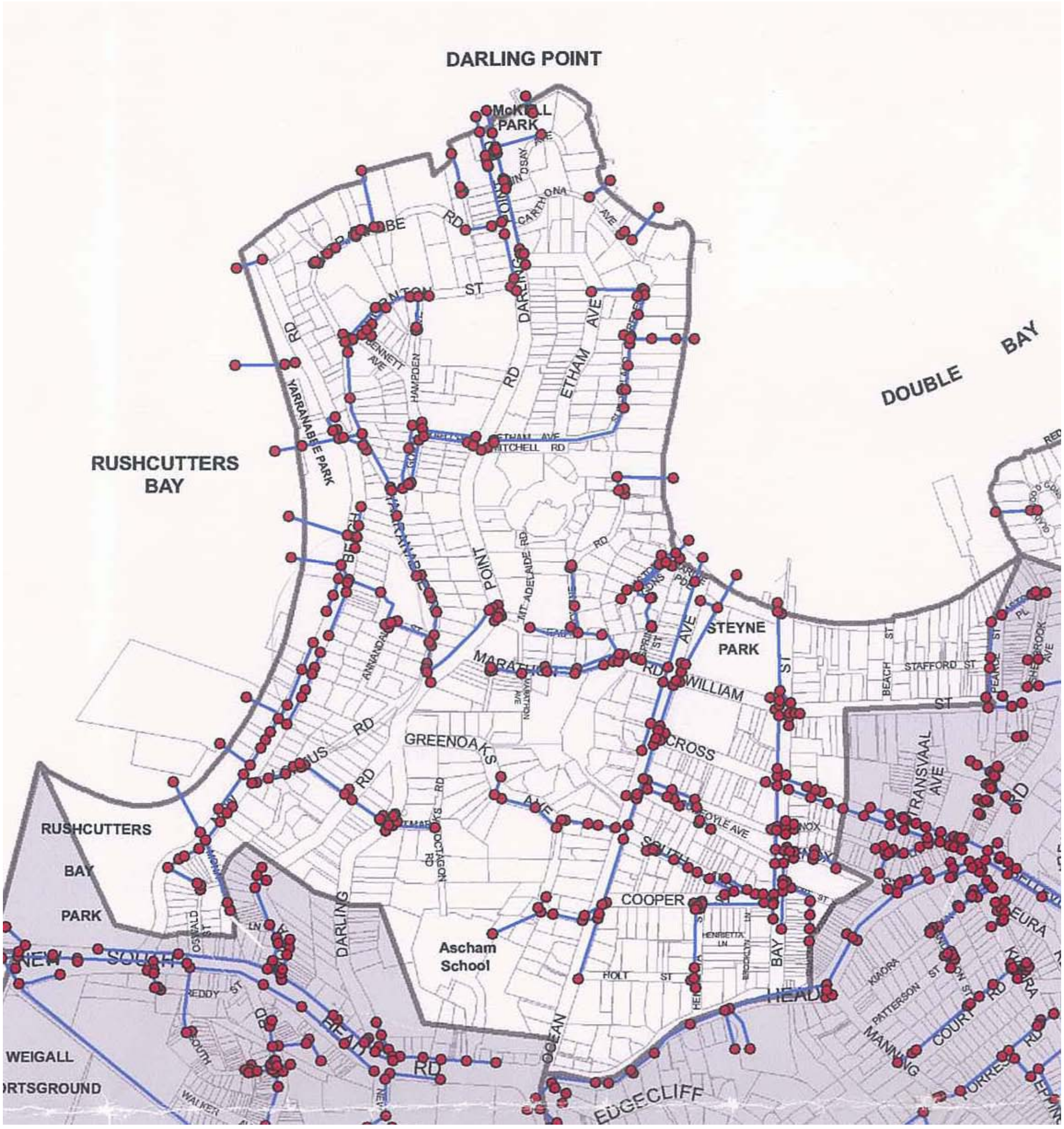

Figure 4: Woollahra Council map of the Darling Point and West Double Bay model area

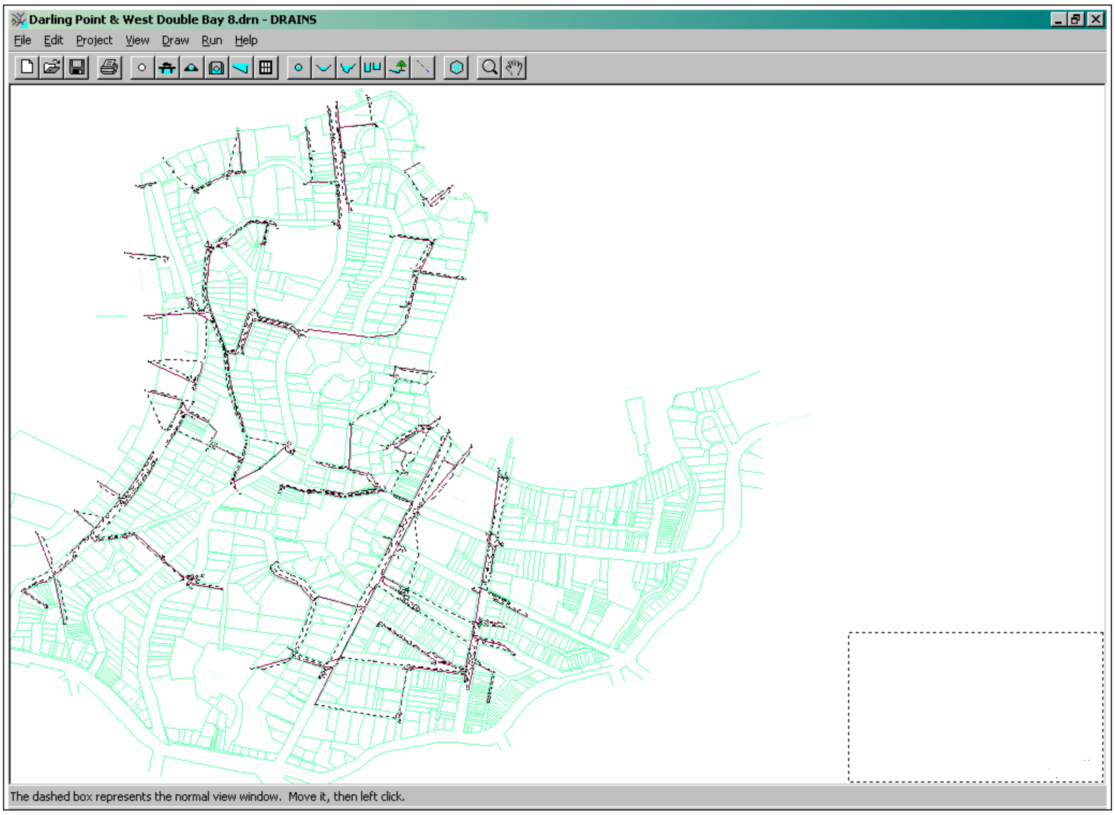

Figure 5: DRAINS model for the Darling Point and West Double Bay area

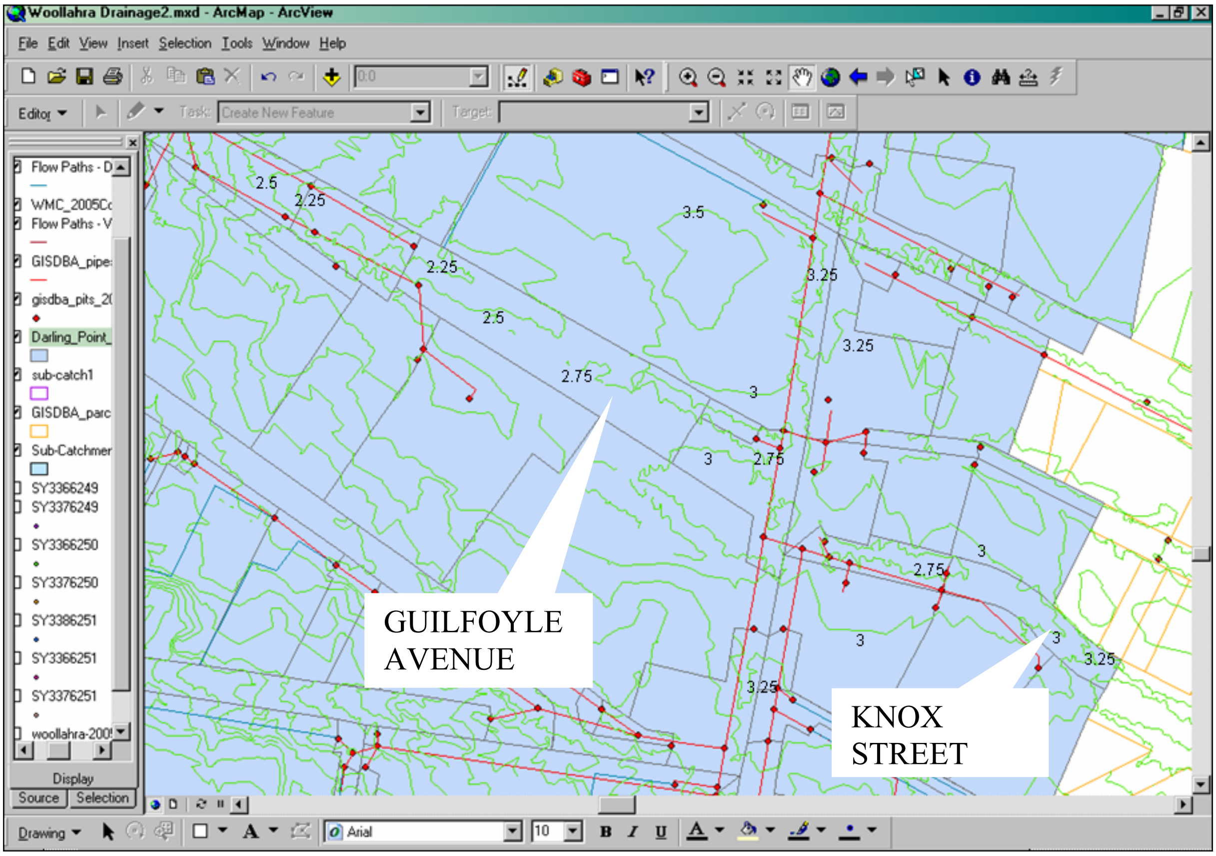

Figure 6: Low Points at Guilfoyle Avenue and Knox Street

Similar flooding due to a trapped low point is likely to occur in Knox Street near the corner of Bay Street (**Figure 6**). Due to the possibility of flows being transferred to and from the main Double Bay catchment to the east, this has not been modelled as a detention storage.

6.3.4 Modelling Results

General modelling results can be inspected in the output files included in the CD, as shown in **Figure 7**. Peak flows, hydraulic grade lines, pipe cross-sections and hydrographs can be inspected, and data can be exported to spreadsheets, and CAD or GIS programs. Significant results are presented in **Table 4** for 1, 10 and 100 year ARI storms of 5 minutes to 3 hours duration and PMP storms of 15 minutes to 6 hours duration.

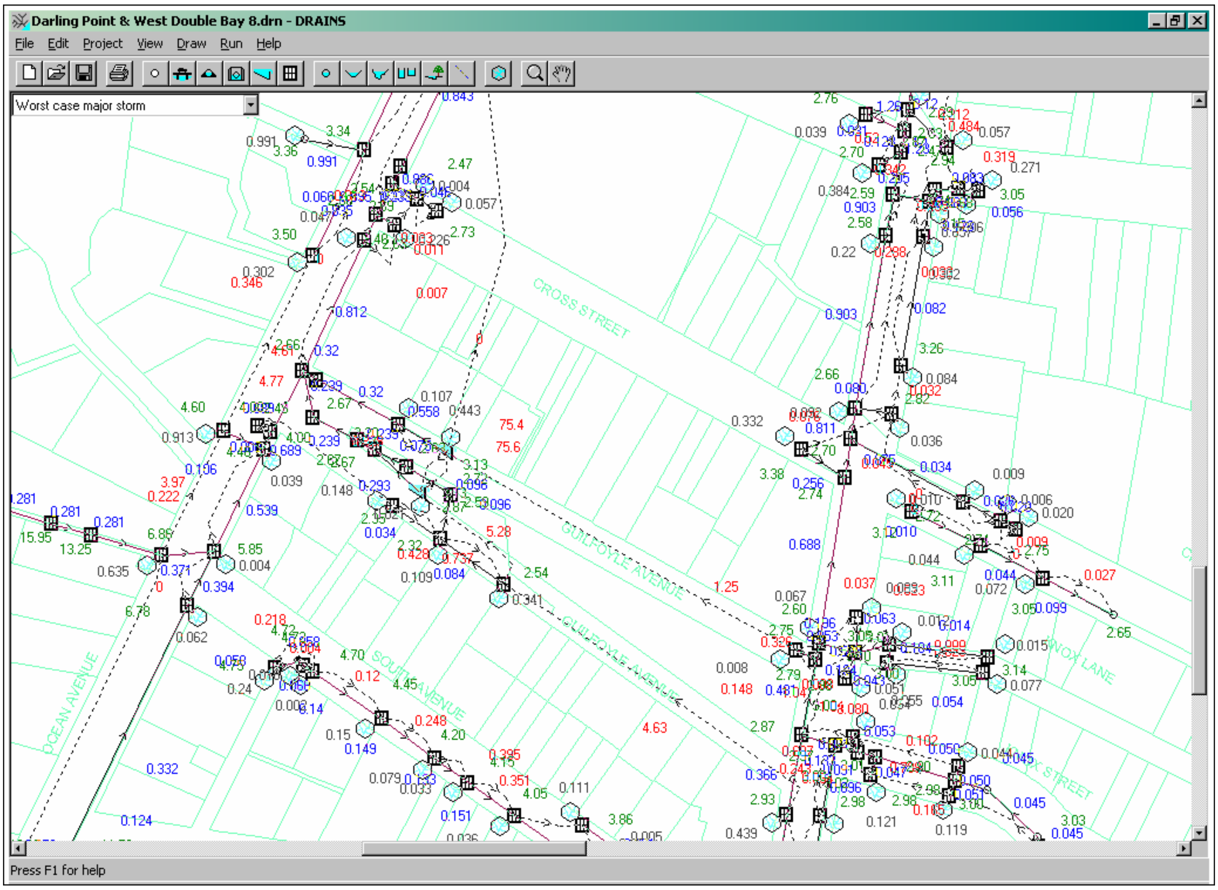

Figure 7: Typical DRAINS model output

For ARIs between 1 year and 100 year, the catchment flows and overflows were greatest for 25 minute storms, while the highest pipe flows corresponded to storms of all durations. The critical storm duration for the PMF event was found to be 15 minutes.

There are only a few locations where flows run through properties and it appears that these will not cause problems in storms more frequent than 10 year ARI. The main problems, as noted earlier, are the low points at Guilfoyle Avenue and Knox Street. Since they are both within the footprint of the TUFLOW hydraulic model, it is recommended that the TUFLOW flood results should take precedence.

TABLE 4: SURFACE OVERFLOWS AT POTENTIAL WEST DOUBLE BAY PROBLEM LOCATIONS

Location [and Relevant Overflow Routes]	**Surface Overflow (m^3/s) for ARI:**			
	1 year	**10 year**	**100 year**	**PMF**
Surface overflows through properties between Spring Street and Marine Parade [oDP1A50/2]	0.23	0.85	1.3	5.6
Level (m AHD) at Guilfoyle Street Ponding Area (Base Level 2.1m AHD) — Note that these are calculated using basic hydraulics; results with unsteady hydraulics are lower — e.g. 3.13m in 100 year ARI storms.	2.61	2.94	3.18 (3.13m determined in more accurate unsteady analysis)	>3.7

6.4 MAIN DOUBLE BAY MODEL

6.4.1 Background

The principal purposes of the Main Double Bay model are to not only assess pit-by-pit pipe and overland flows (as for the other Woollahra Council DRAINS models) but to also supply flow information for the lower catchment TUFLOW model. Hence given that there are aspects of floodplain drainage that are complex and which could not be adequately modelled using DRAINS (e.g. potentially complex exchanges between ponded surface water and flows along the partly-open channel and also the flow split at the SWC tunnel located at the corner of Carlotta Road and Kiaora Road), the flow regimes modelled within the TUFLOW model area should take precedence.

6.4.2 Catchment Characteristics

Most of the Main Double Bay Catchment, shown in **Figure 8** and **Figure 9** is a steeply-sided valley that is initially oriented in an east-west direction but then turns to the north and opens out onto Sydney Harbour. Parts of the valley floor are flat and occupied by parks and sporting fields. Most of the catchment land-use is residential,

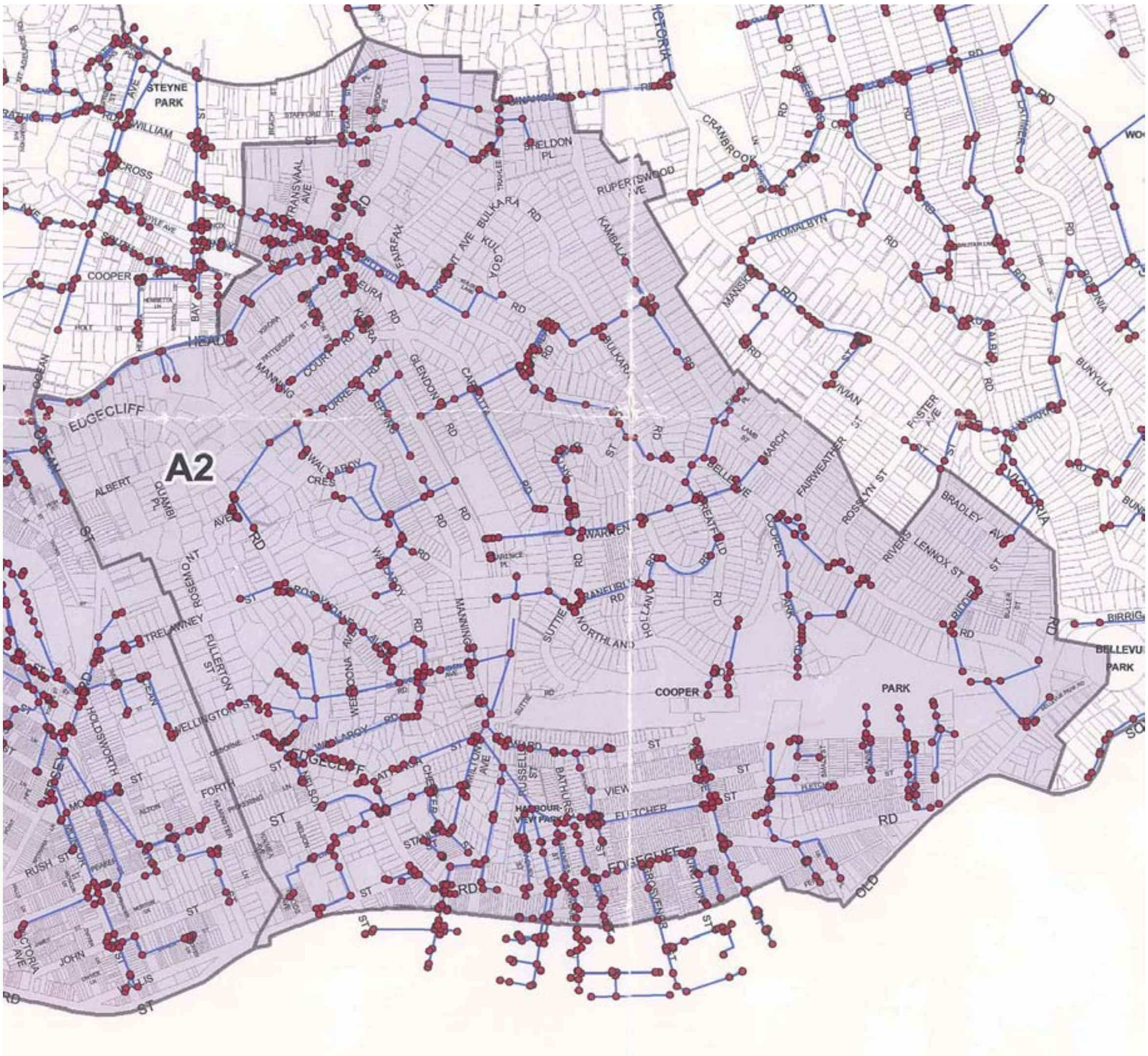

Figure 8: Woollahra Council Map of the Main Double Bay Model Area

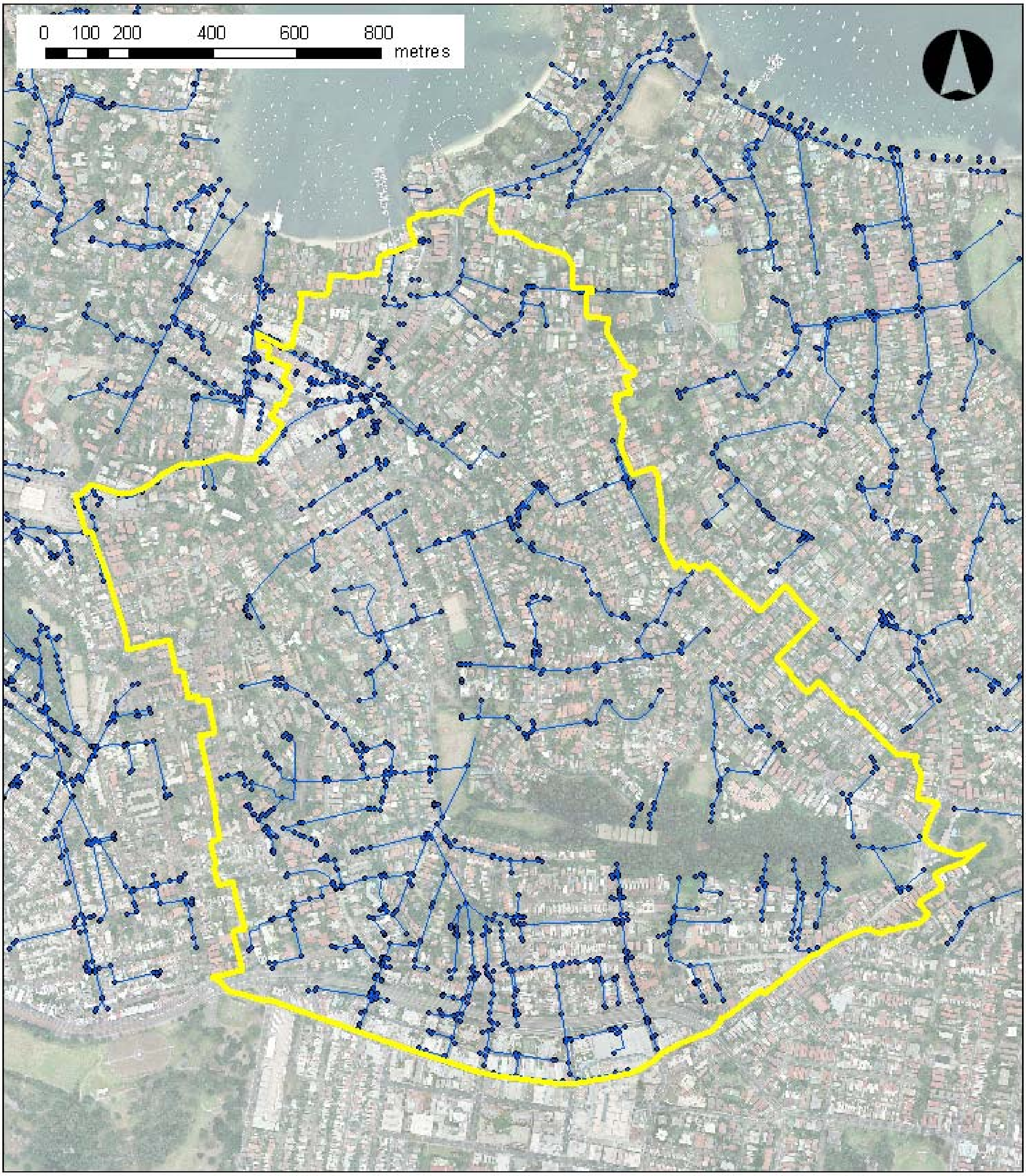

Figure 9: Main Double Bay Modelled Area showing Aerial Photograph

with single cottages predominating. There is a shopping centre on Bellevue Hill Road at the top of the catchment, part of the Bondi Junction commercial area to the south and the Double Bay shopping centre near the catchment outlet.

The trunk drainage system is controlled by Sydney Water Corporation and consists of diverse open channel and closed conduit elements.

6.4.3 The DRAINS Model

The DRAINS model of the pipe system, shown in **Figure 10**, includes 1062 pits and nodes and 685 sub-catchments, covering an area of 249ha. The breakdown of surface types is 65% paved, 1% supplementary and 34% grassed. Limited information was available for the 14ha of the catchment which lies within the Waverley Local Government Area (LGA), and this was defined approximately.

Care was taken to match the overall boundaries of the model to the adjoining Rushcutters Bay (**Reference 6**) and Darling Point and Bellevue Hill models (**Reference 12**). Definition of some boundaries, particularly those at the Double Bay shopping centre, is difficult even with the detailed contours available from aerial laser scanning.

Certain features of the complex main drainage system required particular attention. As mentioned earlier, the modelling of the separation of the main channel and tunnel flows at Carlotta Road and Kiaora Road was found to be quite complex.

Other instabilities have been traced up through the pipe system. Five pits that were sealed or bolted down were inspected – BH10A30, BH10A55, BJ10J10, W3AA100A and W3AF40A. In all these cases there was a reduction in pipe diameter occurring at a sealed pit. Since the lids of these pits are likely to be unsealed or “blown out” during storm events and some overflows will occur, they were modelled as ‘open’ pits.

Some small drainage systems located quite high up in the system showed localised instabilities that can be large in the vicinity of the pit and cause fluctuations in downstream flow hydrographs. Adjustments were made to some of these, but others that caused small or local fluctuations were retained (since they would have little impact on the lower catchment’s TUFLOW model).

6.4.4 Modelling Results

General modelling results can be inspected in the CD outputs provided to Council.

The main flood-affected areas were found to be the Double Bay Shopping Centre, the Kiaora Road area, Manning Road near Lough Park and low lying properties along Bellevue Hill Road north of Yamba Road. For the de-facto basin in Lough Park, the model predicts very extended ponding times. For example, the total ponding time in the 3 hour 100 year ARI storm is about 36 hours. The peak 100 year ARI ponding level in Lough Park was calculated to be 9.1m AHD.

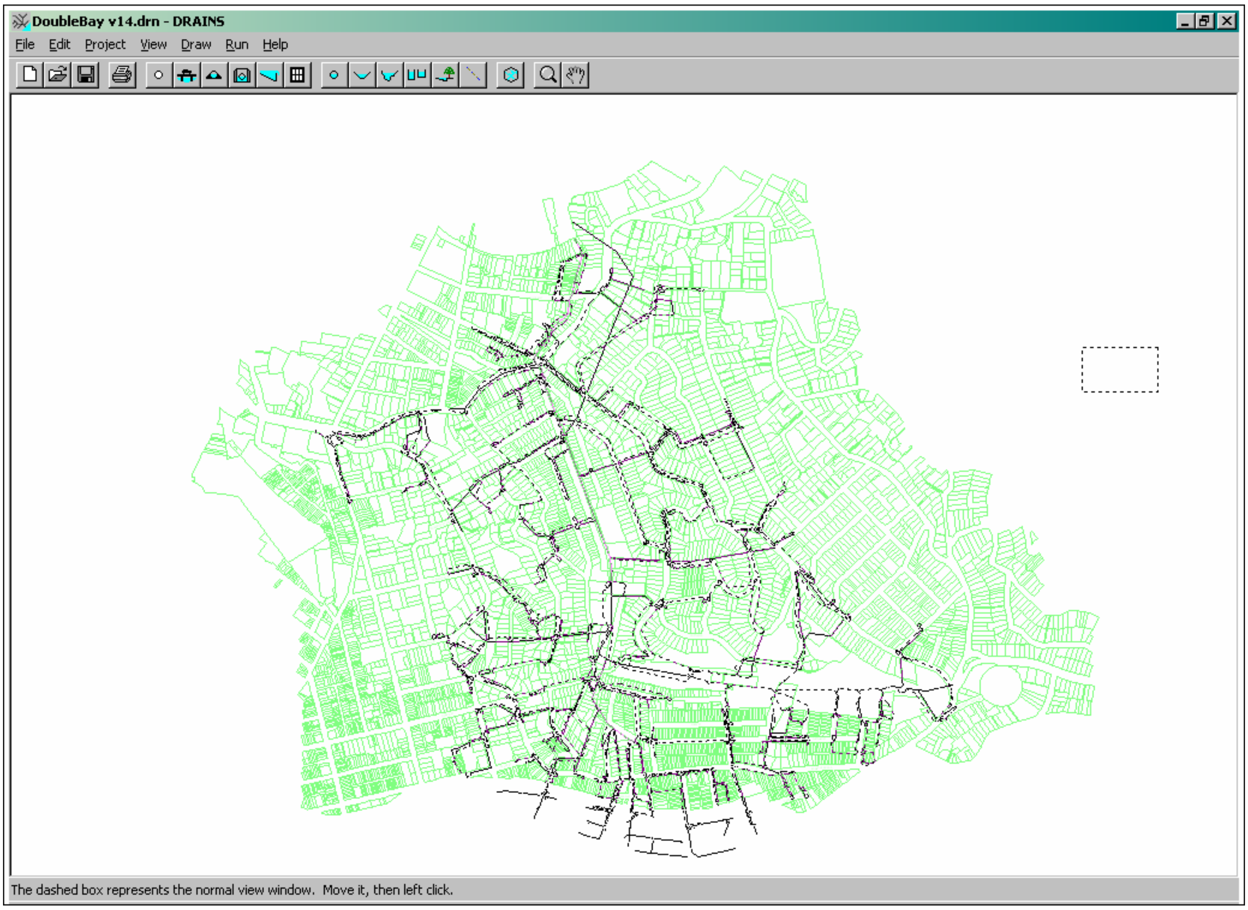

Figure 10: DRAINS model for the main Double Bay area.

The most serious problem in the higher parts of the catchment appears to be flows through properties between Edgecliff Road and Chester Street.

Significant results for some upper catchment areas are presented in **Table 5** for 1, 10 and 100 year ARI storms of 5 minutes to 3 hours duration and PMP storms of 15 minutes to 6 hours duration.

6.5 CATCHMENT WIDE FLOW RATES

Figure 11 defines pipe capacities in terms of average recurrence intervals and it can be seen that many of the pipes have only a 1 year ARI capacity. It is noted that while some pipes show significantly greater capacities, this may occur because inlet capacities govern how much flow enters the system and/or upslope overland flow (sourced from local runoff and/or upper catchment pit surcharge) is diverted elsewhere.

TABLE 5: SURFACE OVERFLOWS AT POTENTIAL UPPER CATCHMENT PROBLEM LOCATIONS

LOCATION (and Relevant Overflow Routes)	**Surface Overflow (m^3/s) for ARI:**			
	1 year	**10 year**	**100 year**	**PMF**
Possible surface overflows through properties Chester Lane (off Stanley Street) and Chester Street [oW2G60]	0.03	0.14	0.22	0.94
Surface overflows through properties between Chester Street and Milton Street [oW2H10]	0.96	2.2	4.2	17
Possible overflows across Railway Line between Edgecliff Road and Weeroona Avenue [oW3AL30]	0	0.97	2.2	12
Overflows through properties between Weeroona Avenue and Glencoe Road [oW3AM10]	0.11	1.1	2.6	14
Overflows through properties between Edgecliff Road and New South Head Road [oDB17AI10]	0.83	2.6	4.1	17
Overflow through property between Sheldon Place and Trahlee Road [oBH1D40]	0	0.11	0.21	0.99
Overflow through properties between Kulgoa Lane and Bellevue Hill Road [oBH3aE20]	0.04	0.2	0.31	1.1
Two overflows through properties between Kambala Road and Bulkara Road [oBH9A170, oBH9A190]	0	0.17	0.56	3.3

Figures 12 to **15** define the peak overland flows for the 5 year, 20 year, 100 year and PMF events. When compared with the TUFLOW-generated flowpaths defined in the Chapter 7 flood inundation maps, some differences can be seen with the flowpath alignments shown in these figures. Since the flood inundation maps represent the combination of both DRAINS and TUFLOW modelling, the TUFLOW-generated flowpaths are more accurate and therefore should take precedence.

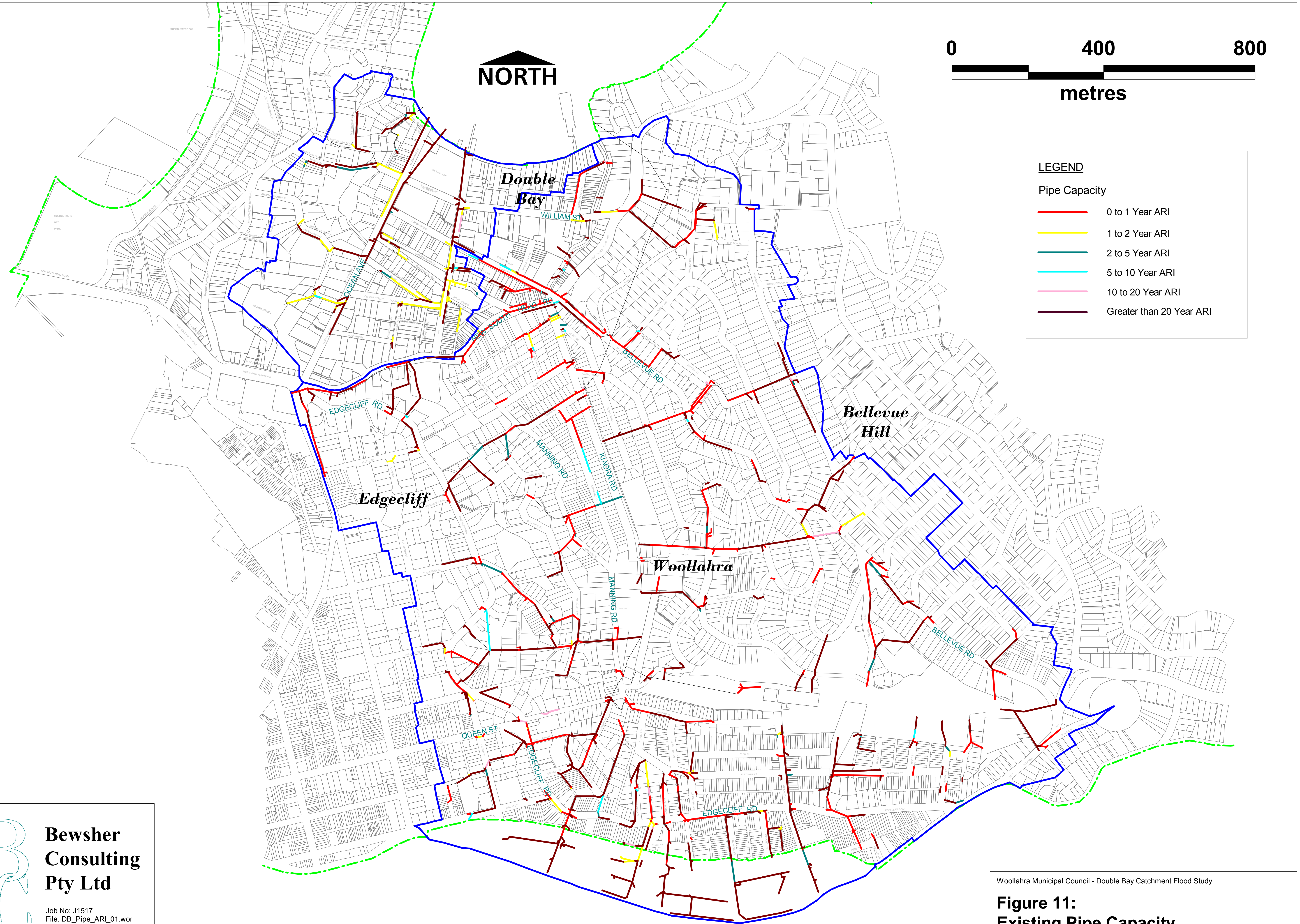

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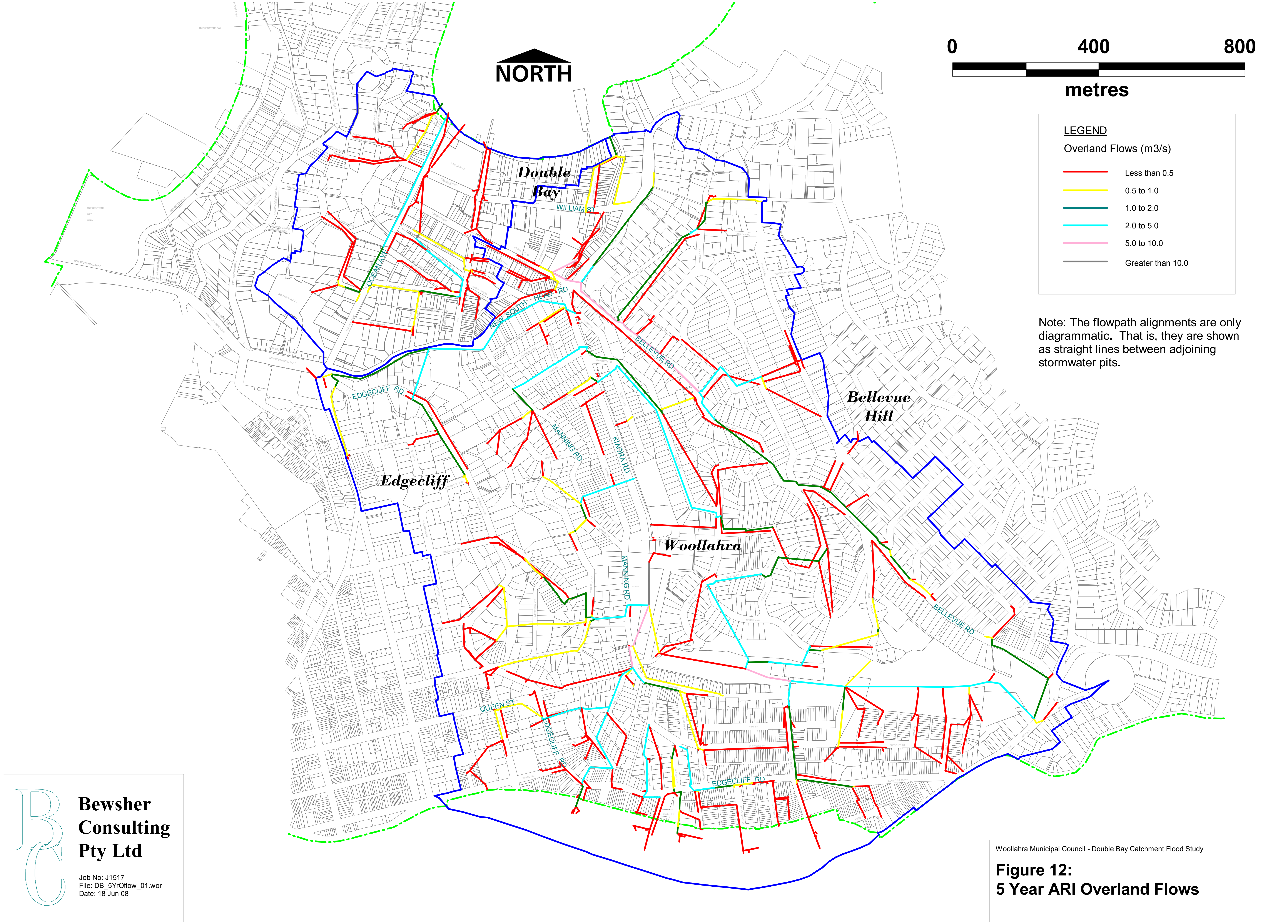
Figure 11:
Existing Pipe Capacity



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Woollahra Municipal Council - Double Bay Catchment Flood Study

Figure 12:
5 Year ARI Overland Flows

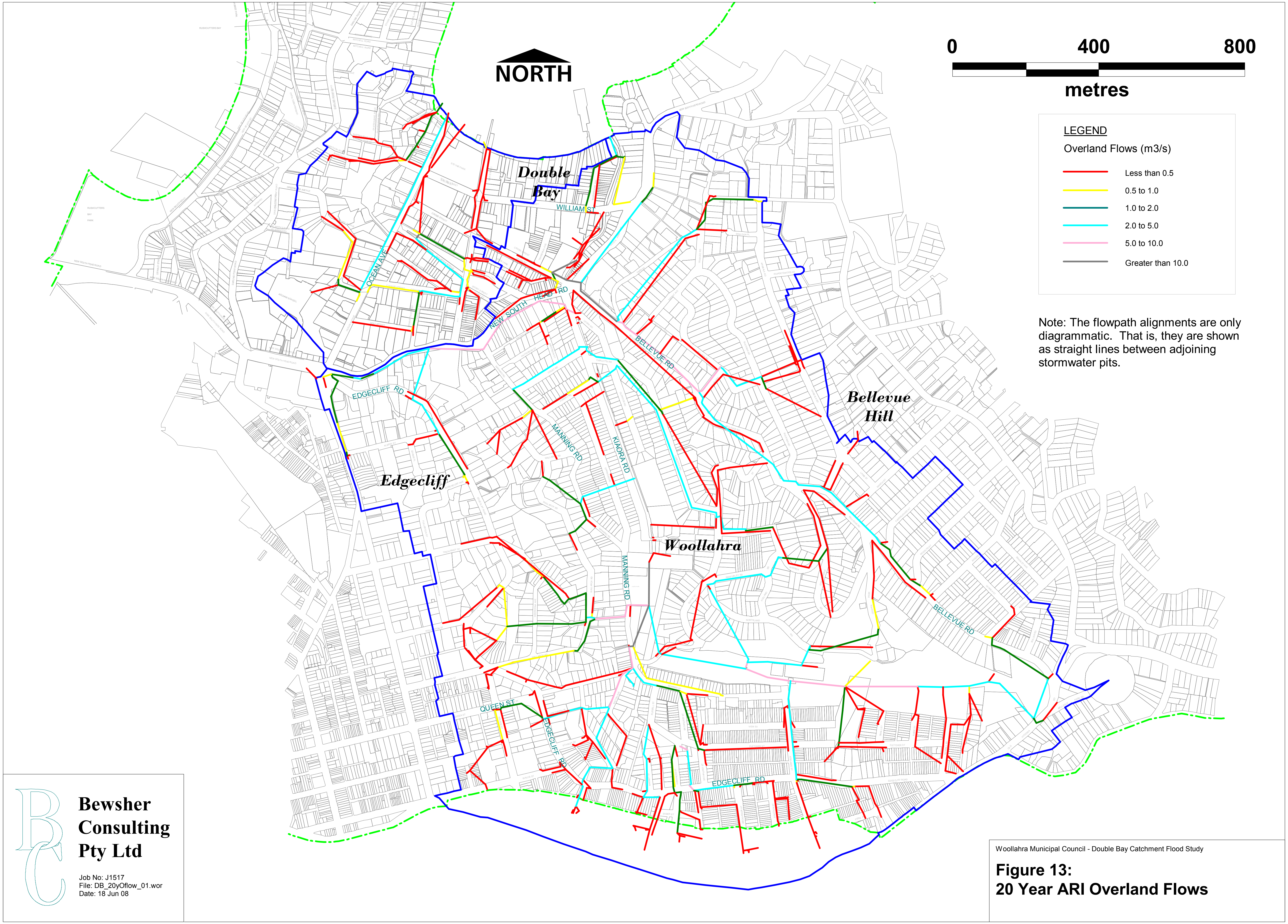

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Figure 13:
20 Year ARI Overland Flows

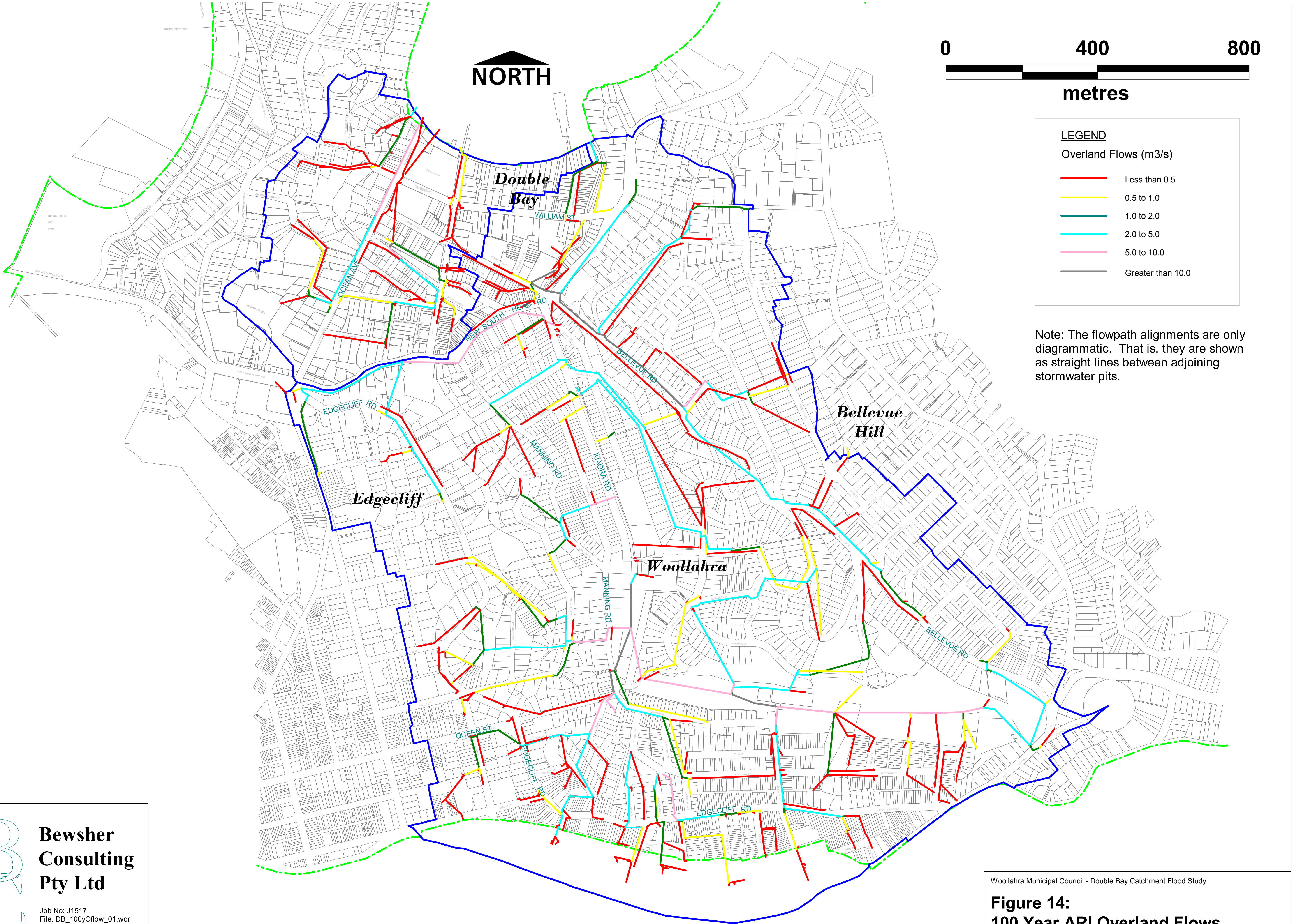

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Figure 14:
100 Year ARI Overland Flows

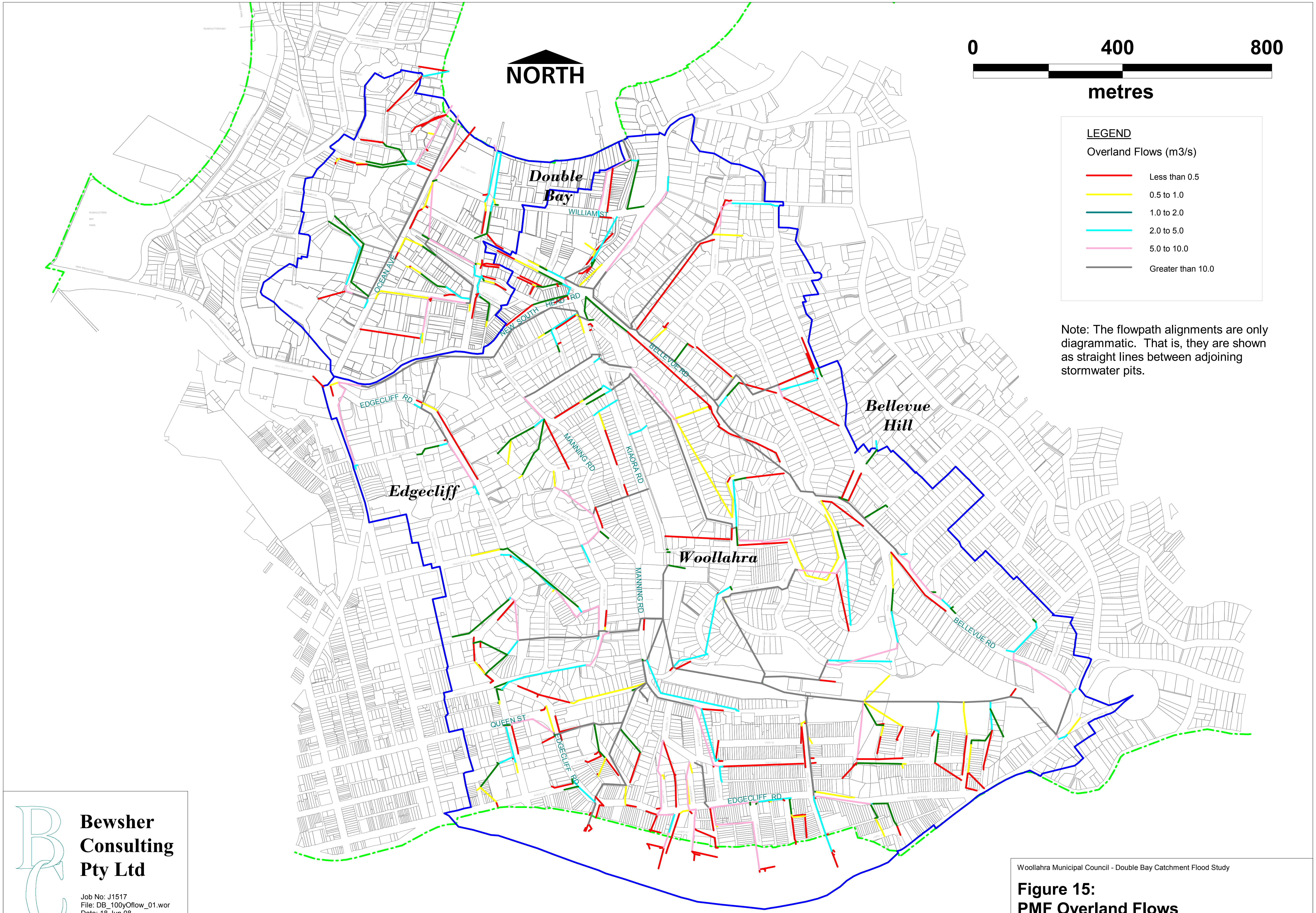

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Figure 15:
PMF Overland Flows

7. TUFLOW MODELLING

7.1 INTRODUCTION

The chapter documents the TUFLOW hydraulic modelling which was undertaken for the lower portion of the catchment and details of the model are provided in **Section 7.2**.

During the early stages of the study it was envisaged that the TUFLOW model footprint would consist of the trunk stormwater elements between Lough Park and the harbour together with modelling of tributary stormwater pipes and overland flows. However, as mentioned earlier in this report, the initial model results showed that there was the potential for floodwaters to spill out of this modelled area — that is, floodwaters in New South Head Road were able to spill into the ‘western’ portion of Double Bay. In order to effectively report on flood problems in the latter area, the Study Committee requested the area of the hydraulic model be extended to include the extra ‘western’ area of Double Bay. This was done and the ‘final’ extent of the modelled area can be seen in the series of flood inundation maps described later in this chapter.

Since Sydney Harbour design water levels reflect the impact of very long duration frontal activity in the Tasman Sea, it follows that at the time of a significant storm event over the Double Bay catchment, the harbour level would not be ‘elevated’. As commissioned, each of the TUFLOW design event models was run with an initial harbour level of 1.0m AHD (which as described earlier also corresponds to the criterion which was adopted for the DRAINS modelling). For completeness, the series of flood inundation maps note the respective design harbour levels.

7.2 MODEL FEATURES

The extent of TUFLOW modelling is shown in the series of flood inundation maps (for example Sheets 1–3 of **Figure 16**) and the floodplain data inputs for the model consist of the following:

- a two metre hydraulic grid based on a Digital Elevation Model (DEM) directly developed from aerial mapping provided by Council and shown on **Figures 16** to **20** covering all flooded areas;
- digitising of all significant buildings lying within the floodplain, including the area potentially inundated in the worst possible flood (the PMF event). The digitising has been undertaken using Council-supplied aerial photographs;
- details of underground pipe systems as modelled in DRAINS. The DRAINS network of pits and pipes exists as a one-dimensional (1D) layer lying under the DEM with inlet capacities derived on the basis of pit lintel and grate openings and blockage factors of 0.5 for sag pits and 0.2 for on-grade pits;

- design and field surveyed cross sections were used to model the following:

  (a) the section of open channel which extends from Lough Park to New South Head Road; and

  (b) trunk drainage elements between Carlotta Road and Sydney Harbour.

As-necessary variable roughness parameters for both the 1D elements and the 2D grid can be assigned and the parameters in the TUFLOW model are based on a combination of:

- floodplain inspections;
- review of present day aerial photography provided by Council; and
- the consultant's experience with using TUFLOW in similar earlier urban flood study applications. For example, all the digitised floodplain building footprints were globally assigned a very high Mannings 'n' roughness coefficient to reflect their likely potential to convey some (very) minor flows either under and/or above floor level. A composite roughness parameter was adopted for private property curtilege areas to reflect the impact of items such as sheds, landscaping and fences, etc.

The flow inputs for the TUFLOW model are the individual subcatchment runoff flow hydrographs imported directly from the DRAINS model results.

7.3 MODEL RESULTS

The depths of inundation and flood contours for the 25 minute storm duration 5 year, 20 year and 100 year events and the 15 minute storm duration PMF event are presented in Sheets 1 to 3 of **Figures 16** to **19**. It is recommended that the impacts of culvert blockage (which may impact on flood levels) be addressed during the floodplain risk management study.

The high, medium and low risk zones have been defined as follows:

- High Flood Risk – land below the 100 year ARI flood that is either subject to a high hydraulic hazard (as defined in Figure L2 of the 2005 Manual, **Reference 9**) or where there are significant evacuation difficulties;
- Medium Flood Risk – land below the 100 year ARI event that is not subject to a high hydraulic hazard and there are no significant evacuation difficulties;
- Low Flood Risk – all other land within the floodplain (i.e. within the PMF extent) but not identified as either in a high flood risk or medium flood risk category.

The resultant (draft) flood risk zones are mapped in Sheets 1 to 3 of **Figure 20**. It is recommended that the zones be finalised during the floodplain risk management study.

The depth and velocity information presented in **Figures 16** to **19** show that there are myriad overland flowpaths operating throughout the lower floodplain and in many cases there are significant flows being conveyed along roadways. One of the main flowpaths is the drainage reserve between Lough Park and the harbour foreshore — see **Figure 20** — within which lies the Sydney Water Corporation's trunk drainage system. Since parts of the SWC system consists of roofed over channels — principally downstream of New South Head Road — it is not unsurprising that in those locations depths of surface flow are often not substantial. This is also the scenario in the overbank areas immediately adjacent to where the SWC system consists of an open channel. Hence as shown in **Figure 20** it can be seen that not all of the drainage reserve exhibits high hazard conditions at the peak of the 100 year flood event.

Electronic copies of the detailed model outputs have been supplied to Council for incorporation into its GIS system.