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Melbourne Water

Report for Bacchus Marsh Area Floodplain Mapping

Main Report

November 2010

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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1. Introduction

1.1 General

This report presents the results of the flood plain mapping and flood and safety risk analysis for the Bacchus Marsh Area.

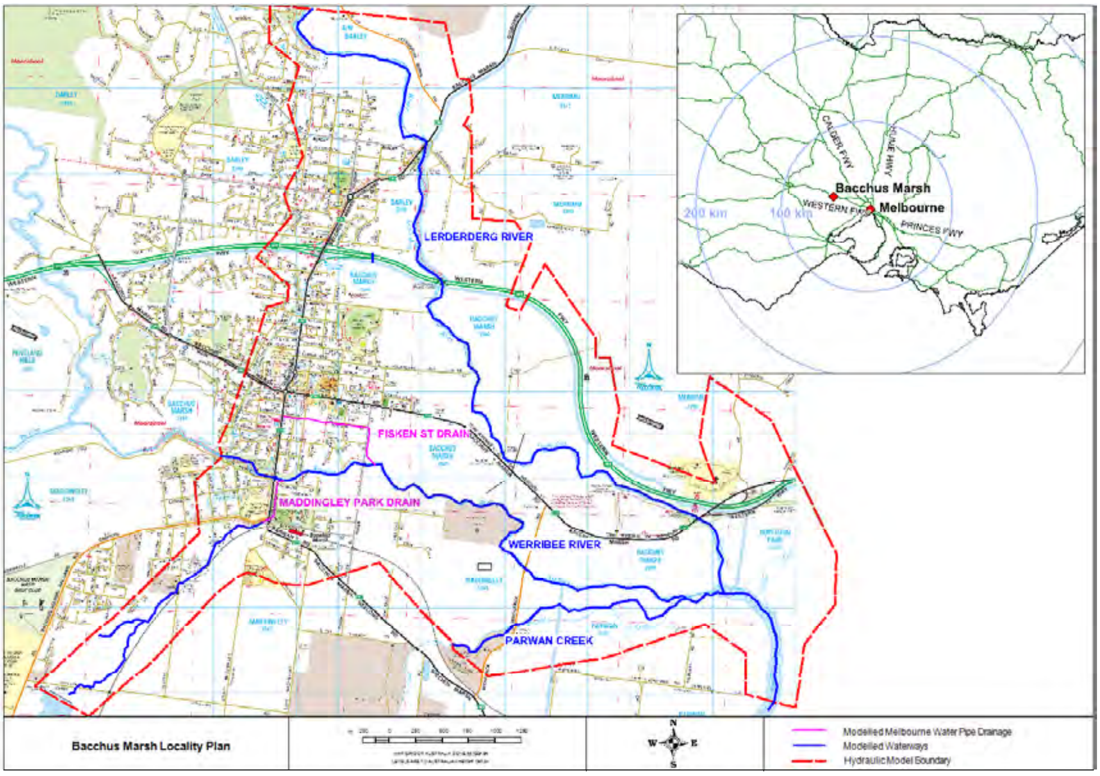
Melbourne Water engaged GHD in April 2008 to undertake flood plain mapping and flood and safety risk analysis of the Bacchus Marsh area. The results from this study will be used by Melbourne Water to provide flood advice and assist in identifying capital works for flood mitigation.

Melbourne Water is responsible for providing regional drainage and flood protection across the Port Philip and Western Port catchments. This role involves providing a safe, effective system for containing and transferring storm runoff (through a network of pipe drains, overland floodways and waterways) and preventing inappropriate development in flood-prone areas. Melbourne Water is working towards protecting flood-prone floors within its area of responsibility.

Bacchus Marsh is located approximately 50 km north-west of Melbourne near the confluence of the Werribee and Lerderderg Rivers as shown in Figure 1-1. The town is situated on a floodplain and has experienced flooding on numerous occasions since it was established in the 1850s.

The study area for this project, as is shown in Figure 1-1, includes the Werribee and Lerderderg Rivers, Parwan Creek and Maddingley Park and Fisken St Drains (Melbourne Water pipe assets 8104 and 8102 respectively).

Figure 1-1 Bacchus Marsh Locality Plan



1.2 Scope of Study

The scope of this project is summarised as follows:

1. Prepare a RORB model for the Bacchus Marsh area.
2. Generate flow hydrographs using the RORB model for the events and scenarios shown in Table 1.

Table 1 Required RORB Model Runs

Design Rainfall Event	PMF	100 yr ARI	50 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
Base Case	✓	✓	✓	✓	✓	✓
Climate Change		✓	✓	✓	✓	✓

Where:

- Base Case = Existing drainage system and existing conditions impervious fractions (as defined by Melbourne Water), and normal rainfall intensities (in accordance with Book 2 of AR&R (*IEAust 1997*)); and
- Climate Change = Existing drainage system and existing conditions impervious fractions (as defined by Melbourne Water), and rainfall intensities increased by 32% (as requested by Melbourne Water).

3. Develop and calibrate an integrated 1D/2D model (TUFLOW) to determine the flood extents for the events and scenarios shown in Table 2.

Table 2 Required TUFLOW Model Runs and Flood Extents

Design Rainfall Event	PMF	100 yr ARI	50 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
Base Case	✓	✓	✓	✓	✓	✓
Climate Change		✓		✓		✓

4. Provide peak discharges at 36 agreed points for the Base Case flood events only, as derived from the TUFLOW model.
5. Determine the peak flood levels to Australian Height Datum (AHD) for each property in the Base Case flood events only.
6. Determine the peak flood levels to AHD for each building “footprint” where the floor is inundated by the Base Case flood events only.
7. Determine Flood Risk for inundated properties within the Base Case 100 year ARI flood extent.
8. Determine property Safety Risk for inundated properties in the Base Case 100 year ARI event, and create Safety Risk for Roads polygons.

9. Provide MapInfo tables of the flood extents, flood levels, water surface grids, water depth grids, velocity-depth grids and velocity grids, for the events identified in Table 2 above, as well as RORB model and TUFLOW model files.
10. Provide data within the PMF extent to assist Melbourne Water to determine Average Annual Damages due to flooding.
11. Prepare a report documenting the findings of the analysis and investigative work undertaken.

All deliverables are based on the technical specifications outlined in the project brief and an update received in October 2009.

2. Background

This flood investigation follows an earlier separate investigation (WBM, 2006) of the Bacchus Marsh area which was undertaken for Moorabool Shire Council. That investigation aimed at characterising existing flooding in the Bacchus Marsh area, reviewing the existing flood warning system and providing recommendations for future flood management investigations. To characterise existing flooding, an integrated 1D/2D hydrodynamic model (TUFLOW) was developed.

Following the completion of that earlier investigation in 2006, concern was raised by Melbourne Water over the accuracy of the hydraulic modelling and the flood extents, in particular the adequacy of the Digital Terrain Model (DTM).

Melbourne Water then engaged GHD to undertake a review of the earlier investigation covering the following:

- Digital terrain model;
- Hydrological model;
- Impervious fractions; and
- Hydraulic model.

For the purpose of that review, Melbourne Water obtained LiDAR data for the Bacchus Marsh area to assist with assessing the accuracy of the existing DTM.

The details and results of the above reviews were recorded in separate documentation and these are presented in Appendix A, Appendix B, Appendix C and Appendix D respectively.

The recommendations from the above reviews can be summarised as follows:

- The LiDAR data covering the whole study area should be obtained and used to create the DTM for flood plain mapping the Bacchus Marsh area;
- A new RORB model should be setup to provide flood flow estimates for the Bacchus Marsh area;
- Some minor adjustments to the impervious fractions should be adopted for the RORB modelling; and
- A number of adjustments should be made to the hydraulic model including, recalibrating as well as incorporation of the new DTM.

Based on these recommendations, GHD was subsequently engaged to undertake this study for the flood plain mapping and flood and safety risk analysis for the Bacchus Marsh Area.

3. Available Information

The following information was utilised in undertaking this flood mapping study:

- General MapInfo layers obtained from Melbourne Water during the course of the project:
  - Cadastral information (building footprints, properties, easements, road alignments);
  - Drainage data for Fisken St and Maddingley Park pipe drains;
  - 20 m, 5 m, 1 m and 0.5 metre contours of the Bacchus Marsh area;
  - Aerial photographs;
  - Bacchus Marsh Area flood extent (WBM, 2006);
  - WBM 2006 Bacchus Marsh Flood Risk Study;
  - Data used to create the DEM for the 2006 flood study, including surveyed cross-sections for the Werribee and Lerderderg Rivers;
  - WBM TUFLOW model and GIS layers;
  - WBM RORB model and GIS layers;
  - Thinned LiDAR data for the Bacchus Marsh area;
  - Survey drawings for bridges in the Bacchus Marsh Area; and
  - Benefit cost analysis model.
- Other data:
  - Bureau of Meteorology pluviograph data for stations 87017, 87039 and 87075;
  - Theiss flow data for stations 231200, 231201, 231204, 231211, 231213, 231222, 231230, 231234; and
  - Southern Rural Water (SRW) rating tables for Pykes Creek Reservoir, Melton Reservoir and Merrimu Reservoir.

4. Catchment and Drainage Description

4.1 Bacchus Marsh Area Catchment

The catchment for the Bacchus Marsh area, draining to the confluence of the Lerderderg and Werribee Rivers is approximately 889 km^2 (Figure 4-1). It includes a large number of minor waterways and three major waterways, the Werribee and Lerderderg Rivers, and Parwan Creek.

Land use is predominantly rural with some normal density residential and rural residential development in Bacchus Marsh and Ballan. For the purposes of this study the outlet of the catchment is located downstream of the Lerderderg and Werribee Rivers confluence, approximately 5 km south-east of Bacchus Marsh town centre.

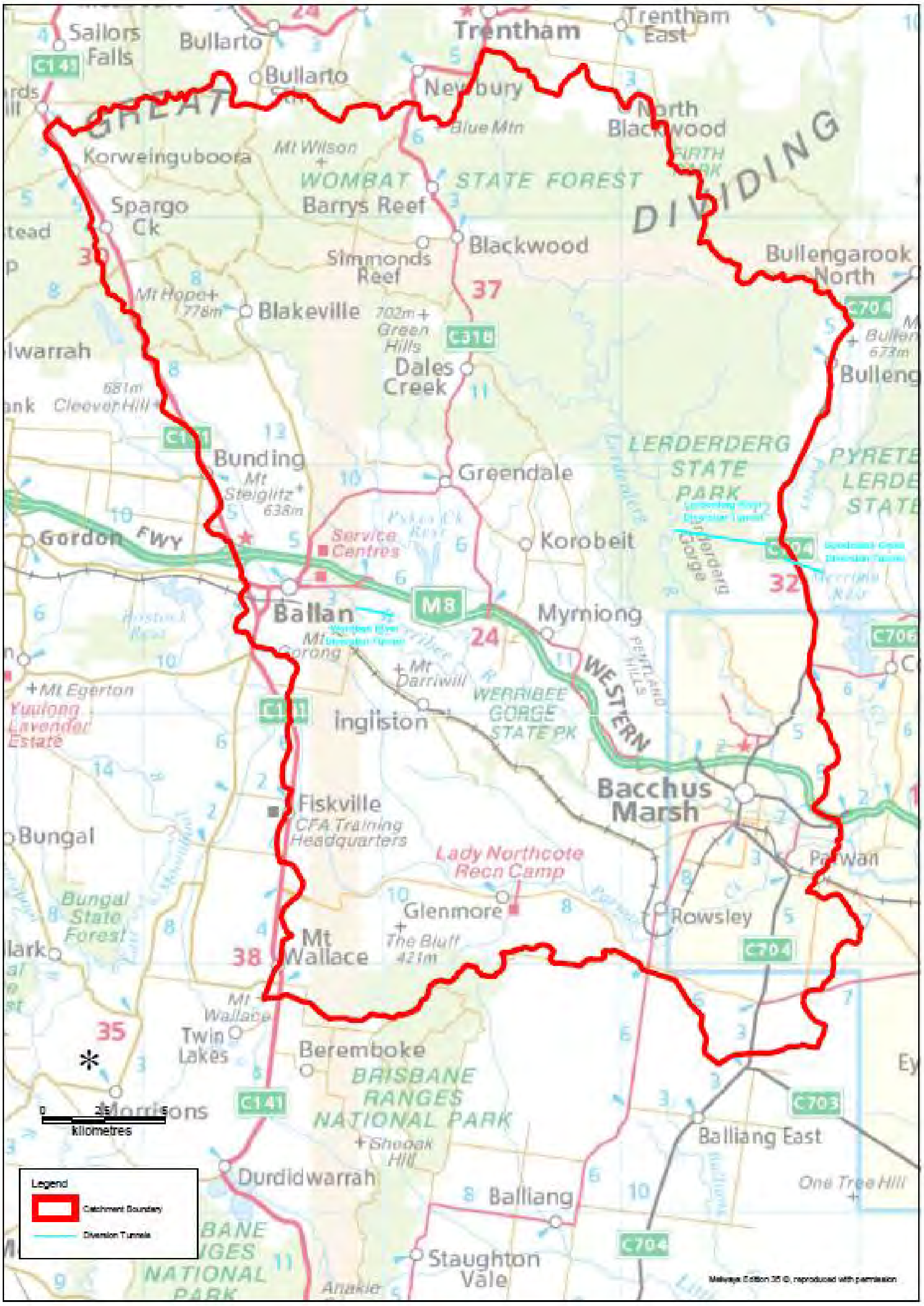
The floodplain in the Bacchus Marsh area is crossed by several major roads including the Bacchus Marsh Rd and the Western Fwy. These roads and a number of others cross the Lerderderg and Werribee Rivers and the Parwan Creek at bridges shown in Figure 4-2.

The drainage system in the Bacchus Marsh area consists of reinforced concrete pipes and open channels discharging into the Lerderderg and Werribee Rivers.

The underground pipe stormwater drainage system in Bacchus Marsh is comprised of assets managed by Moorabool Shire Council and Melbourne Water. In general larger pipes with a catchment area of greater than 60 ha are owned by Melbourne Water and other (typically smaller) pipes by council.

Melbourne Water pipes discharge at a number of locations on the Lerderderg and Werribee Rivers (Figure 4-2). The Fisken St Drain and Maddingley Park Drain are responsible for conveying the majority of piped stormwater runoff to the Werribee River in the Bacchus Marsh town centre.

Figure 4-1 Werribee River Catchment at Bacchus Marsh



4.2 Melbourne Water Drainage

4.2.1 Fisken St Drain 8102

The Fisken St Drain is a reinforced circular concrete pipe of approximately 1200 m in length that varies between 1200 and 1525 mm in diameter. The drain starts near the intersection of Waddell and Grant St and flows east for approximately 800 m before turning south for another 400 m and discharging into the Werribee River approximately 80 m downstream of the Fisken St Bridge (Figure 4-2).

4.2.2 Maddingley Park Drain 8104

The Maddingley Park Drain starts as an open channel near Kerrs Rd, south west of the Bacchus Marsh town centre. The open drain flows north east for approximately 2500 m to the intersection of Parwan Rd and Griffith St where it becomes a pipe drain (see photograph in Figure 4-3). The piped section of the Maddingley Park Drain begins as a 1675 mm diameter reinforced circular concrete pipe. The alignment runs parallel to Grant St and increases in diameter to 1825 mm north of Taverner St before discharging into the Werribee River approximately 50 m downstream of the Grant St Bridge (Figure 4-2 & Figure 4-4).

Figure 4-2 Bacchus Marsh Area Drainage

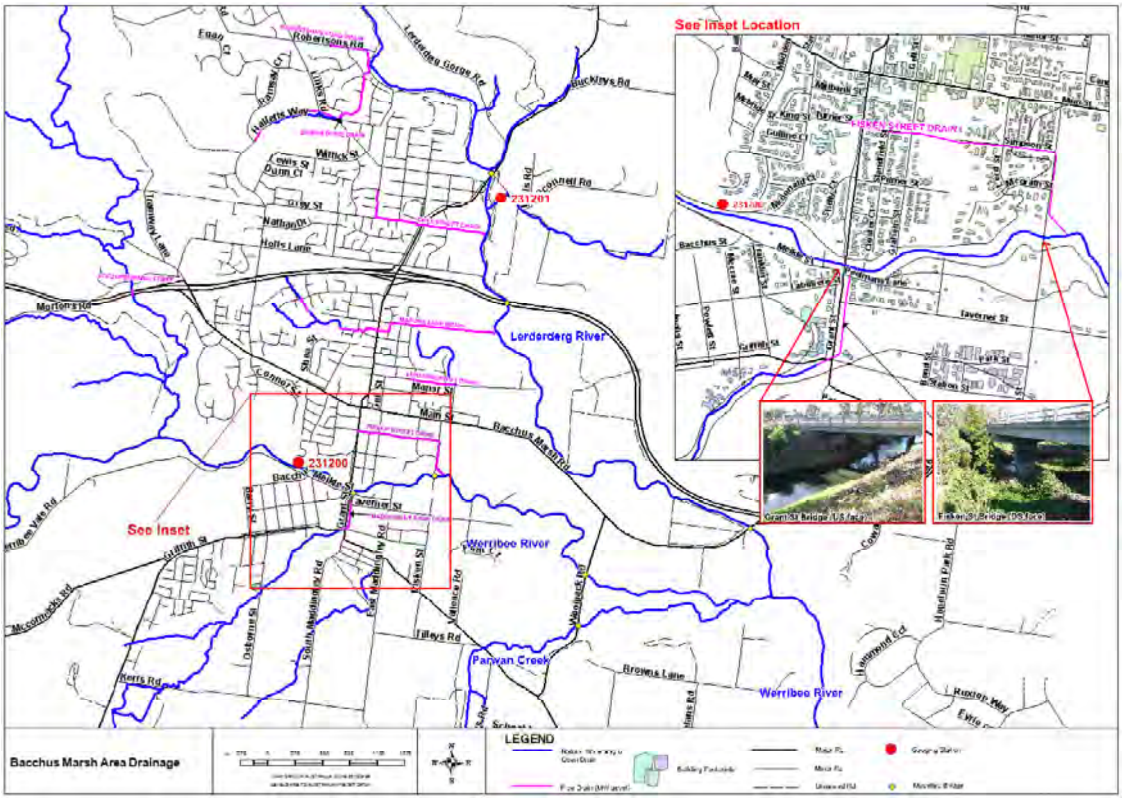


Figure 4-3 Entrance to the piped section of the Maddingley Park Drain (near the corner of Griffith St and Parwan Rd)

	4 August 2009

Figure 4-4 Maddingley Park Drain outlet at the Werribee River near Grant St

	4 August 2009

4.2.3 Other Melbourne Water Drains

The following list presents other Melbourne Water drains in the Bacchus Marsh area that were not required within the study brief to be included in this study. These pipes discharge to the Lerderderg River north of the Bacchus Marsh town centre (refer to Figure 4-2):

- Links Road Outfall Drain 8538:
  - Pipe size: 900 mm to 1500 mm;
- Robertsons Road Drain 8511:
  - Pipe size: 750 mm to 1200 mm;
- Cairns Drive Drain 8510:
  - Pipe size: 600 mm to 1650 mm;
- Grey Street Drain 8506:
  - Pipe size: 750 mm to 1800 mm;
- Masons Lane Drain 8504:
  - Pipe size: 375 mm to 1800 mm;
- Lerderderg Street Drain 8502:
  - Pipe size: 1225 mm to 1525 mm.

5. Digital Terrain Modelling

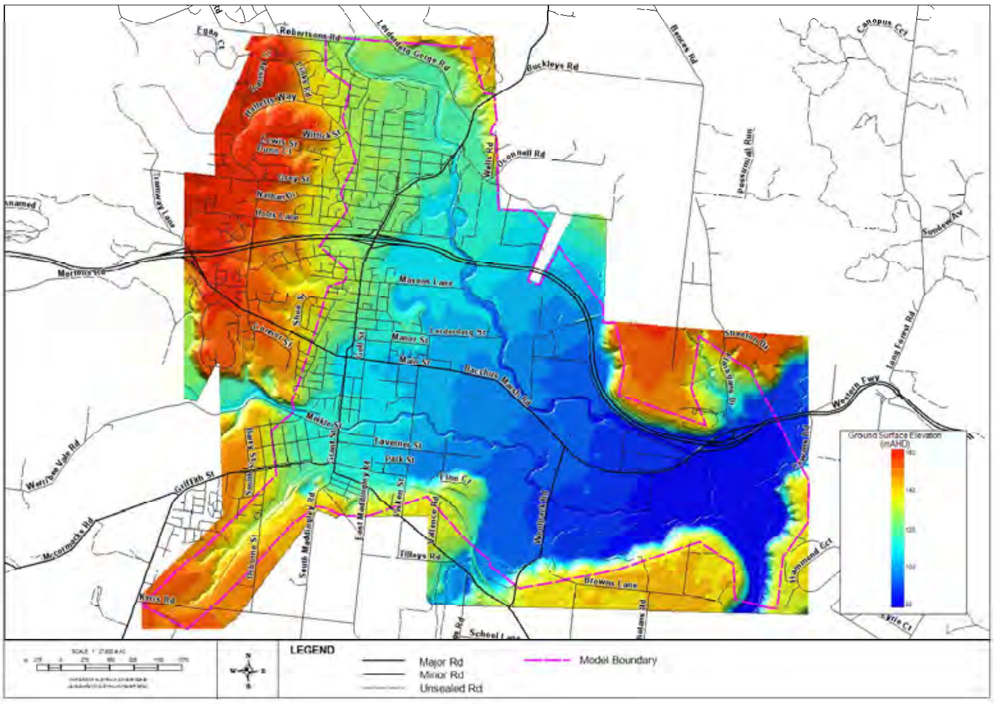
A Digital Terrain Model (DTM) of the Bacchus Marsh area was developed using a combination of LiDAR thinned ground points and survey data provided by Melbourne Water (Figure 5-1). The DTM formed the basis of the RORB model layout and the two dimensional grid for use in the TUFLOW model.

Survey data was used to cross-check the LiDAR data along the Werribee and Lerderderg River. It was found that along the Lerderderg River the LiDAR data and survey data showed a close correlation. However on the Werribee River the LiDAR data was consistently higher than the survey. It was considered that this was partially due to the river's incised nature, which may have meant that the LiDAR filtering algorithms that normally remove vegetation were unable to differentiate between the bank and vegetation. The LiDAR data was also clearly affected by the presence of water in the channel in places.

On the basis that the survey data more accurately represented the channel of the Werribee River, it was combined with the LiDAR data in the DTM and used in the generation of cross sections for the one dimensional TUFLOW network along the Werribee River.

The LiDAR data was the basis for the two dimensional grid and cross sections of the Lerderderg River, Parwan Creek and open channel section of the Maddingley Park drain.

Figure 5-1 Bacchus Marsh Area Digital Terrain Model



6. Hydrology

The hydrological assessment for this flood mapping study has been presented in a separate report entitled Bacchus Marsh Hydrology Report (GHD, 2010). For more detail on the RORB model and the hydrology of the Bacchus Marsh area, please refer to that report.

The RORB hydrological model represents the 889 km^2 catchment of the Werribee River draining to Bacchus Marsh as described in Section 4. The model was used to derive input flows for the TUFLOW hydraulic model.

The following presents a summary of the RORB modelling approach:

- Data Collection:
  - Streamflow, 6 min pluviograph and daily rainfall data;
- Model Development:
  - Defining the RORB node, reach and subarea network used to represent the catchment;
- Calibration:
  - Undertaken by setting up historic storm files and running the RORB model with parameters (kc and m) and losses such that a match was achieved against the recorded flood hydrographs at gauging station 231200 (Werribee River at Bacchus Marsh) and 231211 (Lerderderg River Upstream Goodman Creek Junction).

    The three events chosen for calibration of the RORB model were:
    - November 1995;
    - September 1993;
    - December 1987;
- Verification:
  - A flood frequency analysis using recorded annual peak flows at gauging stations on the Werribee and Lerderderg rivers and Parwan Creek was carried out to verify the RORB model parameters determined during the calibration phase; and
- Event Modelling:
  - The calibrated RORB model was run for the PMF, 100, 50, 20, 10 and 5 year ARI events, and the 100, 20, and 5 year ARI events representing a climate change scenario.

7. Hydraulic Modelling

7.1 Approach

Hydraulic modelling was undertaken using TUFLOW. TUFLOW is a hydrodynamic model used for simulating one-dimensional (1D) and two-dimensional (2D) flows. The model is based on the solution to the free-surface flow equations. It links 1D networks (ESTRY) to 2D domains (TUFLOW) to represent the catchment terrain and its drainage system. The version of the TUFLOW model used for this study was 2008-AI-ISP.

TUFLOW modelling was undertaken to determine the peak water levels in the Bacchus Marsh area for the events and scenarios listed in Table 2.

The TUFLOW model covers an area of approximately 21 km^2 that includes the Bacchus Marsh township. It consists of a 2D domain representing the catchment terrain, a 1D network representing waterways and the modelled Melbourne Water drainage pipes. Refer to Appendix E for a layout of the TUFLOW model.

The following summarises the hydraulic modelling process:

- Setup:
  - Setup of the TUFLOW model involved determining the model extent and coverage of the 1D and 2D domains. The TUFLOW model developed in the previous study (WBM, 2006) was used as the basis for this TUFLOW model. Bridges spanning the Werribee, Lerderderg and Parwan River, with the exception of the Grant St bridge, were retained from the original model;
- Calibration:
  - Calibration of the TUFLOW model was undertaken for the Werribee and the Lerderderg Rivers using observed flood levels and gauged flows from two separate flood events;
- Run:
  - RORB hydrographs were used as inflows for each design event (ARI), and the model run for twenty different storm durations ranging from 10 minutes to 72 hours in order to determine the critical peak flood levels (for the scenarios presented in Table 2).

7.2 2D Domain

The 2D domain represents the surface terrain of the floodplain. It conveys all overbank flow from the major waterways that were modelled in the 1D domain. Using the DTM to represent the terrain (Section 5), a grid covering the modelled area and comprising 8 metre square cells was formed. Each cell is made up of nine points, with each point having an elevation corresponding to the surface elevation at that location. The grid was rotated approximately 8 degrees in a clockwise direction so that the grid was aligned with the road network within the Bacchus Marsh township. This was aimed at capturing flow paths along roads and road elevations more effectively.

The bed resistance was allocated to each cell as a Manning's n value based on land use type and model calibration. The values presented in Table 3 are the Manning's n values adopted for the model design runs (as defined in Table 2).

Table 3 Bed Resistance Values for 2D Network

Material Number	Land Use	Manning's n
1	Dense Urban	0.2
2	Sparse Urban	0.1
3	Industrial/Commercial Site	0.075
4	Road (DEFAULT)	0.025
5	Open Land –cleared	0.1
6	Open Land – some vegetation	0.1
7	Agriculture	0.1
8	Vineyards	0.1
9	Dams	0.025

7.3 1D Network

The one-dimensional network consists of the following:

- Fisken St and Maddingley Park piped drains (see Section 4.2 for details);
- The open channel section of the Maddingley Park drain; and
- The Werribee and Lerderderg Rivers and Parwan Creek.

The Fisken St and Maddingley Park pipe drains were the only Melbourne Water owned pipe drains modelled. No council pipes were modelled. The modelled pipe drains included all known connections to the surface (pits) as defined by the Melbourne Water underground drainage MapInfo layer.

Appropriate losses were determined throughout the pipe network, based on standard pit loss tables (*MWC 2006*). Each pit loss value was assigned to the downstream pipe as a form loss, rather than in the pits themselves. For culverts or ends of pipes, an entrance loss of 0.5 and exit loss of 1.0 were applied.

Pits connecting the 1d pipe to the 2d surface were modelled to ensure flow in the pipe was not restricted by pit size. This approach attempted to compensate for the council pipes that were not modelled but would ordinarily convey flow into the drains. All pits were modelled as Weir type channels with connections to the 2d surface.

Most sections of the open channel network were modelled as “steep” channels. Lower sections of the Parwan Creek were modelled using “Normal/Non Inertial” channels to help stabilise the model in that area. The “Normal” channel type does not model super critical flow and the “Non Inertial” flag means the inertia term is suppressed from the momentum equation. Supercritical flows would be unlikely along this lower section of the model during flood conditions and therefore this use of the “Normal/Non Inertial” channels was considered appropriate. Other channel types used in the channel network include “bridges” (where roads crossed the waterways) and “weirs”.

Bridges were modelled in the 1D network. Table 4 presents the bridges represented in the Bacchus Marsh TUFLOW model:

Table 4 Bridges Represented in the Bacchus Marsh TUFLOW Model

Road	Waterway	Melway Reference
Gisborne Rd	Lerderderg	334 B1
Western Fwy	Lerderderg	334 B4
Private Rd	Lerderderg	334 C8
Bacchus Marsh Rd	Lerderderg	334 H9
Woolpack Rd	Parwan Creek	334 D12
Woolpack Rd	Werribee River	334 D11
Fisken St	Werribee River	333 K8
Grant St	Werribee River	333 H8
Osborne St	Maddingley Park Drain	333 F11

Model representation of bridges other than the Grant St bridge was retained from the previous TUFLOW model (WBM, 2006). An additional structure was added to represent the Osborne St crossing of the Maddingley Park Drain. This crossing was represented as a weir type structure in the TUFLOW model.

The Grant St bridge was modelled using a bridge and weir channel type setup. The bridge represented in the base case and climate change TUFLOW models is the current structure that was replaced in 2006. To represent this structure in TUFLOW, a loss table was calculated using a separate HEC-RAS model and the methodology described in the Hydraulics of Bridge Waterways (FHA, 1973). Losses were set to ‘fixed’ for this structure to ensure the calculated losses were applied without the default loss adjustment.

The hydraulic roughness coefficient allocated to each waterway was a Manning’s ‘n’ value based on the results of the calibration in the case of the Werribee and Lerderderg Rivers (see Section 7.6) and based on channel characteristics observed from areal photographs in the cases of the Parwan Creek and Maddingley Park Drain. The Manning’s n values applied are presented in Table 5.

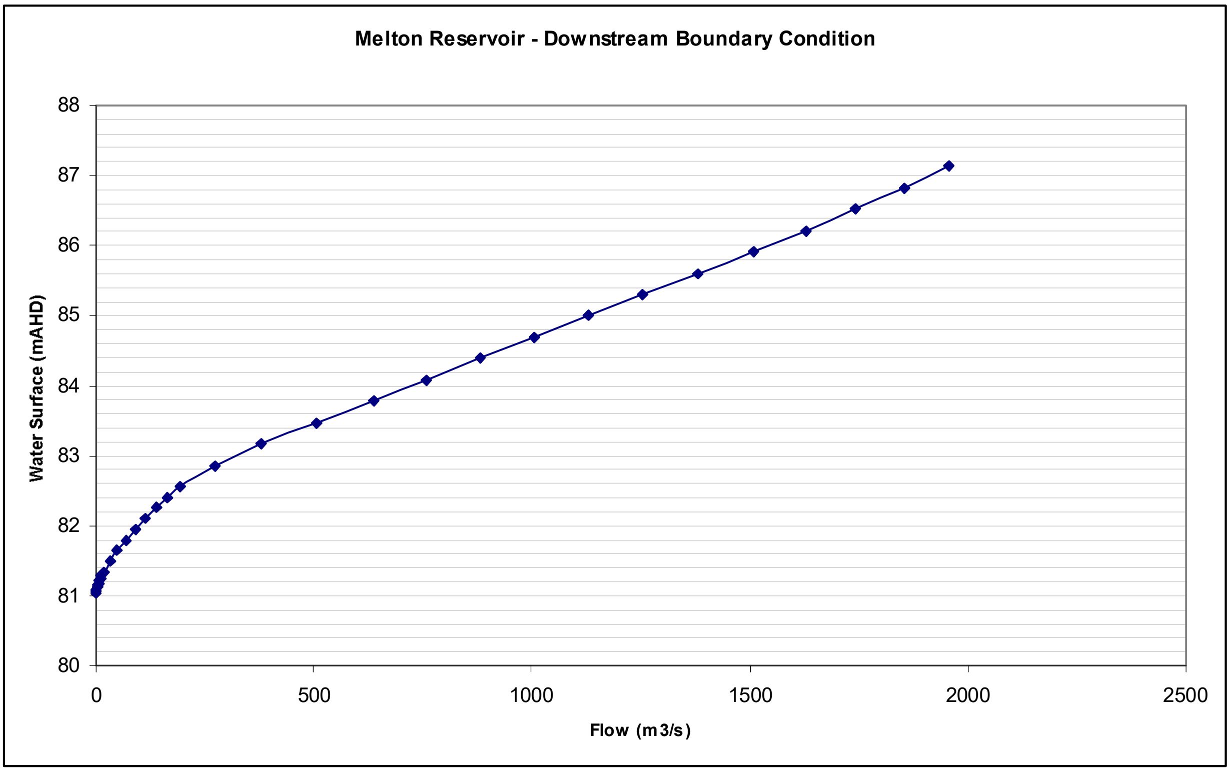
Table 5 Manning's 'n' Values for 1D Channel Network

Surface Material	Manning's 'n'
Reinforced Concrete Pipe	0.015
Maddingley Park Drain (open channel)	0.05
Parwan Creek	0.035 – 0.06
Werribee River	0.052
Lerderderg River	0.035 – 0.07

7.4 Boundary Conditions

The downstream boundary of the model was a rating curve generated from levels and flows at the head gauge of the Melton Reservoir (Site 231221). This was represented by an, 'HQ' boundary condition that adjusts the modelled water level based on the flow at the boundary. Figure 7-1 presents the 'HQ' curve used in the model. This curve was linearly interpolated for modelling of the PMF event.

Figure 7-1 Melton Reservoir – Downstream Boundary for TUFLOW



Hydrographs generated using the RORB model (see Section 6) were adopted as the flow boundary conditions ("QT" – flow versus time). Flows were input into the 1D domain either by applying a hydrograph to a single node on the 1D network or distributing a hydrograph evenly between a number of nodes on the network. The former approach was generally used to apply a hydrograph to a defined waterway or pipe where hydrographs were generated outside the model and the latter where a hydrograph was expected to enter from more than one location along a length of conduit.

Inflow hydrographs were also applied directly to the 2D domain via of 2d_sa polygons. A 2d_sa polygon applies the hydrograph to the lowest cell in the polygon if the area is dry, or is evenly distributed over already wet cells. A 2d_sa polygon aims to simulate local catchment runoff generated from an area where there is no clear defined drainage path.

Table 6 below summarises the peak flows for each of the main inflow hydrographs used as input into the TUFLOW model. For further explanation of TUFLOW input type refer to Section 7.4. Details of other inflows into the hydraulic model are presented in Appendix F.

Appendix E shows the locations of where the inflows summarised in Table 6 were input into the TUFLOW model.

Table 6 TUFLOW Inflow Hydrographs – Peak Flows (m3/s)

TUFLOW Identifier	TUFLOW input type	PMF	100 yr ARI	50 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
Werribee River†	1d_bc	4648.69	587.18	477.83	354.07	270.98	199.31
Parwan Creek†	1d_bc	2942.40	266.67	209.19	148.37	82.37	54.72
Lerderderg River†	1d_bc	4111.30	621.11	525.67	406.59	327.54	269.20
Fisken St Drain*	1d_bc	24.52	5.50	4.13	2.82	2.10	1.80
MPd2* (Maddingley Park Drain)	1d_bc	98.45	17.31	15.04	12.68	10.48	8.66

†Largest inflow hydrographs input to the waterway. Additional inflow hydrographs representing local catchment runoff are applied along the modelled length of the waterway.

*Flows directly input at the upstream end of drains. Additional inflow hydrographs are input along the length of the drains that increase the magnitude of flows significantly (particularly in the Maddingley Park Drain).

7.5 Model and Run Parameters

The following parameters were found to achieve the most stable model runs across a wide range of storm durations, and have been adopted for all runs (unless otherwise specified):

- A time step of two seconds for the 2D network and a time step of 0.5 seconds for the 1D network;
- Model run times long enough for peak flood levels to occur through out the drainage system. This was often considerably longer than the storm duration to allow enough time for flow to reach the outlet of the model and for storage levels to peak; and
- An initial water level of 83.5 m AHD. This water level was used to stabilise the model without impacting on flood extents.

No other special commands were required to stabilise the Bacchus Mash TUFLOW model.

7.6 Model Calibration

7.6.1 Werribee River

The Werribee River modelled in TUFLOW was calibrated to observed levels recorded after a flooding event that occurred in November 1995. During this event the peak flow at the Werribee River gauging station (231200) was recorded as 577 m^3/s. Based on the hydrology undertaken in this project this flow was considered to correspond to between a 50 and 100yr ARI event.

For the November 1995 event, 111 observed levels along the banks of the Werribee River and in the surrounding floodplain were available for use in the calibration process. These levels were compiled as part of the Flood Data Transfer Project. The calibration process focussed mainly on calibrating the main channel Manning's 'n' value. From the 111 points, forty-one levels were observed on the banks of the Werribee River and were used in this calibration process.

The approach to the calibration process was iterative and involved:

- Adjusting the Manning's 'n' roughness value on the Werribee River within the TUFLOW model;
- Running the model; and
- Comparing the results to the observed levels.

Particular emphasis was placed during the calibration process on the model in the Bacchus Marsh township area.

It was observed based on a site visit that there was no significant change in main channel hydraulic characteristics (e.g. vegetation, bed material, degree of irregularity across each cross section, variation between cross sections) along the modelled reach of the Werribee River. The calibration process was therefore undertaken to identify a single Manning's 'n' value to represent this entire reach.

Grant St bridge was replaced in 2006, therefore the for the calibration event the original profile was used (prior to 2006).

The calibrated Manning's n value for the main channel of the Werribee River was determined to be 0.052. A comparison between the calibrated modelled water levels and the observed water levels on the Werribee River is presented in Appendix G. The following comments are made regarding the calibration results:

- The calibrated Manning's 'n' values were considered to be within the ranges expected for the modelled reaches of the Werribee River;
- Generally at the top of the modelled reach of the Werribee River (upstream from Fisken Street Bridge) and downstream from the winery, reasonable calibration was achieved with the 1995 event observed flood levels (generally within 200 mm of the observed levels);
- There were problems calibrating the model along the reach of the Werribee River adjacent to the winery. The model generally underestimated the observed flood levels (by more than 500 mm in places). The flood plain along this middle reach of the Werribee River is relatively deep (up to 0.5m) and relatively fast moving and therefore flood levels are likely to be sensitive to the flood plain roughness. However a Manning's 'n' value of 0.1 was adopted in the model across this flood plain for calibration and further increases in this value had limited effect and were considered not justified (General discussion on potential reasons for differences between the model and observed levels is provided below); and
- There was some initial difficulty in achieving good agreement on the afflux across the Grant Street Bridge between the bridge modelled in HEC-RAS (over 1 m) and that inferred from the observed flood levels (760 mm). The bridge geometry has been obtained from the survey undertaken for the previous study (WBM, 2006) which represents the 'old bridge'. Based on comparisons with older drawings of the Grant Street Bridge (received from Melbourne Water), it would appear that the bed level beneath the bridge may have been lower in 1995 and this may explain the difference in the two affluxes. For the purpose of calibration the modelled losses across Grant Street Bridge have been adjusted to achieve an afflux that approximately matches that inferred by the observed flood levels.

Due to the potential and probably expected inaccuracies associated with the observed flood levels, achieving greater agreement between the model and the observed levels can be difficult and sometimes inappropriate. Problems associated with calibrating a model to observed flood levels include the following:

- Physical changes to the hydraulic properties of the surveyed waterway:
  - A tree falls into the river and partially blocks flow, observed levels upstream of the model may be higher than one would expect if the channel were free of debris;
  - The channel geometry may have changed through erosion or deposition since the flood event;
- The observed water levels are generally recorded sometime after the event and are based on evidence of water levels from flood debris:
  - Flood debris may have moved in the time between the event and the survey;
  - The accuracy of the observed flood level can vary widely if it is based on flood debris;
- Systematic variability in the observation technique:
  - For example if the surveyor of one section used the top of the flood debris and the surveyor of another section used the bottom.

Evidence of the above potential inaccuracies can be observed just from inspection of the observed levels. Figure 7-2 shows an unlikely increase in observed flood levels from upstream to downstream across Fisken Street Bridge. The observed flood water levels in Figure 7-3 show an unlikely drop in the water surface near Graham Street of almost 1m over a distance of approximately 80 m.

Due to difficulties in reaching agreement with all the observed flood water levels, the calibration process focussed on achieving good agreement along the reach through the Bacchus Marsh township between the gauging station and the Fisken St Bridge.

Figure 7-2 Observed Flood Levels near the Fisken St Bridge – Levels Increasing from downstream to upstream

Figure 7-3 Observed Flood Levels near Graham St – large drop in levels over a short distance

7.6.2 Lerderderg River

The Lerderderg River was calibrated to a storm event that occurred in October 1985 using 22 observed flood levels from the Flood Data Transfer project.

As distinct to the Werribee River, the modelled reach of the Lerderderg River was assessed to be formed of three distinct hydraulically different reaches as described in Table 7.

Table 7 Lerderderg Calibration Reaches

Reach	Description	Vegetation	Final Cross Section	Reach Length	Calibrated Manning's 'n'
1	Northern boundary of the TUFLOW model to the Western Fwy	Moderate	BM_Lerderderg_xs-5244	3.6 km	0.035
2	Western Fwy to approximately 500m north west of the Western Water Sewage Pumping Station	Heavy	BM_Lerderderg_xs-2132	3.1 km	0.070
3	Final reach, to the confluence with the Werribee River	Moderate	BM_Lerderderg_xs-32.csv	2.1 km	0.045

The calibrated Manning's 'n' values for each identified reach and that were used in the model design runs are presented in Table 7. A comparison between the calibrated modelled water levels and the observed water levels on the Lerderderg River is presented in Appendix H. The following comments are made regarding the calibration results:

- The calibrated Manning's 'n' values were considered to be within the ranges expected for the modelled reaches of the Lerderderg River;
- There are nine observed water levels and generally reasonable calibration (difference <250 mm) has been achieved with the model for the six most upstream observed levels, with the exception of '104.08' and '97.13', where there is over 500 mm difference. Given that there is relatively good agreement either side of this two observed levels, it is considered that the significant difference is either due to the accuracy of the observed levels being poor or that the river geometry has changed significantly and what is represented in the model does not accurately represent what was there in 1985; and
- The model significantly underestimates the three most downstream observed levels by over 1 m. It appears that this is due to a backwater effect from the Old Western Highway Bridge that has not been replicated in the model. Information on the previous design for this bridge was not available for this study.

8. Results

Water level, velocity and velocity-depth results were obtained at each wet 2D cell for each TUFLOW run (*h.dat, *v.dat and *z0.dat respectively). For each of the events and scenarios listed in Table 2, envelopes of maximum water levels, maximum velocities and maximum velocity-depths were created using the DAT_to_DAT utility. The maximum envelopes were then converted to 1 m ascii grids using the TUFLOW_to_GIS utility. The 1 m ascii grids were processed further to create the required MapInfo layers, as described further in Chapter 9.

For every TUFLOW run flow results were obtained at a selection of locations throughout the catchment (as defined in a 2d_po layer). For the Base Case Scenario, these results were collated and provided in the MapInfo layer "Flow_Values.tab". The asset flows reported in that layer are taken at the time at which the maximum overland flows occur, or are the maximum asset flows if there are no corresponding overland flows. Asset flows for open waterways such as the Werribee and Lerderderg River represent the flows recorded in the 1D network. These flows are presented in Appendix F for the Base Case Scenario 100 year ARI event.

Peak flood levels, time to reach peak flood level and flows for each return period are also reported in Appendix I. Since TUFLOW produces a flood level on each 2D cell, the flood levels listed in the tables are averages for each location.

Flood level hydrographs at key locations throughout the model for the Base Case Scenario 100 year ARI event are presented in Figure 8-1, Figure 8-2, Figure 8-3 and Figure 8-4.

Figure 8-1 100-yr ARI Flood Level Hydrograph – Lerderderg River at Lerderderg St

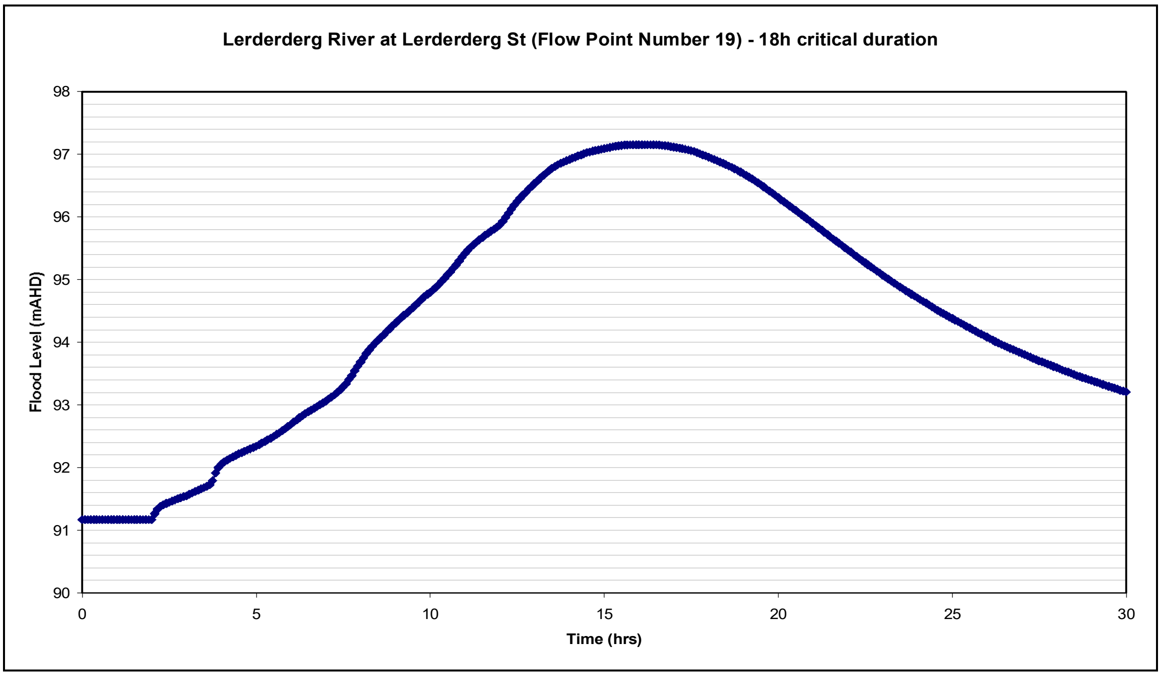


Figure 8-2 100-yr ARI Flood Level Hydrograph – Fisken St at Grant St

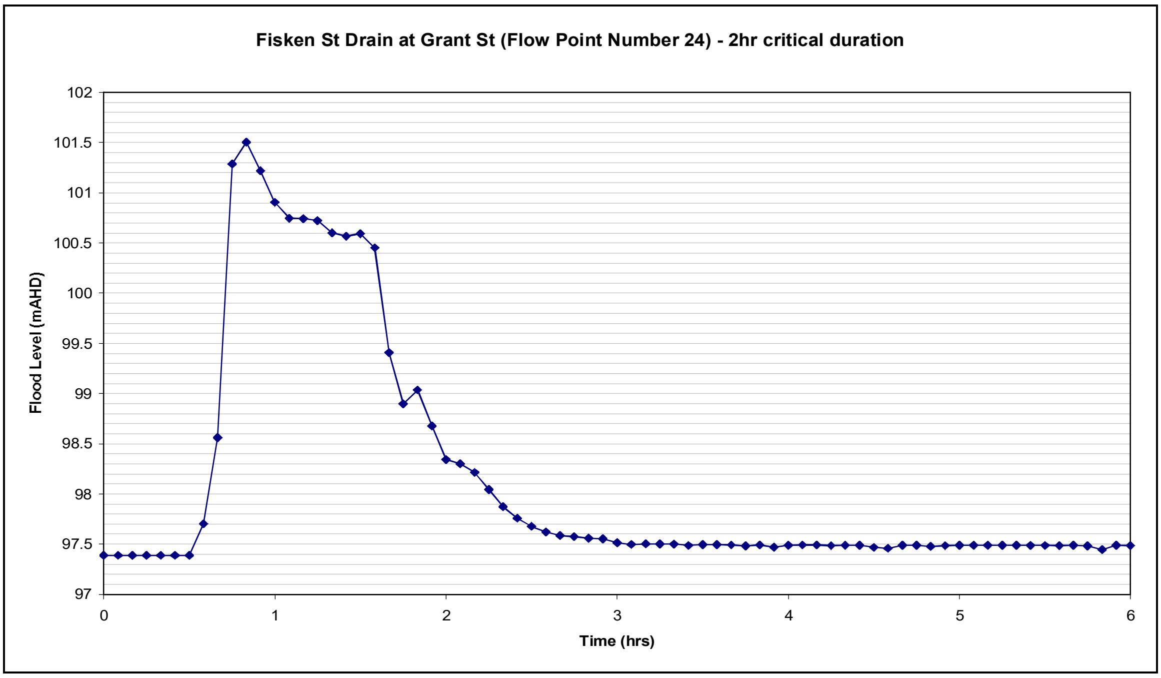


Figure 8-3 100-yr ARI Flood Level Hydrograph – Werribee River downstream of Grant St Bridge

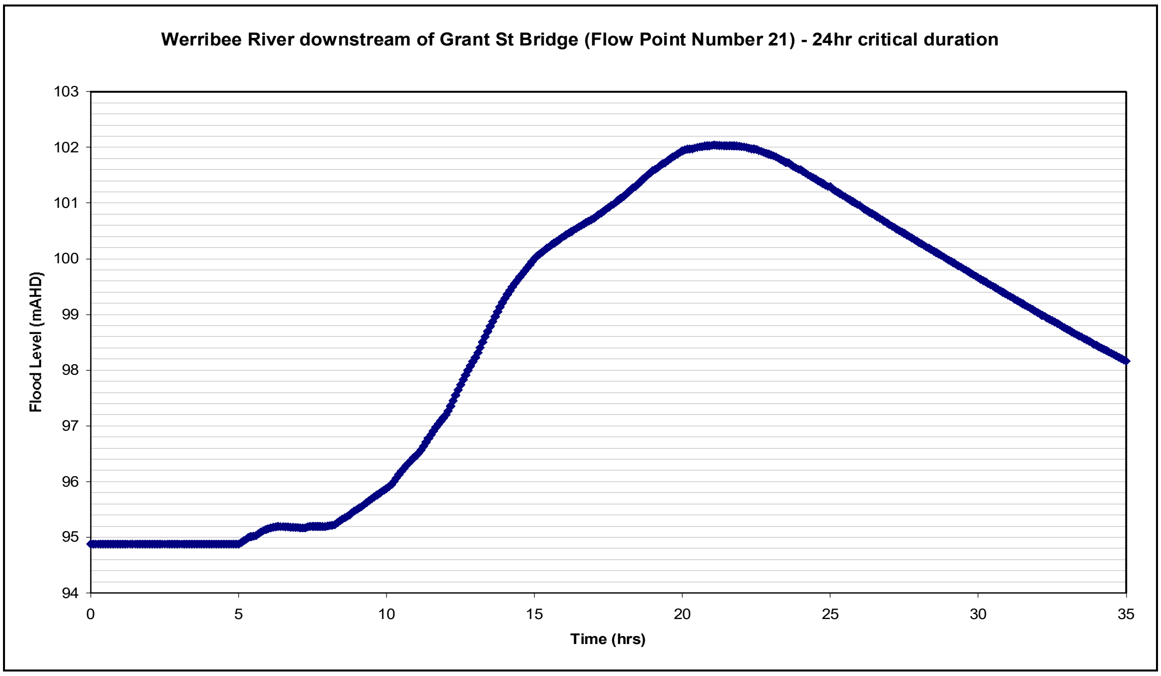
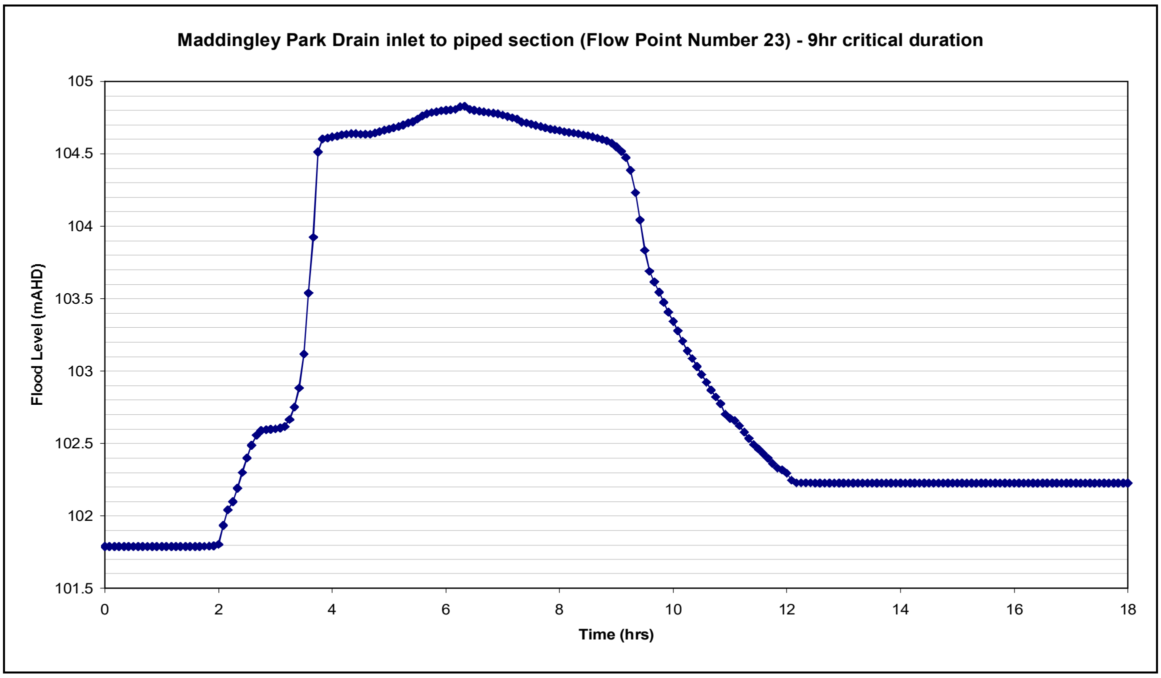


Figure 8-4 100-yr ARI Flood Level Hydrograph – Maddingley Park Drain inlet to piped section



9. Flood Mapping and Risk Assessment

9.1 Flood Extents

The 1 m grids of water levels were used to create flood extents for the events and scenarios listed in Table 2. Natural surface levels were subtracted from the water level results to create 1 m grids of depth results. The zero depth contours for these depth grids was produced to form the flood extents. A set of A3 flood maps are provided in Appendix J. These maps show the peak PMF, 100, 50, 20, 10 and 5 year ARI flood extents.

9.2 1m Results Grids

For each of the events and scenarios listed in Table 2, a MapInfo layer was created containing points on a 1 m orthogonal grid within the corresponding flood extent. Each point contains the following information for each event:

- Maximum water level (based on TUFLOW “h.dat” results);
- Maximum depth (calculated by subtracting the ground level at that point from the maximum water level);
- Maximum velocity (based on TUFLOW “v.dat” results); and
- Maximum velocity-depth product (based on TUFLOW “z0.dat” results).

9.3 Properties and Floors Flooded

Melbourne Water provided MapInfo layers of property and building footprint polygons in the Bacchus Marsh Area.

The maximum 100, 50 and 20 year ARI flood levels were attached to each property for the Base Case Scenario only, based on the 1 m results grids:

For each building footprint polygon, maximum PMF, 100, 50, 20, 10 and 5 year ARI flood levels on the building footprint were attached for the Base Case Scenario only, also based on the 1 m results grids. Floor levels of residential and commercial buildings were supplied by Melbourne Water as an attribute to the “Building Footprints” Mapinfo layer. The surveyed floor level of a building is assumed to apply to the whole of that building. Approximately 5% of buildings within the 100 year ARI flood extent were unable to be surveyed. A floor level of 300 mm above the ground level was therefore instead assigned to these buildings.

The total numbers of properties and floors inundated within the Bacchus Marsh Catchment for each design event, based entirely on the “Properties Flooded” and “Building Footprints” layers, is shown in Table 8.

Table 8 Properties and Floors Affected by Flooding within the Bacchus Marsh Area

	Number of Properties Affected by Flooding	Number of Floors Flooded	No. of buildings/dwellings affected with flood level above or within 0.15 m of floor level	No. of buildings/dwellings affected with floor level - flood level > 0.15 m
PMF	1829	1434	1452	56
100 year	961	140	311	298
50 year	712	104	237	232
20 year	653	71	181	232
10 year	602	46	135	229
5 year	376	21	55	142

For the Base Case 100 year ARI event only, 25th percentile, median, 75th percentile and average values of depths and velocity-depth products on flooded properties across the Bacchus Marsh catchment are presented in Table 9. The high average values for flood depth and the velocity x depth product is skewed by a small number of large values. Large values generally occur where the property boundary extends into the Werribee and Lerderderg River channels.

Table 9 Statistical summary of depth and the velocity*depth product for properties in the Bacchus Marsh Area for the 100 year ARI event

	Property Flood Depth	Property Velocity x Depth Product
25th percentile	0.2	0.02
50th percentile (median)	0.33	0.06
75th percentile	0.54	0.16
Average[1]	1.00	2.34

Notes:

1. The high average values for flood depth and the velocity x depth product is skewed by a small number of large values. Large values generally occur where the property boundary extends into the Werribee and Lerderderg River channels.

9.4 Flood Risk Rating

The calculation of Flood Risk has changed from a return period/flood level based assessment to solely a flood level based assessment for the 100 year ARI event. Flood Risk was calculated for each building foot print that was affected by the 100 year ARI flood extent with the following definitions for each of the five levels of risk:

Flood Risk Rating 1 Flood level < Floor level

Flood Risk Rating 2 Flood level < 0.35 m above Floor level

Flood Risk Rating 3 Flood level 0.35 – 0.8 m above Floor level

Flood Risk Rating 4 Flood level 0.8 – 1.2 m above Floor level

Flood Risk Rating 5 Flood level > 1.2 m above Floor level

The maximum flood levels on the building footprints and properties flooded tables were determined using custom GHD routines. Maximum flood levels were determined for the each building floor for the PMF, 100 year ARI, 50 year ARI, 20 year ARI, 10 year ARI and 5 year ARI events. Maximum flood levels for the properties flooded tables were only required for the 100 year ARI, 50 year ARI and 20 year ARI events.

The total number of buildings in each Flood Risk Category is shown in Table 10.

Table 10 Flood Risk Categories within the Bacchus Marsh Area

Flood Risk Rating	Number of Floors Effected
1	469
2	127
3	9
4	2
5	2

9.5 Safety Risk in Properties

Safety Risk for both properties and roads were determined for the Bacchus Marsh Area as part of this study.

The Safety Risk for each property was determined for the 100 year ARI flood based on the maximum value of the product of depth and velocity $(D \times V)_{max}$ for the property. This differs to previous requirements for designating Safety Risk that used a 'Safety Risk Classification' based on egress, and then categorised the severity of the safety risk governed by combination of $(D \times V)_{max}$ and depth.

The Safety Risk Classifications, according to Melbourne Water's Brief for this project, are defined as:

Safety Risk Rating 1 $(D \times V)_{max} < 0.2\ m^2/s$

Safety Risk Rating 2 $(D \times V)_{max}$ 0.2 – 0.4 m^2/s

Safety Risk Rating 3 $(D \times V)_{max}$ 0.4 – 0.6 m^2/s

Safety Risk Rating 4 $(D \times V)_{max}$ 0.6 – 0.84 m^2/s

Safety Risk Rating 5 $(D \times V)_{max} > 0.84\ m^2/s$

TUFLOW is able to calculate velocity-depth product throughout the model simulation. The maximum velocity-depths products from all of the TUFLOW model runs were extracted to create a "Safety Risk surface". The maximum velocity-depth product at any given location may not coincide with the maximum depth or maximum velocity.

A summary of the Safety Risks within the Bacchus Marsh Area is shown in Table 11.

Table 11 Safety Risk Classifications within the Bacchus Marsh Area

Safety Risk Rating	Number of Properties within each Safety Risk Category
1	747
2	61
3	13
4	10
5	136

9.6 Safety Risk in Roads

Five categories for Safety Risk in Roads are defined by Melbourne Water. Each category is defined in terms of the product of depth and velocity $(D \times V)_{max}$ and depth of floodwaters in the 100 year event (as distinct from the Property Safety risk which is defined solely on the product of depth and velocity $(D \times V)_{max}$), as follows:

Low Risk (Safety Risk value = 1) $(D \times V)_{max} < 0.2\ m^2/s$ or depth < 0.2 m

Low to Moderate Risk (Safety Risk value = 2) $(D \times V)_{max}$ 0.2 – 0.4 m^2/s or depth 0.2 - 0.4 m

Moderate Risk (Safety Risk value = 3) $(D \times V)_{max}$ 0.4 – 0.6 m^2/s or depth 0.4 - 0.6 m

Moderate to High Risk (Safety Risk value = 4) $(D \times V)_{max}$ 0.6 – 0.84 m^2/s or depth 0.6 - 0.84 m

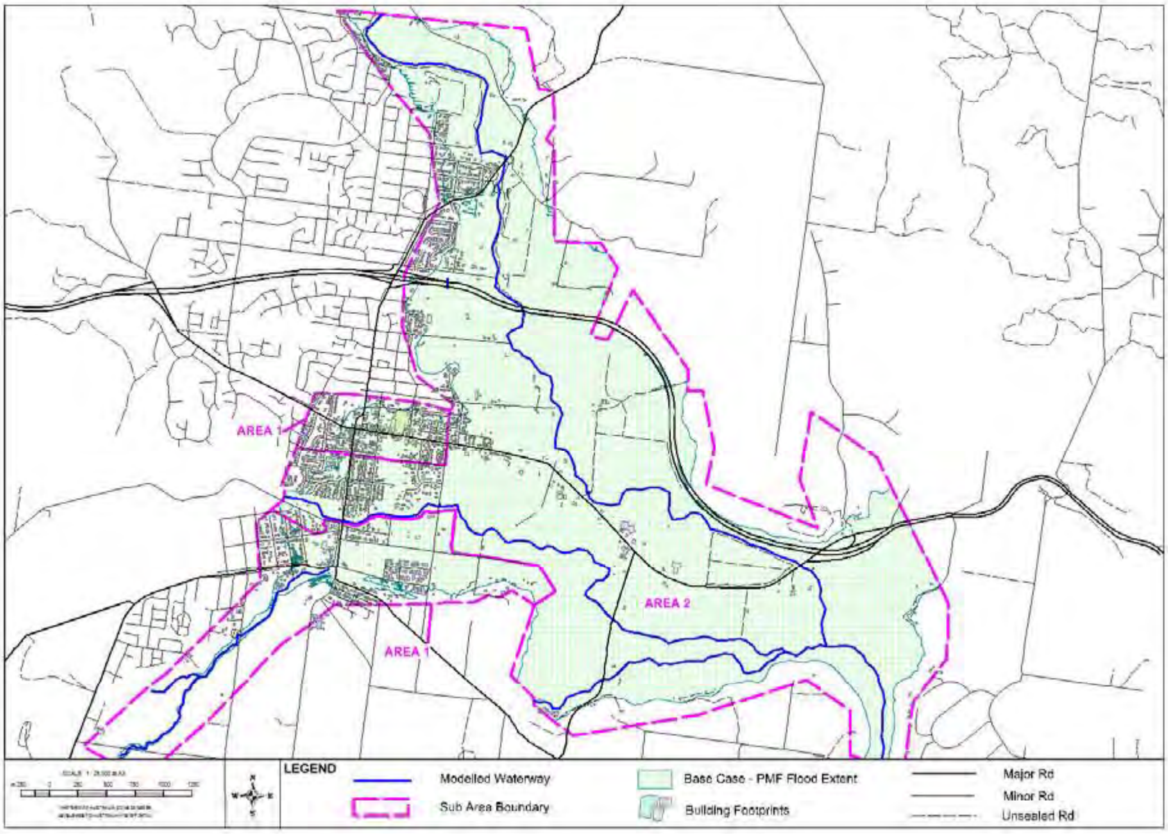
High Risk (Safety Risk value =5) $(D \times V)_{max} > 0.84\ m^2/s$ or depth > 0.84 m

9.7 Average Annual Damages

The Annual Average Damages (AAD) for the base case scenario were calculated using a spreadsheet model supplied by Melbourne Water entitled “Melbourne Water Flood BCA v2” (URS[a], 2006).

The calculation of AAD was split between two sub-areas that were defined based on the expected flood warning time (Figure 9-1). Properties within a single defined sub area must have similar flood warning time. Flood warning time is used with the flood experience input to the spreadsheet model in order to determine actual property damage for a particular scenario.

Figure 9-1 AAD Subarea boundaries



Area 1 was assigned to regions to the north and south of the Werribee River that are predominantly affected by stormwater flooding. It was considered that no warning could be given to properties within this area from stormwater flooding (localised flooding, not mainstream). Area 2 was assigned to cover the rest of the area within the PMF flood extent, which was predominantly affected by mainstream flooding. Although there is currently no flood warning system in place for Bacchus Mash, it was estimated that a flood warning could be issued approximately 13 hours prior to river flooding occurring on the Lerderderg or Werribee Rivers.

The input page from spreadsheet model for both sub areas is presented in Appendix K.

9.8 Climate Change Sensitivity

A3 flood plain maps are provided in Appendix L showing the peak 100, 20 and 5 year ARI flood extents under the climate change scenario.

9.9 GIS Output

The MapInfo layers listed below were provided to Melbourne Water as the major outcome of this flood mapping project. This report describes the methodology and steps taken to arrive at these layers. The layers listed in Table 12 conform to Melbourne Water's supplied metadata standards and naming conventions, as outlined in the project brief and an update received in October 2009.

The projection of all layers is Map Grid of Australia Zone 55 (GDA94) with the Bounds (0, 5500000) (1000000, 6500000).

9.10 Qualifications relating to Flood Mapping Output

The TUFLOW hydraulic model was established primarily for the purpose of modelling the 100 year ARI event. The implication of this is that the modelling results for smaller events such as the 5 year and 10 year ARI, will need to be appropriately interpreted with an understanding of the model limitations.

The accuracy of the final results is in part also a function of the resolution of the TUFLOW model (which uses an 8 m cell size). The higher resolution of results (provided on a 1 m grid) is provided as a partially interpreted data source for the convenience of Melbourne Water. This higher resolution grid of results does not infer a higher accuracy.

Table 12 **Mapinfo Deliverables – Melbourne Water "Standard" Layers**

Layer Name	Description
FE_PMF.tab	PMF flood extents
FE_100YR.tab	100 year ARI flood extents
FE_50YR.tab	50 year ARI flood extents
FE_20YR.tab	20 year ARI flood extents
FE_10YR.tab	10 year ARI flood extents
FE_5YR.tab	5 year ARI flood extents
FE_100YRCC.tab	100 year ARI Climate Change flood extents
FE_20YRCC.tab	20 year ARI Climate Change flood extents
FE_5YRCC.tab	5 year ARI Climate Change flood extents
Flood_Contours.tab	100 year ARI flood level contours at 0.5 m intervals
Flood_Mapping_Limits.tab	Mapping Limits
SR_LOW.tab	Property Safety Risk (Safety Risk Rating = 1)
SR_LOW_MOD.tab	Property Safety Risk (Safety Risk Rating = 2)
SR_MOD.tab	Property Safety Risk (Safety Risk Rating = 3)
SR_MOD_HIGH.tab	Property Safety Risk (Safety Risk Rating = 4)
SR_HIGH.tab	Property Safety Risk (Safety Risk Rating = 5)
SRR_LOW.tab	Safety Risk in Roads (Safety Risk Value =1)
SRR_LOW_MOD.tab	Safety Risk in Roads (Safety Risk Value =2)
SRR_MOD.tab	Safety Risk in Roads (Safety Risk Value =3)
SRR_MOD_HIGH.tab	Safety Risk in Roads (Safety Risk Value =4)
SRR_HIGH.tab	Safety Risk in Roads (Safety Risk Value =5)
BM_RORB_Catchment_Boundaries.tab	Main catchment boundary
BM_RORB_Subcatchment_Boundaries.tab	Sub area boundaries for RORB model
BM_RORB_Nodes.tab	RORB nodes
BM_RORB_Reach_Alignments.tab	RORB reaches
InterimFloodwayOverlays.tab	Extent of inundation with flood depth of great than or equal to 1m
Natural_Surface_Contours.tab	Ground contours at 0.5 m intervals
Flow_Values.tab	Locations of flow results extracted from TUFLOW model – when peak overland flow occurs (all return periods)
Properties_Flooded_by_Waterways.tab	Database of flood affected properties

Table 13 Mapinfo Deliverables – Additional Layers

Layer Name	Description
Points_PMF.tab	PMF 1 m result Grid
Points_100YR.tab	100 year ARI 1 m result Grid
Points_50YR.tab	50 year ARI 1 m result Grid
Points_20YR.tab	20 year ARI 1 m result Grid
Points_10YR.tab	10 year ARI 1 m result Grid
Points_5YR.tab	5 year ARI 1 m result Grid
Points_100YRCC.tab	Climate change 100 year ARI 1 m result Grid
Points_20YRCC.tab	Climate change 20 year ARI 1 m result Grid
Points_5YRCC.tab	Climate change 5 year ARI 1 m result Grid

10. Recommendations

It is recommended that:

- Melbourne Water adopts the outcomes of this investigation in determining the classification of the catchment in terms of severity of flooding;
- Melbourne Water adopts the outcomes of this investigation for future planning purposes and assessment of mitigation options; and
- Further investigation is undertaken to determine and assess the impact of flood mitigation options that may also cater for future development within the catchment.

11. References

BMT WBM (2008)	TUFLOW User Manual – GIS Based 2D/1D Hydrodynamic Modelling, January 2008.
FHA (1973)	*U.S. Department of Transportation, Federal Highway Administration (US FHA 1973),* Hydraulics of Bridge Waterways Hydraulic Design Series No. 1, Second Edition.
GHD (2010)	Bacchus Marsh Flood Mapping Study – Hydrology.
MWC (2006)	*Melbourne Water Corporation*, Land Development Manual, Victoria, 2006.
Siriwardena, L. and Weinmann, P.E. (1996)	*Cooperative Research Centre for Catchment Hydrology,* Areal reduction factors for design rainfalls in Victoria, Victoria, 1996.
URS[a], 2006	Development of a Model to Prioritise Flood Mitigation Works, Prepared for Melbourne Water Corporation.
URS[b], 2006	Flood Benefit Cost Analysis Model – User Documentation, Prepared for Melbourne Water Corporation.
WBM, 2006	Bacchus Marsh Flood Risk Study – Final Report, Prepared for Moorabool Shire Council

Appendix A

Digital Terrain Data Review

Review of DTM – 20 May 2008

CLIENTS | PEOPLE | PERFORMANCE

20 May 2008

Ms Hester van Zijl
Melbourne Water
100 Wellington Parade
EAST MELBOURNE VIC 3002

Our ref: 31/22909/150183
Your ref:

Dear Hester

Bacchus Marsh Area - Flood Mapping
Review of DTM

1 Introduction

This letter presents the findings from our review of the Digital Terrain Model (DTM) that was used as part of the Bacchus Marsh Flood Risk Study undertaken by WBM in 2006 for Moorabool Shire Council. It follows our earlier letter dated 14 May 2008 and your comments by e-mail dated 15 May 2008. This review has been undertaken as part of the current Bacchus Marsh area flood mapping study for Melbourne Water.

The purpose of this review is to:

- Assess the accuracy of the existing DTM and determine whether it is adequate for estimating flood extents; and
- Where necessary make recommendations for improvements to the DTM.

2 Data

In 2006, WBM prepared the Bacchus Marsh Flood Risk Study for Moorabool Shire Council. The flood extents for that study were produced using a TUFLOW model. The DTM used in that TUFLOW model is the focus on this review and hereafter is referred to as the existing DTM. Melbourne Water supplied the existing DTM for the purpose of this study in the following file:

- 2d_zpt_bacchus_30.TAB

Following the completion of the Bacchus Marsh Flood Risk Study in 2006, Melbourne Water began obtaining LiDAR data for the Bacchus Marsh area covering the areas shown in Attachment 1. The LiDAR coverage is divided into a number of separate areas that are at different stages of availability as follows:

- Flown in 2007 and data already processed;
- Flown in 2007 but the data is not processed (no timeframe available on when processing will occur); and
- To be flown in 2008.

The LiDAR data that was flown in 2007 and has been already processed has been made available for this study and was supplied by Melbourne Water in the following files:

- e270n5822_flood_mapping_10cm.txt

- e270n5824_flood_mapping_10cm.txt
- e270n5826_flood_mapping_10cm.txt
- e270n5828_flood_mapping_10cm.txt
- e270n5830_flood_mapping_10cm.txt
- e272n5822_flood_mapping_10cm.txt
- e272n5824_flood_mapping_10cm.txt
- e272n5826_flood_mapping_10cm.txt
- e272n5828_flood_mapping_10cm.txt
- e272n5830_flood_mapping_10cm.txt
- e274n5824_flood_mapping_10cm.txt
- e274n5826_flood_mapping_10cm.txt
- e274n5828_flood_mapping_10cm.txt
- e274n5830_flood_mapping_10cm.txt

Based on the project brief, we understand that the vertical accuracy of the LiDAR data supplied is between 0.04-0.1m. We are not aware of what the source data was that was used to create the existing DTM. Based on this understanding, we have assumed for the purpose of this review that the supplied LiDAR data provides a more accurate and more recent representation of the natural ground surface than the existing DTM. We have further assumed that objects that do not form part of the natural ground surface, such as buildings and vegetation, have been adequately removed during the processing of the LiDAR data.

3 Methodology

The review of the existing DTM was based on a comparison of the vertical levels with the available LiDAR data. The review was therefore limited to where there was coverage with the available LiDAR data.

At this stage a site visit has not been undertaken as part of this review.

It is assumed that the LiDAR coverage, as presented in Attachment 1, is adequate for the purpose of the current flood mapping study.

4 Review Findings

4.1 Overall

The direct difference in levels between the existing DTM and LiDAR data is presented in Attachment 2. In Attachment 3, the differences have been grouped together and categorised for clarity as follows:

- LiDAR > 0.3m higher than existing DTM;
- LiDAR +/- 0.3m of existing DTM; and
- LiDAR > 0.3m lower than existing DTM.

It should be noted that the existing DTM presented in Attachments 2 and 3 does not include the 1D network.

Attachment 3 shows that there are a number of areas where the difference between the LiDAR data and the DTM is greater than 0.3 m. While relatively small differences of even 50 mm may be significant in some locations we have used a tolerance of 0.3 m because it provides a better indication of the magnitude of the difference.

At present we do not have a digital version of the 100-year ARI flood extent that was prepared by WBM and that we could add to the figures in Attachments 2 and 3. Figure 5-3 from the main WBM report is presented in Attachment 4, which shows the 100-year ARI flood extent.

For the purpose of this review, we created a new DTM that used the LiDAR data where it was available and the existing DTM elsewhere. This further highlighted the differences between the two datasets. Attachment 5 shows the new DTM in the area adjacent to Bacchus Marsh Road and a clear difference in levels of up to 0.5m for adjacent areas where the two different datasets have been used. Attachment 6 shows the new DTM in the area adjacent to the Bacchus Marsh – Gisborne Road and larger differences of up to 3 m.

4.2 Werribee River

The following comments are made on the existing DTM along the Werribee River:

- Generally along the Werribee River through the study area, the levels from the LiDAR data and the existing DTM are similar and therefore flood extents derived using the existing DTM should be generally acceptable; and
- Along the north side of Bacchus Marsh Road (See Attachment 3) the LiDAR data is generally more than 0.3 m higher than the DTM and the WBM 100-year ARI flood extent shows this area to be inundated. Using a DTM based on the LiDAR data it is possible that this area may not be shown to be inundated.

4.3 Lerderderg River

The following comments are made on the existing DTM along the Lerderderg River:

- Generally along the Lerderberg River through the study area, there are a number of areas where there are differences (>0.3m) between the vertical levels provided by the LiDAR data and the existing DTM;
- In most cases the LiDAR data indicates that the ground levels are greater than the DTM levels. However generally the WBM 100-year ARI flood extent does not extend into these locations and therefore using the LiDAR data instead of the DTM may not make a significant difference; and
- In a few locations, the LiDAR data indicates that the ground levels are lower than the existing DTM, most notably adjacent to Lerderderg Street and Bacchus Marsh Gisbourne Road (See Attachment 3). The WBM 100-year ARI flood extent does not extend into these locations but using the LiDAR data instead of the existing DTM may possibly change this and lead to these areas actually being shown to be inundated in the 100-year ARI event.

5 Conclusions

Based on the findings of the above review, the following conclusions have been drawn:

- We have assumed that the LiDAR data supplied by Melbourne Water provides a better representation of the natural ground surface throughout the study area than that provided by the existing DTM;
- There are a number of locations within the study area where large differences (>0.3 m) in the vertical level provided by the LiDAR data and the existing DTM occur;
- Some of these locations are within the likely flood plain and therefore creating a new DTM with the available LiDAR data could potentially change the flood extents and flood levels from those derived by WBM; and
- Given the differences between the natural ground surface levels provided by the existing DTM and the LiDAR data where it is available, it is likely that further differences will exist in the areas where we do not currently have LiDAR data.

6 Recommendations

Based on the conclusions from the above review, we make the following recommendation:

- The LiDAR data covering the whole study area should be obtained and used to create the DTM for the current Bacchus Marsh flood mapping study.

We look forward to discussing the above with you further. In the meantime if you have any questions or comments regarding the above, please do not hesitate to contact me.

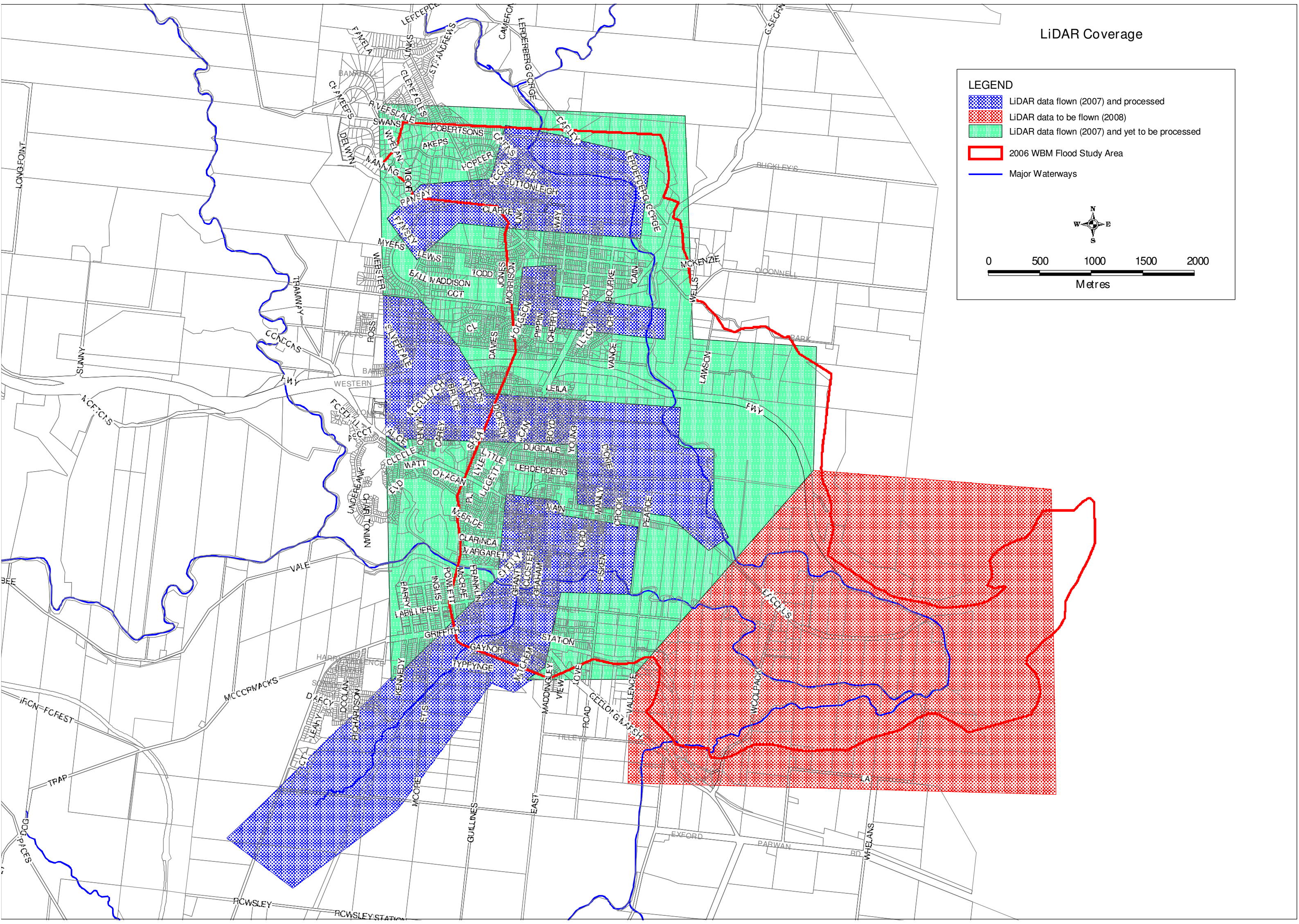
Yours sincerely

Philip Joyce
Senior Engineer
(03) 8687 8868

Attachments:
1 LiDAR Coverage
2 Comparison of 2006 Flood Study DEM and 2007 LiDAR DEM – Direct
3 Comparison of 2006 Flood Study DEM and 2007 LiDAR DEM - Categorised
4 100-Year ARI Peak Flood Height and Extent (Figure 5-3 from Bacchus Marsh Flood Risk Study Final Report, WBM, 2006.)
5 DEM Produced from combination of 2006 flood study DEM and 2007 LiDAR data – Area adjacent to Bacchus Marsh Road
6 DEM Produced from combination of 2006 flood study DEM and 2007 LiDAR data – Area adjacent to Bacchus Marsh – Gisborne Road

Attachment 1

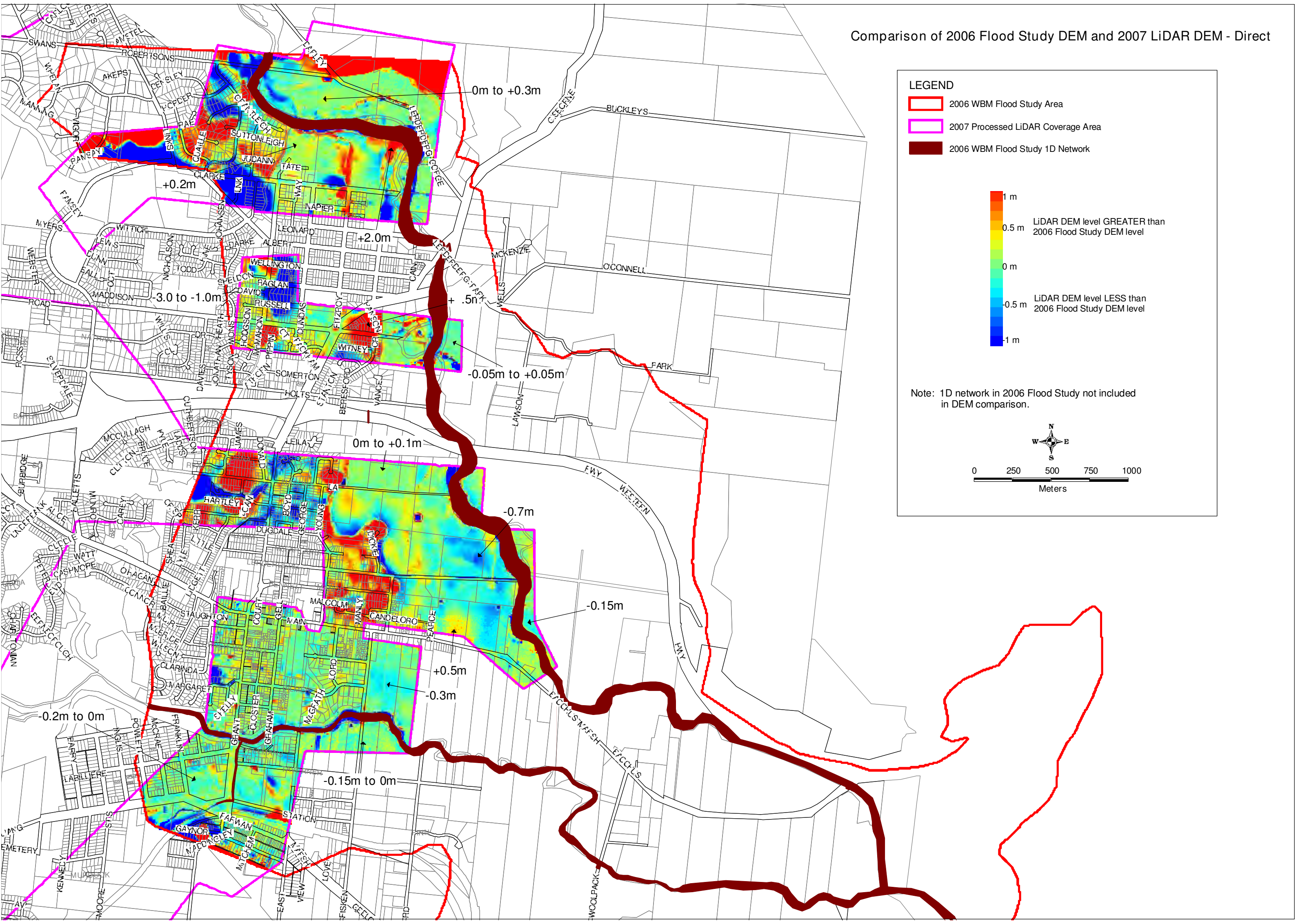
LiDAR Coverage



LiDAR Coverage
LEGEND
LiDAR data flown (2007) and processed
LiDAR data to be flown (2008)
LiDAR data flown (2007) and yet to be processed
2006 WBM Flood Study Area
Major Waterways
N
W
E
S
0
500
1000
1500
2000
Metres

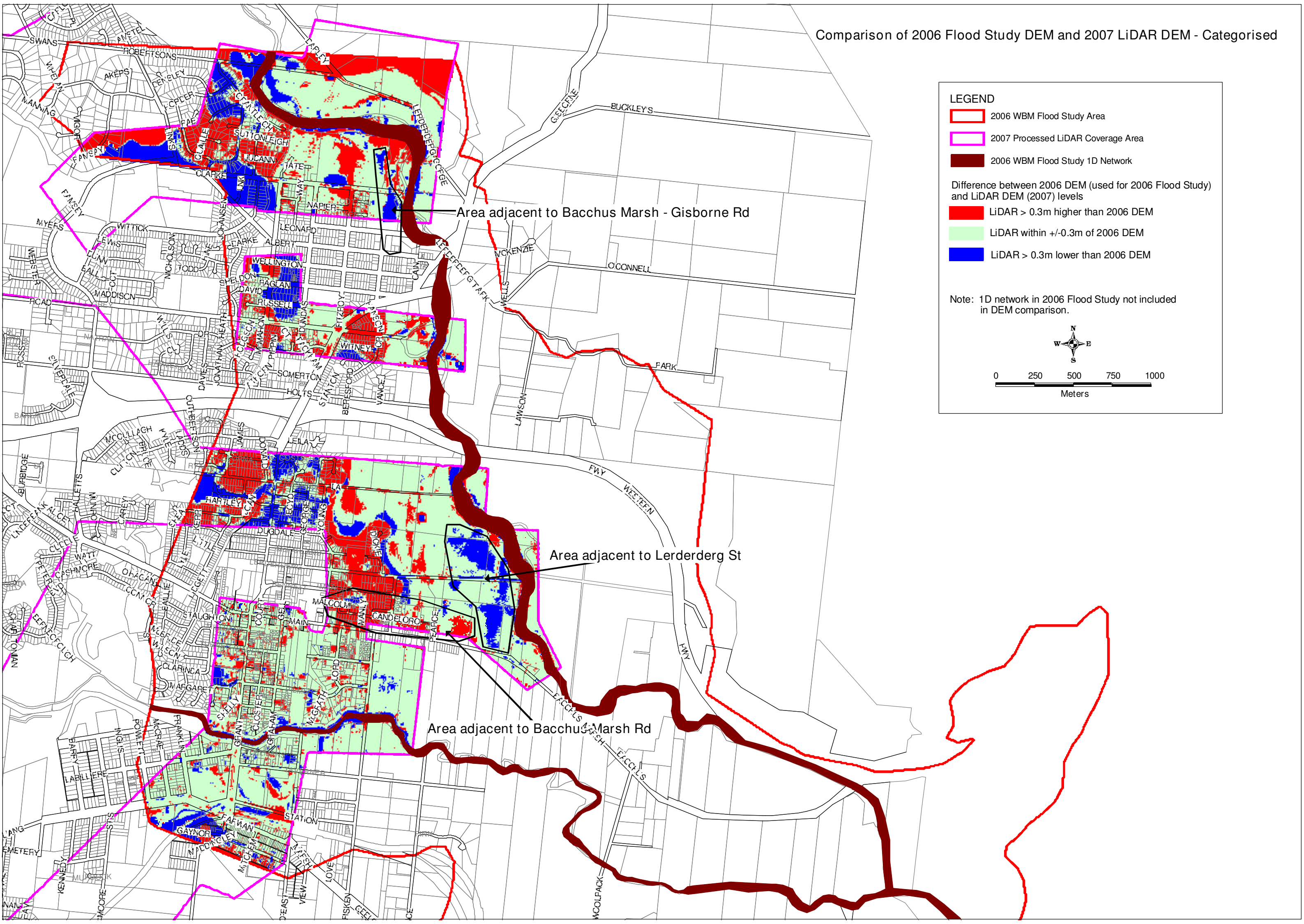
Attachment 2

Comparison of 2006 Flood Study DEM and 2007 LiDAR DEM – Direct


Comparison of 2006 Flood Study DEM and 2007 LiDAR DEM - Direct
LEGEND
2006 WBM Flood Study Area
2007 Processed LiDAR Coverage Area
2006 WBM Flood Study 1D Network
1 m
0.5 m
0 m
-0.5 m
-1 m
LiDAR DEM level GREATER than 2006 Flood Study DEM level
LiDAR DEM level LESS than 2006 Flood Study DEM level
Note: 1D network in 2006 Flood Study not included in DEM comparison.
N
S
E
W
0
250
500
750
1000
Meters
0m to +0.3m
+0.2m
+2.0m
-3.0 to -1.0m
-0.05m to +0.05m
0m to +0.1m
-0.7m
-0.15m
+0.5m
-0.3m
-0.2m to 0m
-0.15m to 0m
BUCKLEYS
O'CONNELL
MCKENZIE
WELLS
LAWSON
WESTERN
FWY
WOOLPACK
STATION
MALCOLM
CANDELORO
PEARCE
DUGDALE
HARTLEY
MCGRATH
NAPIER
LEONARD
ALBERT
WELLINGTON
RAGLAN
RUSSELL
WITNEY
SCMERTON
HOLTS
LEILA
MADDISON
MYERS
SWANS
ROBERTSONS
LABILLIERE
CLARINDA
STAUGHTON
GAYNOR
FARWAN
MITCHEM

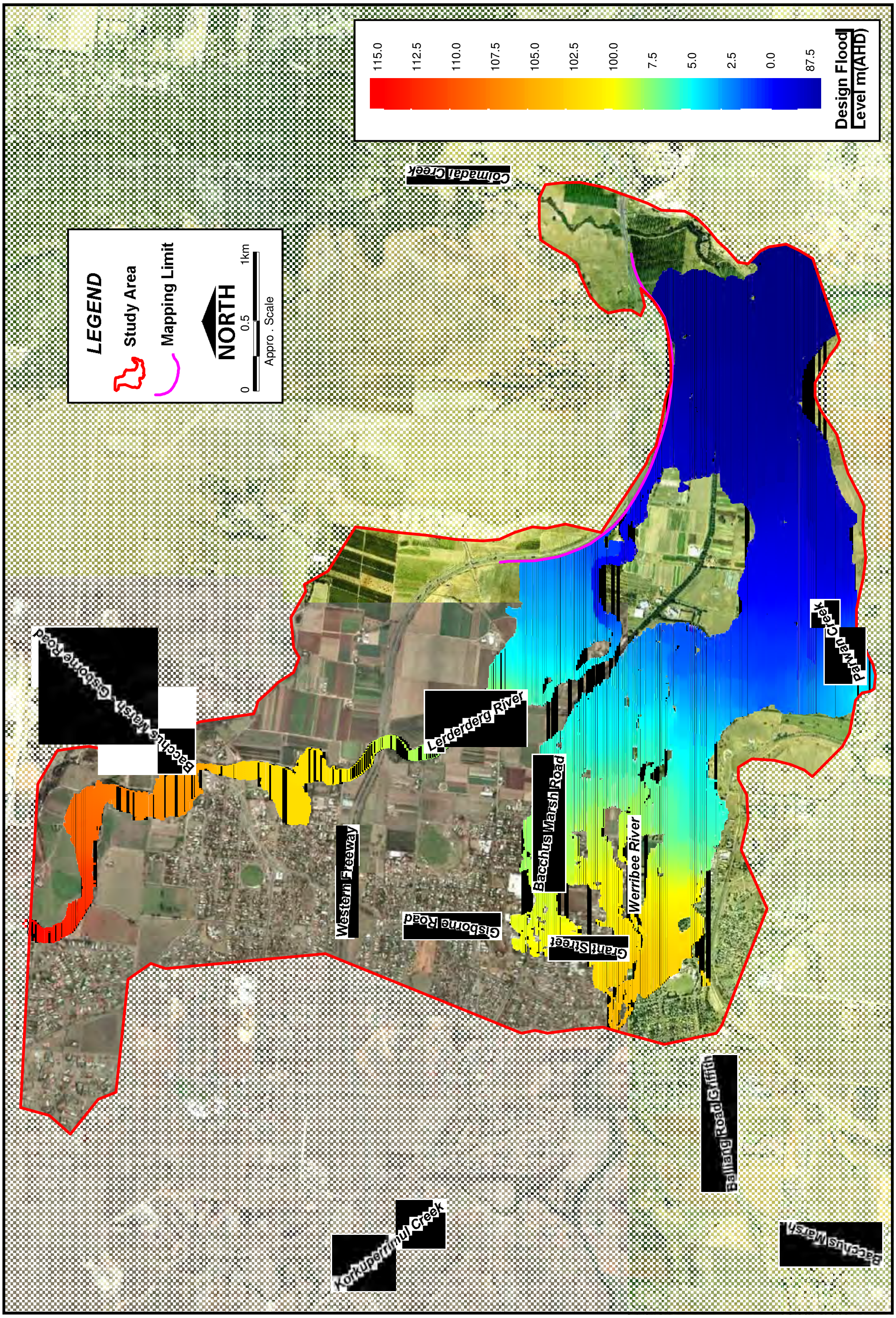
Attachment 3

Comparison of 2006 Flood Study DEM and 2007 LiDAR DEM – Categorised


Comparison of 2006 Flood Study DEM and 2007 LiDAR DEM - Categorised
LEGEND
2006 WBM Flood Study Area
2007 Processed LiDAR Coverage Area
2006 WBM Flood Study 1D Network
Difference between 2006 DEM (used for 2006 Flood Study) and LiDAR DEM (2007) levels
LiDAR > 0.3m higher than 2006 DEM
LiDAR within +/-0.3m of 2006 DEM
LiDAR > 0.3m lower than 2006 DEM
Note: 1D network in 2006 Flood Study not included in DEM comparison.
N
W
E
S
0
250
500
750
1000
Meters
Area adjacent to Bacchus Marsh - Gisborne Rd
Area adjacent to Lerderderg St
Area adjacent to Bacchus Marsh Rd

Attachment 4

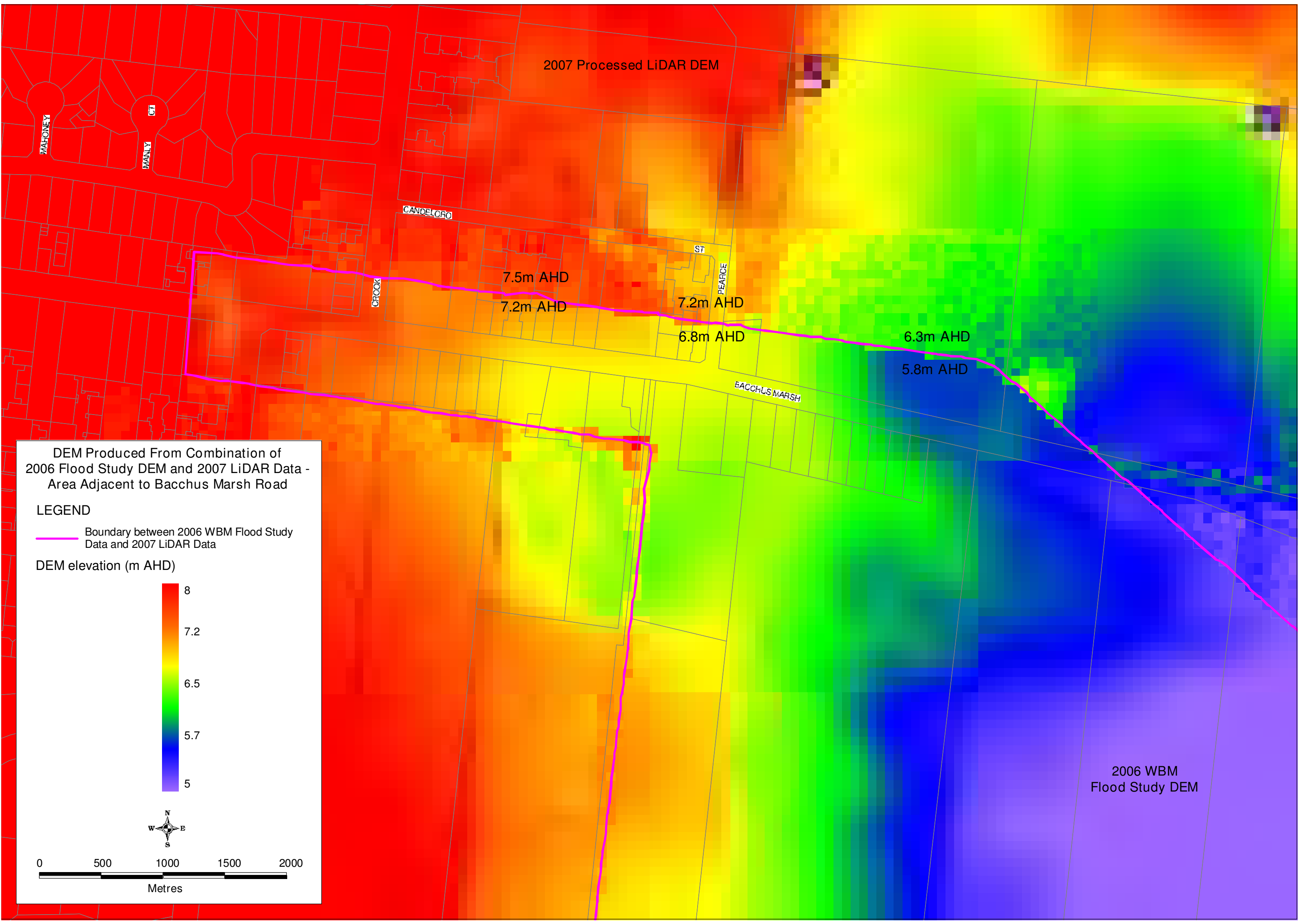
100-Year ARI Peak Flood Height and Extent (Figure 5-3 from Bacchus Marsh Flood Risk Study Final Report, WBM, 2006.)



100 Year ARI Peak Flood Height and E tent Figure 5-3

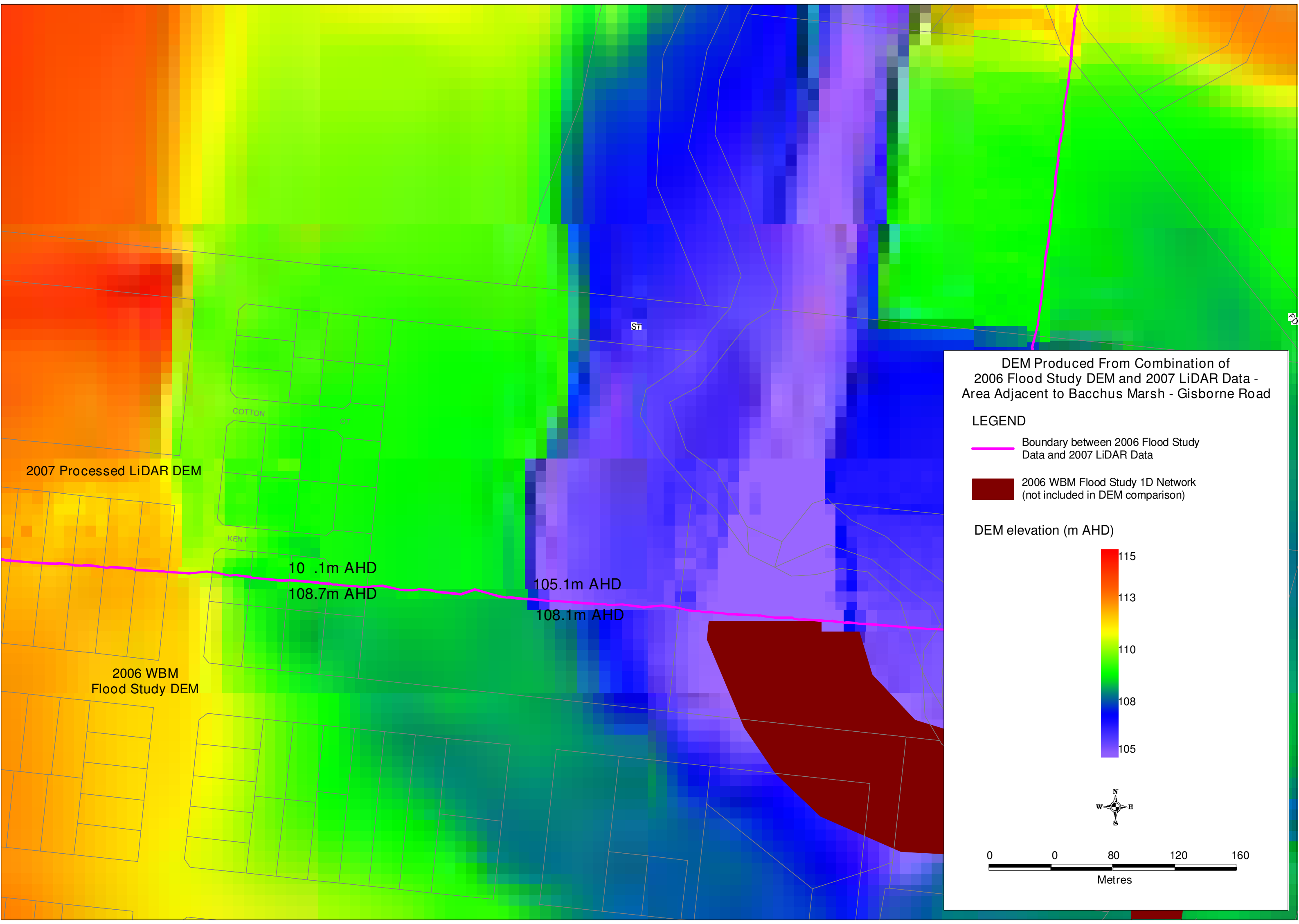
Attachment 5

DEM Produced from Combination of 2006 Flood Study DEM and 2007 LiDAR Data – Area Adjacent to Bacchus Marsh Road


2007 Processed LiDAR DEM
CANDELO GRO
MAHONEY
CT
MANLY
ST
PEARCE
CROOK
7.5m AHD
7.2m AHD
7.2m AHD
6.8m AHD
6.3m AHD
5.8m AHD
BACCHUS MARSH
DEM Produced From Combination of
2006 Flood Study DEM and 2007 LiDAR Data -
Area Adjacent to Bacchus Marsh Road
LEGEND
Boundary between 2006 WBM Flood Study Data and 2007 LiDAR Data
DEM elevation (m AHD)
8
7.2
6.5
5.7
5
N
W
E
S
0
500
1000
1500
2000
Metres
2006 WBM
Flood Study DEM

Attachment 6

DEM Produced from Combination of 2006 Flood Study DEM and 2007 LiDAR Data – Area Adjacent to Bacchus Marsh Road – Gisborne Road


DEM Produced From Combination of
2006 Flood Study DEM and 2007 LiDAR Data -
Area Adjacent to Bacchus Marsh - Gisborne Road
LEGEND
Boundary between 2006 Flood Study Data and 2007 LiDAR Data
2006 WBM Flood Study 1D Network (not included in DEM comparison)
DEM elevation (m AHD)
115
113
110
108
105
N
W
E
S
0
0
80
120
160
Metres
2007 Processed LiDAR DEM
2006 WBM Flood Study DEM
10 .1m AHD
108.7m AHD
105.1m AHD
108.1m AHD
COTTON
CT
KENT
ST

Appendix B

Hydrological Review

RORB Model Review– 05 June 2008

CLIENTS | PEOPLE | PERFORMANCE

05 June 2008

Ms Hester van Zijl
Melbourne Water
100 Wellington Parade
EAST MELBOURNE VIC 3002

Our ref: 31/22909/150698
Your ref:

Dear Hester

Bacchus Marsh Area - Flood Mapping
RORB Model Review

1 Introduction

This letter presents the findings from our review of the RORB Model that was used as part of the Bacchus Marsh Flood Risk Study undertaken by WBM in 2006 for Moorabool Shire Council. This review has been undertaken as part of the current Bacchus Marsh area flood mapping study for Melbourne Water.

The purpose of this review is to:

- Assess the existing RORB model and determine whether it is adequate for estimating flood flow hydrographs as inputs for the hydraulic modelling as part of the current Bacchus Marsh area flood mapping study; and
- Where necessary make recommendations for improvements to the RORB model.

2 Data and Information

Along with a final copy of the Bacchus Marsh Flood Risk Study report, the following RORB file and MAP-INFO tables were supplied for the purpose of this review:

- Bacchus_3.cat;
- BM_Reaches3.TAB; and
- BM_Subcatch4.TAB.

In addition to the above, a number of other supporting documents were supplied by Melbourne Water and these are listed in Attachment 1.

3 RORB Model Setup and Structure

The following comments are made on the setup and structure of the RORB model used for the Bacchus Marsh Flood Risk Study (Bacchus_3.cat):

- The adopted RORB model parameters presented in Table 4-1 of WBM's report show that Reach Types 2 and 3 were used. However a review of the catchment file shows that only Reach Types 1 and 4 were actually used. Reach Types are used within RORB to model appropriate delay times for the runoff response of the catchment and they thus contribute to the amount of storage along flow paths within the catchment. Reach Type 1 is defined in the RORB manual as being representative of a 'natural channel', which has a relatively high delay time and thus large storage. Reach type 4 has a delay time in the model of zero and is defined in the RORB manual as being representative of a drowned reach or reservoir that is full. While it may be appropriate to use a Reach Type 1 for the flow paths along the main rivers, we consider that a Reach Type 2 would better model the runoff from the generally steep subareas in the upper parts of the catchment, particularly for cleared land, where the runoff response time may be relatively quick. This change could potentially have a significant effect on the RORB modelling. Reach Type 1 may still be appropriate in places. Reach Type 3s may also be appropriate in developed areas;
- The adopted impervious fractions are based on planning scheme zones and seem appropriate, although the default value for transport of 0.9 (assuming this comprises road zones RDZ1 and RDZ2) is slightly high, where we would typically use a value of 0.6 to 0.7. Based on the adopted values, the weighted impervious fractions for each subarea within the RORB model seem reasonable. It should be noted that Current Planning Scheme Zones are probably different to those originally used (eg. FZ, GWZ are new zone types);
- Throughout the RORB model Control Code 2 (add and route in single reach) have been used to add sub-areas. This approach only allows one Reach Type to be used to jointly describe the run-off from the sub-area and the main flow path through the subarea. Following on from above, we consider that in many cases different Reach Types should be used to describe run-off from the sub-area and the main flow path through the subarea. Therefore the existing structure of the RORB model, which uses Control Code 2s should be replaced with an equivalent set of instructions which enables separate routing of the sub are and the main flow path in accordance with Melbourne Water and GHD standard practise;
- A number of subareas could be split to better represent the response of individual valleys and correctly define areas contributing to gauge and printout locations;
- Some reaches don't follow valleys and go across ridge lines, but this was observed only a few times;
- Generally the external catchment boundary has been defined relatively well but the internal subcatchments could be defined better with their boundaries more accurately following ridge lines;
- Current GIS layers appear to be consistent with the current version of the catchment file;

- Pykes Creek Reservoir has been included within the RORB model. The reservoir has been modelled as 'weir only' and it has been assumed for the RORB modelling that the reservoir starts full. Current storage volumes within Pykes Creek reservoir are only 4.7% full (April 2008, DSE Monthly Water Report). However in defining the 100-year ARI flood plain it is perhaps appropriate to assume the worst case and assume the reservoir is full. It was stated in the WBM report that prior to the 1995 event (the event that was used to verify the RORB model) all available on-stream storages were filled by rainfall within the Werribee River catchment. It is not specifically mentioned, but we assume that this would therefore include Pykes Creek Reservoir. This should be checked because Pykes Creek Reservoir on occasions when it has not been full has in the past sufficiently attenuated flood flows to prevent flooding downstream at Bacchus Marsh (for example in 1941);
- A 20 mm initial loss has been adopted for the RORB model. Although potentially a reasonable value, there seemed to be no explanation within WBM's report on what this value is based on or reference to where it came from;
- A continuing loss of 2 mm/h was initially used, but revised to 1 mm/h following discussions with DSE. This value may be justifiable with reliable calibration data but otherwise smaller than typically adopted;
- Table 4-1 of WBM's report implies that aerial reduction factors are used. This is probably appropriate given the catchment size and as the study area is in the vicinity of the catchment outlet; and
- State Rivers streamflow books and old reports (from planning scheme amendment objection letter) indicate that diversion tunnels exist between Werribee River and Pykes Creek Reservoir, between Lerderderg River and Goodmans Creek, and between Goodmans Creek and Merrimu Reservoir. These do not appear to be represented within the RORB model and should be further investigated for their potential effect on the RORB modelling.

4 RORB Model Calibration/Verification

A summary of the calibration/verification process for the RORB model is presented as follows:

- Three k_c values were calculated based on empirical equations following ARR(98) methodology ($kc = 2.57A^{0.45} = 55$; $kc = 0.49A^{0.65} = 40$; and the RORB estimate of kc = 66);
- Peak 100-year ARI flow estimates were calculated with the RORB model using each k_c value and compared with the published 1995 flow estimate (historical) for Werribee River at Bacchus Marsh gauge (577 m^3/s); and
- DSE believed that the 1995 flood event was less than a 100-year ARI event, but the largest 100-year ARI flow estimate based on the selected k_c values was only 420 m^3/s (k_c = 40).

At this point the TUFLOW model was then used to assist with the calibration/verification process as follows.

- Flow estimates from the RORB model based on a k_c value of 55 (with this k_c value the 100-yr ARI flow estimate at Bacchus Marsh gauging station was 315 m^3/s) were run through the TUFLOW model and water levels estimated by the model were compared with 1995 (historical) flood levels along the reach upstream of Grant Street Bridge. Upstream of Grant Street Bridge the modelled flood levels from TUFLOW were consistently 0.5 m below the historical flood levels;

- Following discussions of these findings with DSE, the following RORB parameters were adopted: k_c = 40, IL = 20 mm, CL = 1 mm/h, m = 0.8. This resulted in a 100-year ARI flow estimate of 500 m^3/s for the Werribee River at Bacchus Marsh gauge; and
- Based on the adopted design flows for the Bacchus Marsh Flood Risk Study and the observed flood levels, the TUFLOW model showed that the 1995 historical flood event would be between a 20-year and 50-year ARI event. It was concluded by WBM that the flow estimate at the gauging station for the 1995 event was probably high.

The following comments are made on the above verification process:

- An attempt was only made to 'ballpark' (WBM terminology) verify the RORB model as part of the Bacchus Marsh Flood Risk Study. The WBM report stated that neither the hydrological or hydraulic models could be calibrated due to insufficient reliable data. We are aware that numerous gauging stations exist throughout the catchment and therefore further investigation into the available data should be undertaken to confirm this;
- While the report states that the 1995 flood level recorded on the Werribee River at Bacchus March Gauging Station (Station Number 231200) was significantly above the maximum gauged height (page 3-2), no discussion is provided on the potential accuracy of the calculated flow. Given the apparent large disagreement between the flow estimates derived at the gauging station and with the RORB model during the RORB model verification process and that the 1995 event was the only event that was used for verification, the accuracy of the 1995 flood flow estimate at the gauging station should be further clarified;
- No calibration/verification of the RORB model appears to have been undertaken on the Lerderderg River. The report states (page 3-2) that record exists between 1907 and 1978 at Darley Gauging Station (Station Number 231201), although maximum instantaneous flows are only available from 1975 to 1978. We are aware that more recent data exists at a Gauging Station upstream from Goodman Creek Junction (Station Number 231211), which is currently in operation and has a record dating back to 1956. A flood flow estimate and flood levels were also available for the 1985 event on the Lerderderg River as part of the Holts Lane Flooding Investigation (CMPS&F, 1991); and
- There appear to be problems with the use of the TUFLOW model to assist with the verification of the RORB model flow estimates. Based on the flood levels presented in Figure 4-2 of the WBM report, there appears to be possible agreement between the observed flood water levels and the TUFLOW model downstream from Grant Street Bridge. However upstream from the bridge, the observed flood water levels are approximately 0.5m above the modelled flood water levels (see Figure 4-2 of WBM Report). Based on this observation, it appears that the TUFLOW model is not accurately modelling the afflux across the Grant Street Bridge. This is a point also raised in the letter by Dennis L Murphy dated 20 March 2008. We are aware that since the 1995 event the Grant Street Bridge was replaced and it states in the WBM report that the new bridge was used in the model (Page 4-11). It is not clear whether this applied during the verification process. This would need to be further investigated as part of the TUFLOW model review, which will be undertaken as part of Hold Point 6. If the old bridge was not included in the model for the purpose of the verification process, the ability of the model to estimate the 1995 flood levels upstream from the bridge would be compromised.

5 Conclusions

Based on the findings of the above review, the following conclusions have been drawn:

1. We consider that Reach Type 2s, instead of Reach Type 1s, should be used to represent the runoff from a number of sub-areas within the RORB model, particularly in the steep upper parts of the catchment. This change could potentially have a significant effect on the RORB modelling. Reach Type 1 may still be appropriate in places. Reach Type 3s may also be appropriate in developed areas.
2. The existing structure of the RORB model, which uses Control Code 2s will need to be changed to enable a more representative routing approach which can route inflow and mainstream reaches separately.
3. The sub-areas and reaches could be better defined in some locations.
4. No allowance for the effect of the diversion tunnels between Werribee River and Pykes Creek Reservoir, between Lerderderg River and Goodmans Creek, and between Goodmans Creek and Merrimu Reservoir.
5. An attempt was only made to verify the RORB model as part of the Bacchus Marsh Flood Risk Study. The WBM report stated that neither the hydrological or hydraulic models could be calibrated due to insufficient reliable data.
6. No discussion is provided on the potential accuracy of the calculated flow for the 1995 event on the Werribee River, at Bacchus March Gauging Station (Station Number 231200).
7. No calibration/verification of the RORB model appears to have been undertaken on the Lerderderg River.
8. It appears that the afflux at Grant Street Bridge within the TUFLOW model may not be appropriately modelled potentially affecting the results obtained from the TUFLOW model that were used to assist with the verification of the RORB model.

6 Recommendations

Based on the conclusions from the above review, we make the following recommendations:

1. A new RORB model should be setup which includes:
   - The use of Control Code 1s for all subarea inputs to allow separate reach types to be defined for the sub-areas and the main flow paths through the sub-areas;
   - Better general definition of sub-areas, particularly with resect to internal boundaries; and
   - Finer subareas around Bacchus Marsh township to enable detailed flood modelling of the Fisken Street Drain and Maddingly Park Drain (new Melbourne Water requirement).
2. Investigate further the availability and suitability of gauged data within the catchment for the purpose of calibrating the RORB and TUFLOW models with particular attention on:
   - Flood flows and levels on the Lerderderg River;
   - The accuracy/reliability of the flow estimates at Bacchus Marsh Gauging Station (Station Number 231200); and
   - The availability of rainfall data for the 1995 event.

3. Investigate the operation of the three diversion tunnels and include in the RORB model if applicable.
4. Investigate water levels in Pykes Creek Reservoir for the 1995 event.

We look forward to discussing the above with you further. In the meantime if you have any questions or comments regarding the above, please do not hesitate to contact me.

Yours sincerely

Philip Joyce
Senior Engineer
(03) 8687 8868

Attachment: Reports and Information Received from Melbourne Water

Attachment 1

Reports and Information Received from Melbourne Water

Title/Description	Author	Format	Date
Re. Planning Scheme Amendment C14 Moorabool Planning Scheme	Denis L Murphy	Letter	20 March 2008
Analysis November 1995	-	Folder	1996
Werribee River at Bacchus Marsh Flood Investigation Draft June 1977	State Rivers and Water Supply Commission	Report	June 1977
Correspondence, memos etc	Shire of Bacchus Marsh Planning Matters	Folder	1977 - 1993
Environment Planning and Management, Floodplain Management, Lerderderg River, Gisbourne & Robertson Road	Rural Water Commission of Victoria	Folder	1992 - 1993
Flood Investigation File, Lerderderg River, Correspondence, enquiries etc	Rural Water Commission of Victoria	Folder	1985 - 1993
Holts Lane Flooding Investigations Phase 1	Camp Scott Furphy P.L.	Report	1991
Holts Lane Flooding Investigations Phase 2 – Detailed Investigation	Camp Scott Furphy P.L.	Report	1991
Ouphan Resources Pty Ltd, Lerderderg River Flood Study, Robertsons Road to Gisbourne Road, Bacchus Marsh	Camp Scott Furphy Pty Ltd	Report	1992
An Investigation of Flood Flows in the Werribee River	Shire of Bacchus Marsh	Report	June 1975
Werribee River at Bacchus Marsh – Calculation Folder	State Rivers and Water Supply Commission	Folder	1976

Title/Description	Author	Format	Date
Bridge over Lerderderg River - Western By-Pass Road (Calcs and Drawings)	Country Roads Board	Folder	Not Shown
Flood Report – Werribee River at Bacchus Marsh – 16 October 1983	Not Shown	Folder	June 1991

Appendix C

Impervious Fraction Values Review

Impervious Fraction Values Review – 18 July 2008

18 July 2008

Ms Hester van Zijl
Melbourne Water
100 Wellington Parade
EAST MELBOURNE VIC 3002

Our ref: 31/22909/152742
Your ref:

Dear Hester

Bacchus Marsh Area - Flood Mapping
Impervious Fraction Values

1 Introduction

This letter presents the impervious fraction methodology and values that we propose to use for the Bacchus Marsh area flood mapping study.

Estimates of the impervious fraction are required throughout the catchment for the hydrological modelling of base case conditions with and without an allowance for the effects of climate change as defined in the brief.

2 Methodology

2.1 Planning Scheme Zones

The Bacchus Marsh area is outside of the Planning Model area of coverage and the urban development programme.

For this study impervious fractions have been based on the planning scheme zones provided by Melbourne Water. This approach assumes that full development has occurred in all areas zoned for development. Based on aerial photography from 2006, Attachment 1 shows that there are several large residential zoned areas that are currently not developed. The hydrological modelling based on the impervious fractions from this approach will therefore likely provide higher peak flow estimates from these areas.

This approach is slightly different to that used in the planning model, which through its assessment of how the impervious fraction relates to block size in residential areas, takes into account the extent of existing development.

2.2 Residential

For this study it is proposed that impervious fractions for residential areas are based on lot sizes following the approach currently adopted for the Redevelopment Services Scheme (RSS) work.

The lot size is the average area within a development that is occupied by a single property. A relationship exists between lot size and the impervious fraction, which was developed as part of the current Redevelopment Services Scheme (RSS) work and is presented in Attachment 2.

Based on the cadastre map background, the lot sizes for existing residential development were found to typically range from 600 m^2 to 1000 m^2. Based on the relationship for outer suburbs, the impervious fraction would therefore range from between 39% and 48%.

The impervious fraction for residential areas adopted by the previous flood mapping study (WBM, 2006) was 50% and the typical range used traditionally in the past by Melbourne Water is 40% to 50%.

Based on our recent experience with Redevelopment Services Scheme projects, we believe that current trends may indicate that impervious fractions will increase in the future. We therefore consider it prudent to be generally conservative when estimating the impervious fraction for future residential development.

We therefore consider that an impervious fraction of 50% should be used for residential zones in this study. This agrees with the previous flood mapping study (WBM, 2006) and is generally at the upper limit of the range based on our assessment of typical lot sizes.

2.3 Non-Residential

For non-residential areas it is proposed that impervious fractions are based on typical values for planning scheme zones (as used in the planning model).

The current planning scheme zone classification for the areas within the catchment were supplied by Melbourne Water and are presented in Attachment 3. At present we are in the process of contacting Moorabool Shire Council to:

- Confirm that this planning scheme zone classification is current; and
- Establish if any changes to the classification are likely in the near future (next 3-years).

3 Previous Flood Mapping Study (WBM, 2006)

As reported in our earlier letter dated 5 June 2008, the adopted impervious fractions for the previous flood mapping study (WBM, 2006) were based on planning scheme zones. These values generally seemed appropriate, although the default value for transport of 0.9 (assuming this comprises road zones RDZ1 and RDZ2) is slightly high, where we would typically use a value of 0.6 to 0.7. Also some current Planning Scheme Zones are probably different to those originally used (eg. FZ, GWZ are new zone types). We do not have the planning scheme zones that were used for the previous flood mapping study (WBM, 2006) to confirm this.

4 Impervious Fractions

The impervious fractions that are proposed to be used by this study are presented in Attachment 4. Also shown, for comparison, are the equivalent impervious fractions from the planning model together with those used in the previous flood mapping study (WBM, 2006).

Generally the adopted values are the same as those used in the planning model and those used for the previous flood mapping study (WBM, 2006). The main differences are as follows:

- Public Conservation and Resource Zone (PCRZ) – We have adopted a value of 0%, which agrees with the planning model, but is different from the value used for the previous flood mapping study, which was 10%;

- Services and Utility Zone (PUZ) – The previous flood mapping study used a single value of 40% to cover all service and utility sites, but based on aerial photography (2006) we have derived separate values for each site that range from 5% to 70%; and
- Road Zone (RDZ) - We have adopted values of 70% and 60% for RDZ1 and RDZ2 respectively, which agree with the planning model, but are different from the values used for the previous flood mapping study, which were 90% for both.

We will apply the impervious fractions proposed in Attachment 4 to the RORB model of the catchment. We do not require Melbourne Water to use their impervious fraction calculator to facilitate this.

We look forward to receiving your comments on the above. In the meantime if you have any questions or you would like to discuss the above further, please do not hesitate to contact me.

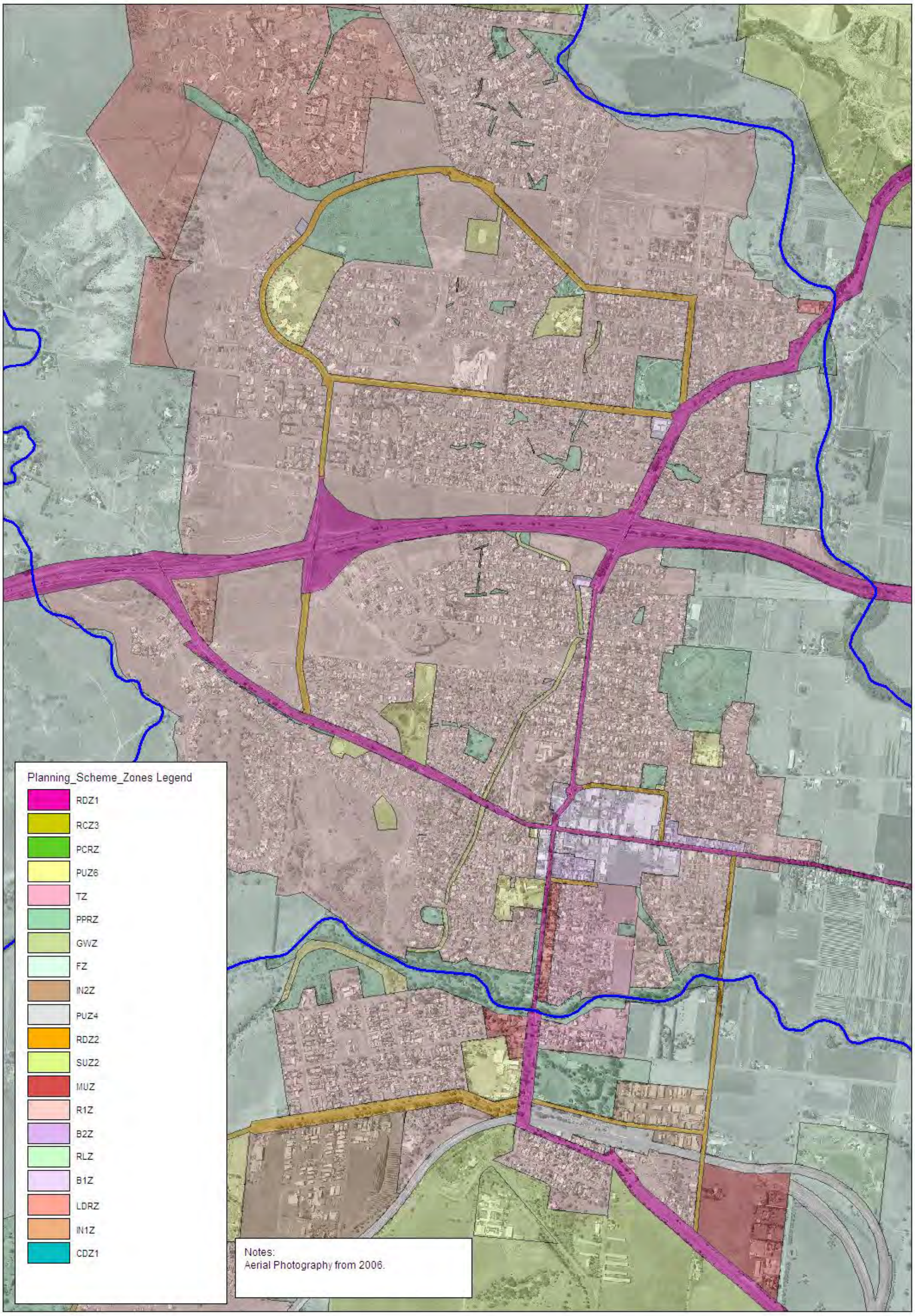
Yours sincerely

Philip Joyce
Senior Engineer
(03) 8687 8868

Attachments 1-4: Reports and Information Received from Melbourne Water

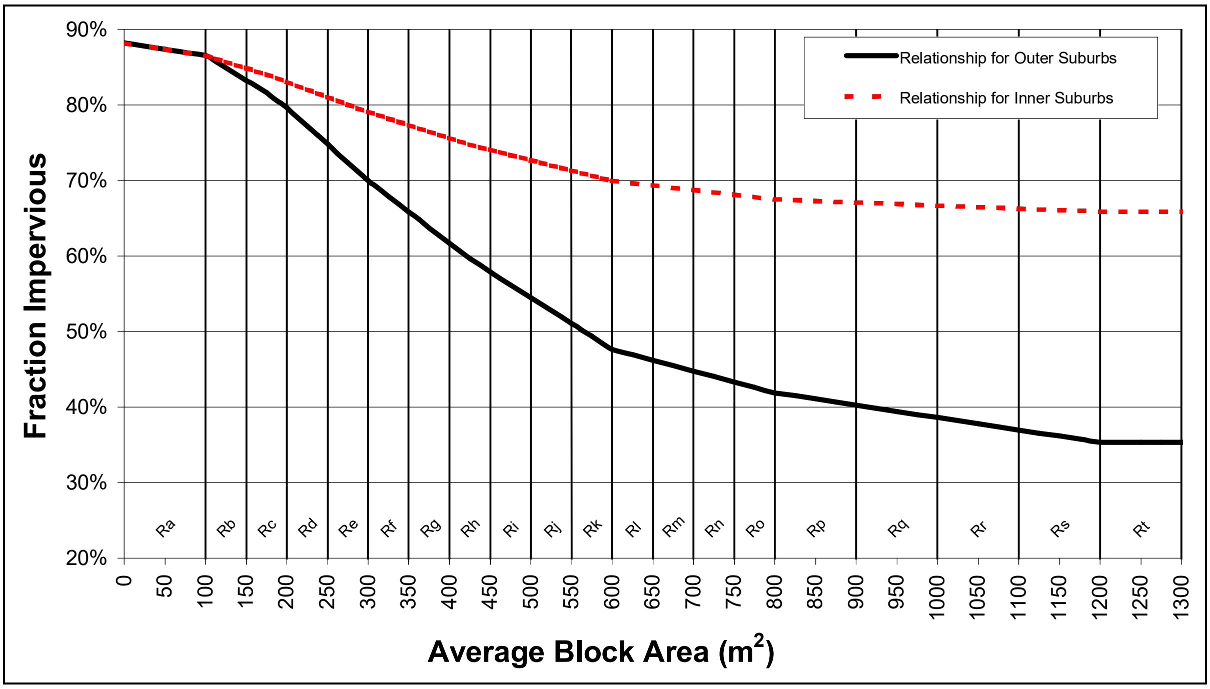
Attachment 1

Existing Levels of Development in Bacchus Marsh Based on 2006 Aerial Photography


Planning_Scheme_Zones Legend
RDZ1
RCZ3
PCRZ
PUZ6
TZ
PPRZ
GWZ
FZ
IN2Z
PUZ4
RDZ2
SUZ2
MUZ
R1Z
B2Z
RLZ
B1Z
LDRZ
IN1Z
CDZ1
Notes:
Aerial Photography from 2006.

Attachment 2

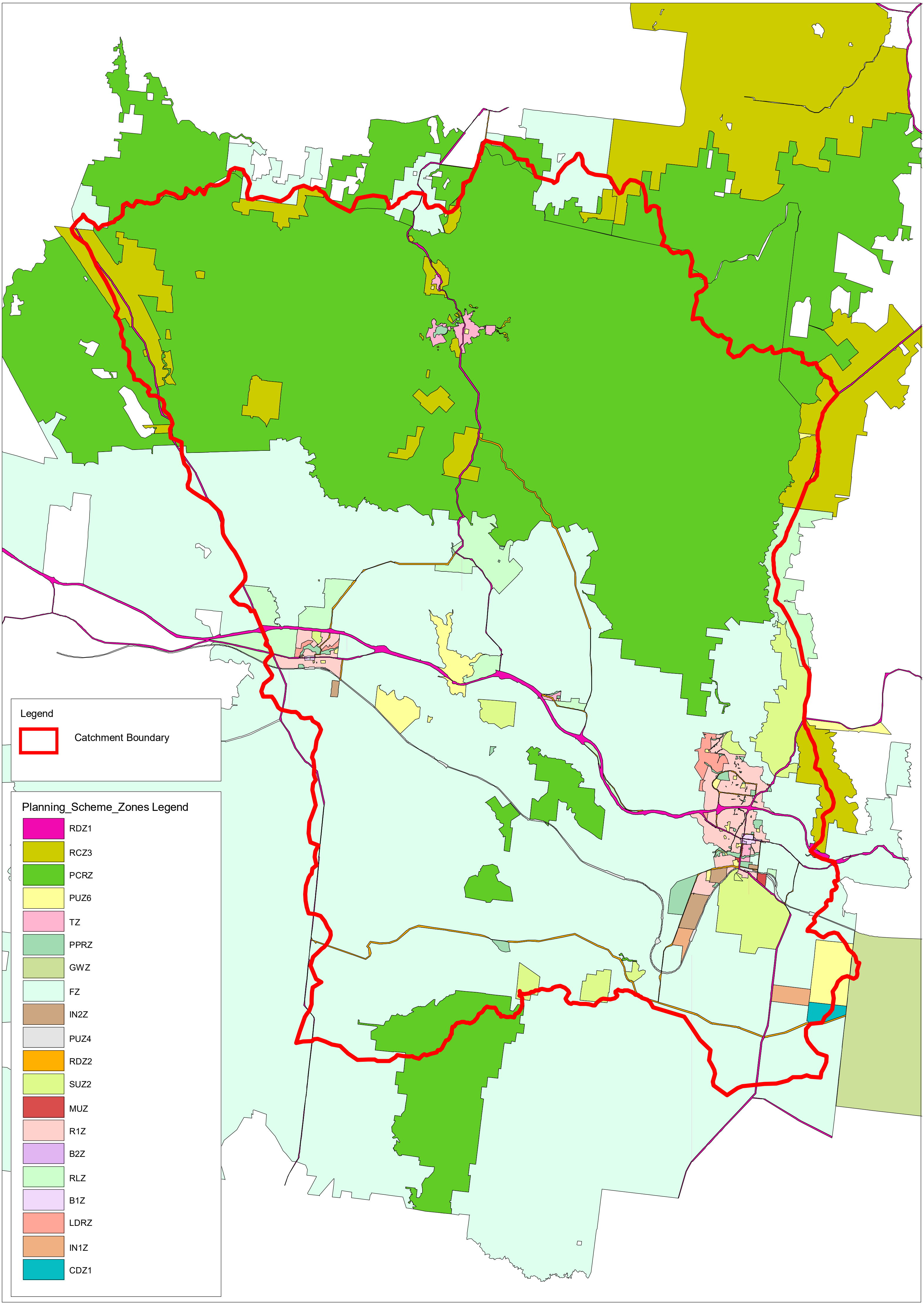
Relationship between Impervious Fraction and Residential Lot Size



Fraction Impervious
90%
80%
70%
60%
50%
40%
30%
20%
Relationship for Outer Suburbs
Relationship for Inner Suburbs
Ra
Rb
Rc
Rd
Re
Rf
Rg
Rh
Ri
Rj
Rk
Rl
Rm
Rn
Ro
Rp
Rq
Rr
Rs
Rt
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
Average Block Area (m^2)

Attachment 3

Planning Scheme Zones



Legend
Catchment Boundary
Planning_Scheme_Zones Legend
RDZ1
RCZ3
PCRZ
PUZ6
TZ
PPRZ
GWZ
FZ
IN2Z
PUZ4
RDZ2
SUZ2
MUZ
R1Z
B2Z
RLZ
B1Z
LDRZ
IN1Z
CDZ1

Attachment 4

Proposed Impervious Fractions

GHD

www.ghd.com.au
Tel. (03) 8687 8000 Fax. (03) 8687 8111
180 Lonsdale Street Melbourne Vic 3000

Melbourne Water - Bacchus Marsh Area - Flood Mapping
Proposed Impervious Fractions for each Zone Type

Zone Code	Default Value[1]	Adopted Value	Interpreted WBM Zone[2]	WBM Value[2]	Comment
B1Z	0.9	**0.9**	Commercial	0.9	
B2Z	0.9	**0.9**	Commercial	0.9	
CDZ1	0.5	**0.1**	Rural	0.2	Bacchus Marsh Speedway - adopted value based on aerial photo
FZ		**0.05**	Rural	0.2	
GWZ		**0.05**	Rural	0.2	
IN1Z	0.9	**0.9**	Industrial	0.9	
IN2Z	0.9	**0.9**	Industrial	0.9	
LDRZ	0.2	**0.2**	Rural Residential	0.2	
MUZ	0.6	**0.6**			
PCRZ	0	**0**	Conservation	0.1	
PPRZ	0.1	**0.1**	Public Open Space	0.1	
PUZ1	0.05 / 0.5	**0.05**	Services & Utility	0.4	Default value of 0.5 is for reservoirs. Default value for all other PUZ1 is 0.05 - confirmed by aerial photo
PUZ1a		**0.5**			Zone renamed for Pykes Creek Reservoir
PUZ2	0.7		Services & Utility	0.4	Generally schools - treated on case by case basis by renaming zones as below
PUZ2a		**0.7**			Bacchus Marsh Primary School - adopted value based on aerial photo
PUZ2b		**0.6**			Darley Primary School - adopted value based on aerial photo
PUZ2c		**0.5**			Bacchus Marsh College (Maddingley Campus) - adopted value based on aerial photo
PUZ2d		**0.4**			Bacchus Marsh College (Darley Campus) - adopted value based on aerial photo
PUZ2e		**0**			unknown site - adopted value based on aerial photo
PUZ2f		**0.7**			School in Myrniong - adopted value based on aerial photo
PUZ2g		**0.5**			School in Ballan - adopted value based on aerial photo
PUZ3	0.7	**0.7**	Services & Utility	0.4	Confirmed by aerial photo
PUZ4	0.7	**0.7**	Services & Utility	0.4	Confirmed by aerial photo
PUZ5	0.6	**0.4**	Cemetery	0.4	Cemeteries - WBM value confirmed by aerial photo
PUZ6	0.7	**0.7**	Services & Utility	0.4	
R1Z		**0.5**	Residential	0.5	WBM value - this would be a maximum value based on aerial photo and average block sizes
R2Z		**0.5**	Residential	0.5	WBM value - this would be a maximum value based on aerial photo and average block sizes
RCZ		**0.1**	Conservation	0.1	Formerly ERZ in Planning Model - default value for ERZ is 0.1
RCZ1		**0.1**	Conservation	0.1	Formerly ERZ in Planning Model - default value for ERZ is 0.1
RCZ3		**0.1**	Conservation	0.1	Formerly ERZ in Planning Model - default value for ERZ is 0.1
RDZ1	0.7	**0.7**	Transport	0.9	
RDZ2	0.6	**0.6**	Transport	0.9	
RLZ	0.2	**0.2**	Rural Residential	0.2	
SUZ1	0.5	**0.1**	Special Use	0.2	Includes coal mine - adopted value based on aerial photo
SUZ2	0.5	**0.1**	Special Use	0.2	Includes quarry - adopted value based on aerial photo
SUZ3	0.5	**0.1**	Special Use	0.2	Covers golf courses only - adopted value based on aerial photo
SUZ4	0.5	**0.5**	Special Use	0.2	Covers Bacchus Marsh Grammar School - adopted value based on aerial photo
TZ	0.55	**0.3**	Rural Residential	0.2	Township Zones in Blackwood and Myrniong - adopted value based on aerial photo

1 Default Values are those used in the Planning Model
2 Refer to Table 4-2 of WBM's Flood Mapping report

Appendix D

Hydraulic Model Review

TUFLOW Model Review – 24 July 2008

24 July 2008

Ms Hester van Zijl
Melbourne Water
100 Wellington Parade
EAST MELBOURNE VIC 3002

Our ref: 31/22909/152440
Your ref:

Dear Hester

Bacchus Marsh Area - Flood Mapping
TUFLOW Model Review

1 Introduction

This letter presents the findings from our review of the TUFLOW Model that was used as part of the Bacchus Marsh Flood Risk Study undertaken by WBM in 2006 for Moorabool Shire Council. This review has been undertaken as part of the current Bacchus Marsh area flood mapping study for Melbourne Water.

The purpose of this review was to:

- Assess the existing TUFLOW model and determine whether it is adequate for estimating flood water levels as part of the current Bacchus Marsh area flood mapping study; and
- Where necessary make recommendations for improvements to the TUFLOW model.

This review covers:

- The TUFLOW model setup and structure;
- The calibration/verification of the TUFLOW model; and
- Provides conclusions and recommendations for its use as part of the current flood mapping study for Melbourne Water.

2 Data and Information

The TUFLOW model files listed in Attachment 1 were supplied for the purpose of this review.

A final copy of the Bacchus Marsh Flood Risk Study report was also supplied together with a number of other supporting documents as listed in Attachment 2.

3 TUFLOW Model Setup and Structure

The following comments are made on the setup and structure of the TUFLOW model used for the Bacchus Marsh Flood Risk Study:

- The downstream boundary for the TUFLOW model is located on the Werribee River approximately 650 m downstream from the confluence between the Werribee and Lerderderg Rivers and 11.5 km upstream from the dam wall of Melton Reservoir. The downstream boundary condition that has been adopted in the TUFLOW model is based on the stage-discharge relationship on the Werribee River at the Head Gauge of Melton Reservoir (site code 231221) obtained from Victoria Water Resources Data Warehouse. Based on normal depth calculations, it appears that during a 100-year ARI event there would still be a backwater effect from the Melton Reservoir at the location of the downstream boundary of the TUFLOW model. Therefore while the head gauge is located approximately 11.5 km downstream, its stage-discharge relationship generally seems to be a reasonable downstream boundary condition for the model provided the constriction in the floodplain width immediately downstream is considered (see next point);
- The location of the downstream boundary is immediately upstream from what appears to be a relatively significant constriction in the overall floodplain width as is shown in Attachment 3. With the adoption of the stage discharge relationship at Melton Reservoir for the downstream boundary condition, the effect of this constriction is not included within the TUFLOW model and therefore it may underestimate flood levels upstream. The TUFLOW model downstream boundary would need to be extended approximately another 500 m downstream to include this constriction. If surveyed cross-sections were unavailable for this extension to the model, cross-sections created from the LiDAR data currently being surveyed may provide adequate representation;
- The cross-section spacing in the 1D network approximately varies from 100 m to 500 m with closer spacing generally used through the built-up developed areas and conversely greater spacings used in the relatively undeveloped floodplain areas;
- A grid spacing of 7 m was used in the 2D domain. This seems to be reasonable although we may investigate a finer grid spacing for use through the developed areas;
- Ridge lines have generally been used within the model to represent the embankments along the Werribee River and Lerderderg River. Ridge lines are generally needed within the TUFLOW to define topographic features such as embankments that may not be adequately represented by the comparatively coarse grid in the 2D domain. Based on our site visit, we observed that embankments are present along the north bank of the Werribee River upstream and downstream from Grant Street Bridge. These embankments are not completely covered by the defined ridge lines and therefore the representation of these embankments in the TUFLOW model will need to be reviewed more thoroughly following receipt of all the LiDAR data;

- A wide range of Manning's 'n' values have been used across the 2D domain and along the 1D network. The range of Manning's 'n' values used in the TUFLOW model are presented in Table 4-7 of the WBM report. The Manning's 'n' values seem generally reasonable although a little high through the 1D network. However this may be justified by significant amounts of vegetation, which were observed along the Werribee and Lerderderg Rivers during our recent site visit (10 July 2008). We propose that the location of the Bacchus Marsh Gauging Station is included within the TUFLOW model to enable the recorded water levels and flow estimates at the Gauging Station to be used to calibrate for Manning's 'n' in the TUFLOW model. The ranges in Manning's 'n' used in the TUFLOW model for the 1D network were as follows:
  - Werribee River upstream from confluence - 0.05 to 0.08;
  - Werribee River downstream from confluence - 0.04;
  - Lerderderg River - 0.045 to 0.1;
- Flows were added into the model at the upstream boundaries of the following three waterways:
  - Werribee River;
  - Lerderderg River
  - Parwan Creek;
- The following bridge structures were included within the model:
  - Grant Street Bridge;
  - Fisken Street Bridge;
  - Woolpack Road Bridge;
  - Gisborne Road Bridge;
  - Private crossing at Bacchus Marsh Road property;
  - Western Highway Bridge;
  - Old Western Highway Bridge;
- It appears that all major bridge structures have been modelled. Bridge losses have been modelled based on energy losses estimated using the methodology in AUSTROADS (1994);
- It appears that the pipe crossing over the Lerderderg River has been omitted; and
- The previous Grant Street Bridge was included in preliminary models, but the new bridge was included in the final model (Section 4.2.1 of the WBM Report).

4 TUFLOW Model Calibration/Verification

The following comments are made on the calibration/verification of the TUFLOW model used for the Bacchus Marsh Flood Risk Study:

- The report states that there was insufficient reliable data available for calibration and therefore only a verification exercise was undertaken where the modelled water levels for each of the design events were compared with the observed flood levels from the 1995 event (WBM Report, Section 4.2.4);

- It is not directly stated in the report why there was insufficient reliable data for calibration. However we assume that the 1995 flood flow recorded at Bacchus Marsh GS was considered by WBM to be unreliable, based on the comment in Section 3.4 of the WBM report that the Bacchus Marsh GS had not been gauged to a significant flood level. This will need to be further investigated along with the suitability of other data for calibration;
- The verification exercise showed that based on the modelled water levels, the 1995 event had an ARI somewhere between 20-years and 50-years. It was concluded in the WBM report that the published flow at the GS for the 1995 event (577 m^3/s) may be high as the modelled flows for the 20-year and 50-year ARI events were 338 m^3/s and 425 m^3/s respectively;
- Other than the flow, another probable reason why the modelled water levels do not agree with the observed water levels is because the Manning 'n' roughness coefficients selected for the model may be too high. The Manning's 'n' roughness coefficients used in the model along the Werribee River upstream from Grant Street Bridge range from 0.055 to 0.065. While these values are not unrealistic, they are high, particularly for a relatively large river such as the Werribee. We propose that the location of the Bacchus Marsh GS is included within the TUFLOW model to enable the recorded water levels and flow estimates at the GS to be used to calibrate for Manning's 'n' in the TUFLOW model;
- Based on Figure 4-4 of the WBM report, the observed afflux across Grant Street Bridge in the 1995 event was approximately 760 mm. The modelled affluxes across Grant Street Bridge for the 20-year and 50-year ARI events were only approximately 290 mm and 360 mm respectively. We understand that the WBM model used for the design events included the new Grant Street Bridge, which was constructed after the 1995 flood event. This may therefore explain the differences between the modelled and observed affluxes. However this difference needs to be considered when interpreting the water levels shown in Figure 4-4 of the WBM report. If the design flood flows were modelled with the 'old' Grant Street Bridge, the modelling may show that the 1995 event was nearer a 20-year ARI event. This seems unlikely given that the 1995 event was clearly the highest recorded water level at the Bacchus Marsh GS in almost 30-years of data (see Attachment 4);
- According to the WBM report, the bridge losses for the Grant Street Bridge were calculated using the methodology in AUSTROADS (1994). The losses through the Grant Street Bridge are important for the calibration of the TUFLOW model to the observed water levels from the 1995 event. We would therefore propose that losses at this bridge in particular are also checked using HEC-RAS and adjusted if necessary for the TUFLOW model to be used as part of this study for Melbourne Water; and
- Based on the WBM report, we understand that no calibration or verification was undertaken for the model on the Lerderderg River. We are aware that flood levels were surveyed for the 1985 event on the Lerderderg River and used for the Holts Lane Flooding Investigation (CSF, 1991). These surveyed flood levels could potentially be used to calibrate for Manning's 'n' on the Lerderderg River. Further investigations will be required to confirm this.

5 Conclusions

Based on the findings of the above review, the following conclusions have been drawn:

- The stage-discharge relationship on the Werribee River at the Head Gauge of Melton Reservoir (site code 231221) generally seems to be a reasonable downstream boundary condition for the model provided that the constriction in the floodplain width immediately downstream is considered (see next point);
- The location of the downstream boundary is immediately upstream from what appears to be a relatively significant constriction in the overall floodplain width as is shown in Attachment 3. With the adoption of the stage discharge relationship at Melton Reservoir for the downstream boundary condition, the effect of this constriction is not included within the TUFLOW model and therefore it may underestimate flood levels upstream;
- Based on our site visit, we observed that embankments are present along the north bank of the Werribee River upstream and downstream from Grant Street Bridge, which are not completely covered by the defined ridge lines in the TUFLOW model;
- The Manning's 'n' values seem generally reasonable although a little high through the 1D network. However this may be justified by significant amounts of vegetation, which were observed along the Werribee and Lerderderg Rivers during our recent site visit (10 July 2008);
- The verification exercise showed that based on the modelled water levels, the 1995 event had an ARI somewhere between 20-years and 50-years. It was concluded in the WBM report that the published flow at the GS for the 1995 event (577 m^3/s) may be high as the modelled flows for the 20-year and 50-year ARI events were 338 m^3/s and 425 m^3/s respectively. Other than the flow, another probable reason why the modelled water levels do not agree with the observed water levels is because the Manning 'n' roughness coefficients selected for the model may be too high;
- We understand that the TUFLOW model used for the design events included the new Grant Street Bridge. If the design flood flows were modelled with the 'old' Grant Street Bridge, the modelling may show that the 1995 event was nearer a 20-year ARI event. This seems unlikely given that the 1995 event was clearly the highest recorded water level at the Bacchus Marsh GS in almost 30-years of data (see Attachment 5);
- According to the WBM report, the bridge losses for the Grant Street Bridge were calculated using the methodology in AUSTROADS (1994); and
- Based on the WBM report, we understand that no calibration or verification was undertaken for the model on the Lerderderg River.

6 Recommendations

Based on the conclusions from the above review, we make the following recommendations:

- The TUFLOW model downstream boundary would need to be extended approximately another 500 m downstream to include the constriction in the floodplain. If surveyed cross-sections were unavailable for this extension to the model, cross-sections created from the LiDAR data currently being surveyed may provide adequate representation;

- The representation of all embankments in the TUFLOW model, in particular those on the north bank of the Werribee River adjacent to Grant Street Bridge, will need to be reviewed more thoroughly following receipt of all the LiDAR data;
- The location of the Bacchus Marsh Gauging Station should be included within the TUFLOW model to enable the recorded water levels and flow estimates at the gauging station to be used to calibrate for Manning's ‘n’ in the TUFLOW model;
- The reliability of the 1995 flood flow recorded at Bacchus Marsh Gauging Station will need to be further investigated along with the suitability of other data for calibration of the TUFLOW model;
- Given its importance for the calibration of the TUFLOW model to the observed water levels from the 1995 event, the hydraulic losses across the Grant Street Bridge should be checked using HEC-RAS and adjusted if necessary in the TUFLOW model to be used as part of this study for Melbourne Water; and
- The flood levels surveyed for the 1985 event on the Lerderderg River and used for the Holts Lane Flooding Investigation (CSF, 1991) should be further investigated for their potential use in calibrating for Manning's 'n' on the Lerderderg River.

We look forward to discussing the above with you further. In the meantime if you have any questions or comments regarding the above, please do not hesitate to contact me.

Yours sincerely

Philip Joyce
Senior Engineer
(03) 8687 8868

Attachment: TUFLOW Model Files
Reports and Information Received from Melbourne Water
Downstream Boundary Location
Bacchus Marsh Gauging Station Recorded Water Levels (station no. 231200)

Attachment 1

TUFLOW Model Files

File Type	File Name
Control Files	
TUFLOW Simulation Control Files	bacchus_20y36h_30.tcf bacchus_20y48h_30.tcf bacchus_50y36h_30.tcf bacchus_100y36h_30.tcf bacchus_500y36h_30.tcf
ESTRY Simulation Control Files	bacchus_20y36h_30.ecf bacchus_20y48h_30.ecf bacchus_50y36h_30.ecf bacchus_100y36h_30.ecf bacchus_500y36h_30.ecf
TUFLOW Geometry Control Files	bacchus_30.tgc bacchus_30a.tgc
TUFLOW Boundary Conditions Control Files	bacchus_25.tbc
Data Input Files	
TUFLOW Materials Files	bacchus_24.tmf
GIS MIF/MID Files	1d_bc_ext_bacchus_29.TAB 1d_nwk_bacchus_24.TAB 1d_tab_bg_bacchus_27.TAB 1d_tab_na_bacchus_01.TAB 1d_WLL_Bacchus_22.TAB 2d_bc_ext_bacchus_14.TAB 2d_bc_int_bacchus_25.TAB 2d_loc_bacchus_01.TAB 2d_mat_bacchus_24.TAB 2d_po_bacchus_18.TAB 2d_zln_bacchus_levee_19.TAB 2d_zln_bacchus_levee_23.TAB 2d_mod_zpts_dogtrap_12.TAB 2d_zpt_bacchus_30.TAB 2d_mod_zpts_stability_13.TAB 2d_mod_zpts_stability_23.TAB 2d_zpts_mod_stability_05a.TAB
Comma Delimited Files	bc_dbase_bacchus_30.csv bg_tab_fiskenst_bacchus_24.csv bg_tab_westernhwy_bacchus_27.csv bg_tab_grantst_bacchus_24.csv bg_tab_oldwesternhwy_bacchus_24.csv bg_tab_private_bacchus_24.csv bg_tab_woolpackrd_bacchus_24.csv bg_tab_gisbornerd_bacchus_24.csv nodal_area_bacchus_01.csv
Mike11 Cross-section Files	1d_M11_Xsections_Bacchus_25.txt 1d_M11_Xsections_Lerderderg_25.txt 1d_M11_Xsections_Werribee_22.txt

Attachment 2

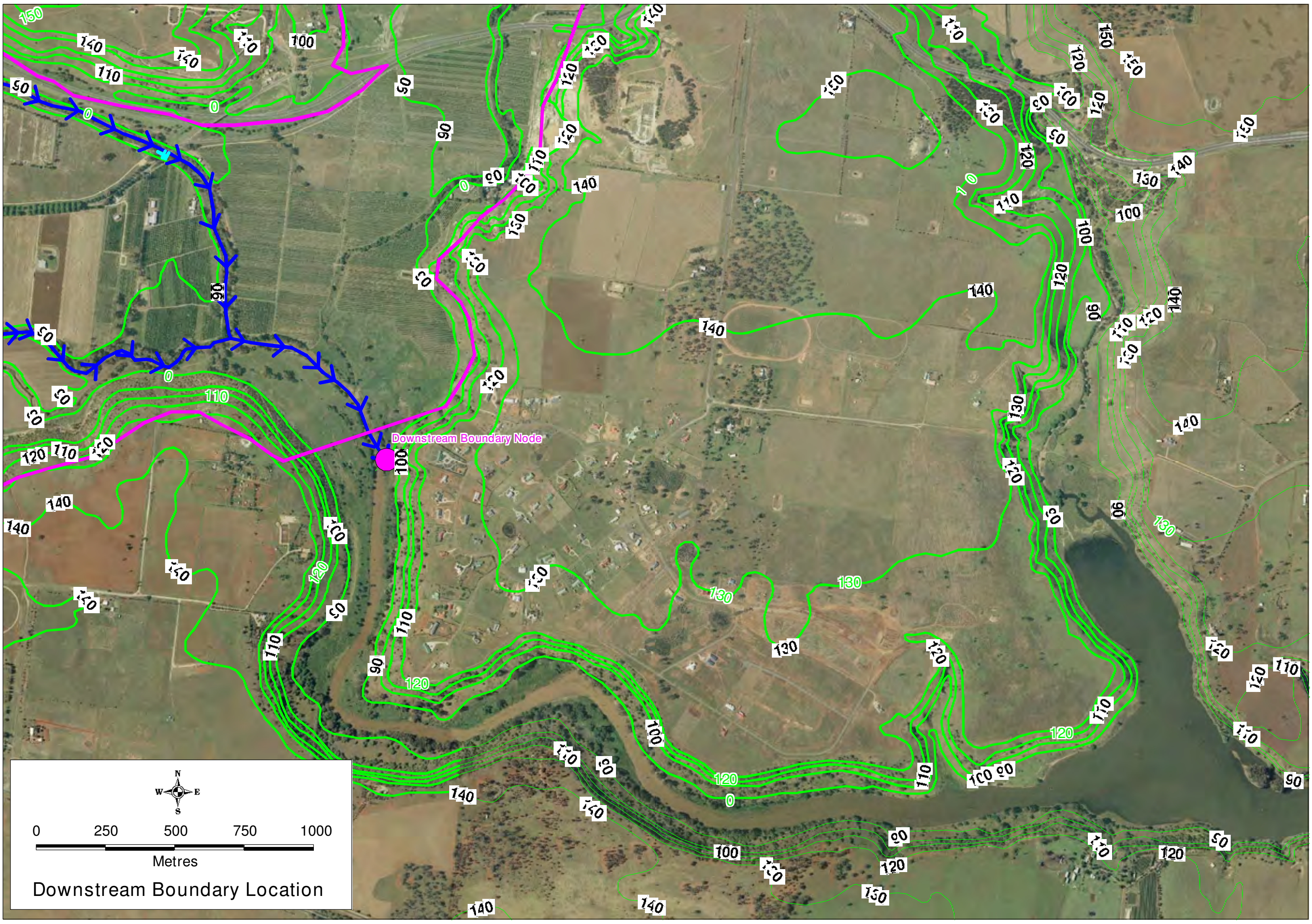
Reports and Information Received from Melbourne Water

Title/Description	Author	Format	Date
Re. Planning Scheme Amendment C14 Moorabool Planning Scheme	Denis L Murphy	Letter	20 March 2008
Analysis November 1995	-	Folder	1996
Werribee River at Bacchus Marsh Flood Investigation Draft June 1977	State Rivers and Water Supply Commission	Report	June 1977
Correspondence, memos etc	Shire of Bacchus Marsh Planning Matters	Folder	1977 - 1993
Environment Planning and Management, Floodplain Management, Lerderderg River, Gisbourne & Robertson Road	Rural Water Commission of Victoria	Folder	1992 - 1993
Flood Investigation File, Lerderderg River, Correspondence, enquiries etc	Rural Water Commission of Victoria	Folder	1985 - 1993
Holts Lane Flooding Investigations Phase 1	Camp Scott Furphy P.L.	Report	1991
Holts Lane Flooding Investigations Phase 2 – Detailed Investigation	Camp Scott Furphy P.L.	Report	1991
Ouphan Resources Pty Ltd, Lerderderg River Flood Study, Robertsons Road to Gisbourne Road, Bacchus Marsh	Camp Scott Furphy Pty Ltd	Report	1992
An Investigation of Flood Flows in the Werribee River	Shire of Bacchus Marsh	Report	June 1975
Werribee River at Bacchus Marsh – Calculation Folder	State Rivers and Water Supply Commission	Folder	1976

Title/Description	Author	Format	Date
Bridge over Lerderderg River - Western By-Pass Road (Calcs and Drawings)	Country Roads Board	Folder	Not Shown
Flood Report – Werribee River at Bacchus Marsh – 16 October 1983	Not Shown	Folder	June 1991

Attachment 3

Downstream Boundary Location



Downstream Boundary Location

Attachment 4

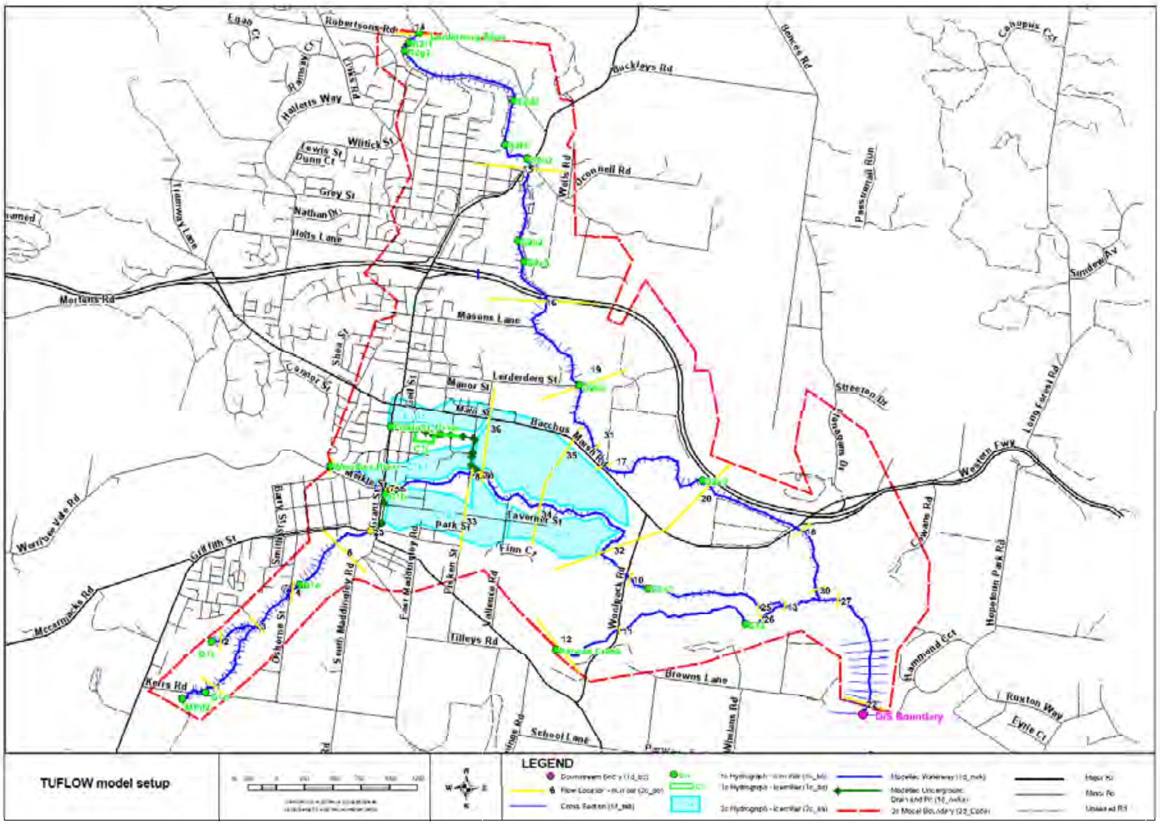
Bacchus Marsh Gauging Station Recorded Water Levels (station no. 231200)

Rank	Year	Recorded Water Level (m)
1	1995	5.19
2	1983	3.35
3	1993	3.28
4	1987	2.11
5	1985	1.93
6	2000	1.87
7	1990	1.68
8	1992	1.61
9	2004	1.29
10	1996	1.19
11	1979	1.02
12	1998	1.02
13	2005	0.97
14	1986	0.95
15	1988	0.88
16	1999	0.86
17	1981	0.81
18	1989	0.77
19	1984	0.7
20	1991	0.51
21	2001	0.46
22	1980	0.45
23	1994	0.42
24	1997	0.38
25	2002	0.36
26	1982	0.34
27	2003	0.33
28	2006	0.27

Appendix E

Hydraulic Model Layout

1 Sheet at 1: 25,000 Scale


TUFLOW model setup
LEGEND
Robertsons Rd
Egan Ct
Ramsay Ct
Halletts Way
Wittick St
Lewis St
Dunn Ct
Grey St
Nathan Dr
Holts Lane
Tramway Lane
Morrisons Rd
Buckleys Rd
Bences Rd
Canopus Crt
Walls Rd
O'Connell Rd
Passmore Run
Sundew Av
Masons Lane
Lerderderg St
Manor St
Main St
Bacchus Marsh Rd
Shea St
Cantor St
Streeton Dr
Long Forest Rd
Western Fwy
Grant St
Park St
Taverner St
Finn Ct
Woolpack Rd
Werribee Vale Rd
Griffith St
Barry St
Smiths St
Mccormacks Rd
Osborne St
South Maddingley Rd
East Maddingley Rd
Parkes St
Vallence Rd
Tilleys Rd
Kerrs Rd
Browns Lane
School Lane
Hammond Crt
Ruxton Way
Hopetoun Park Rd
Cowies Rd
Eyrie Ct
D/S Boundary

Appendix F

Model Inflows

Peak Inflows for the 100 year ARI Event

Table F1 Peak Inflows at all locations for the TUFLOW hydraulic model

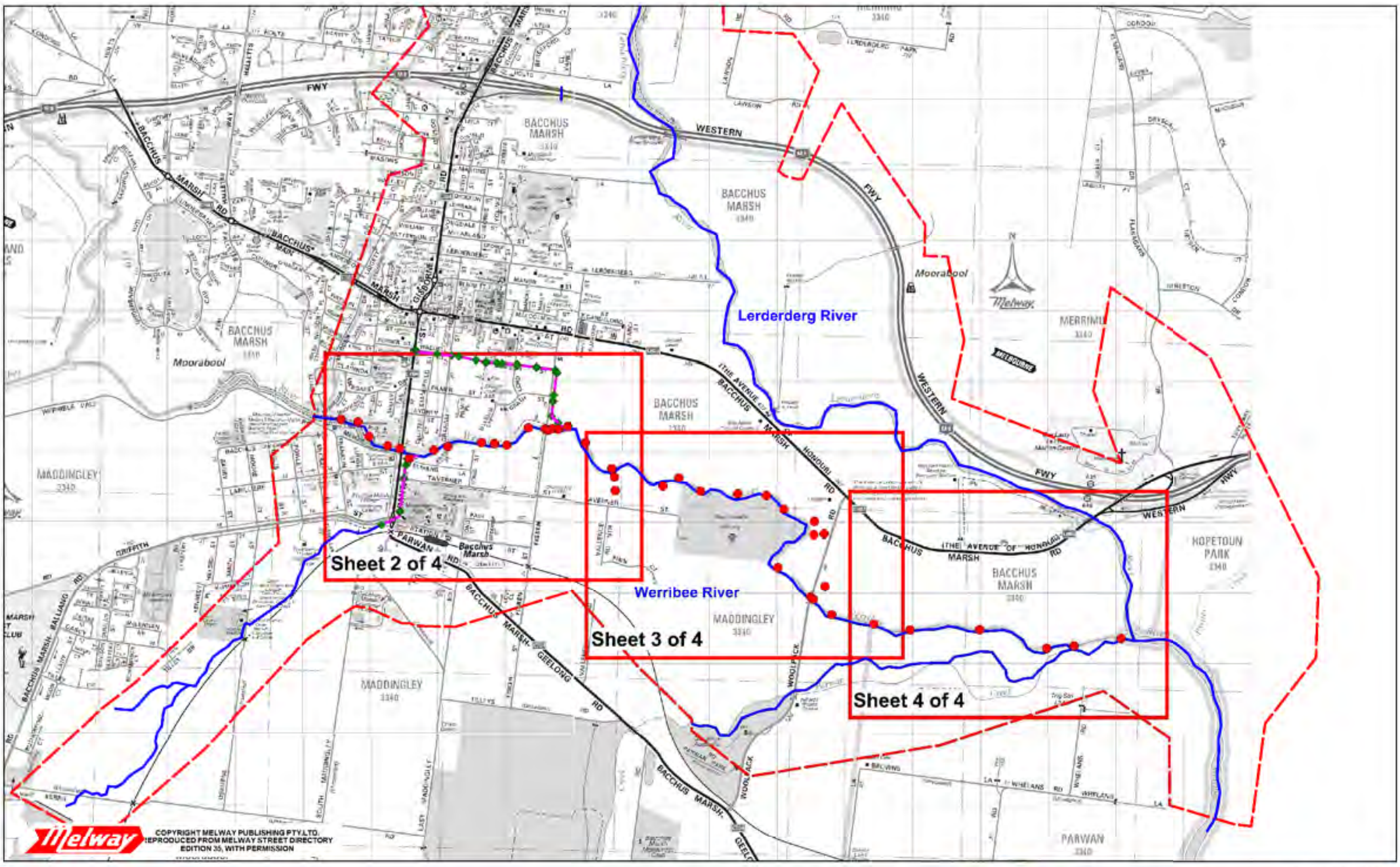
TUFLOW Identifier	TUFLOW input type	PMF	100 yr ARI	50 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
-	-	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s
Werribee River	1d_bc	4648.69	587.18	477.83	354.07	270.98	199.31
Parwan Creek	1d_bc	2942.40	266.67	209.19	148.37	82.37	54.72
Lerderderg River	1d_bc	4111.30	621.11	525.67	406.59	327.54	269.20
FiskenSt Drain	1d_bc	24.52	5.50	4.13	2.82	2.10	1.80
R2f1	1d_bc	67.40	26.85	23.87	19.25	13.71	9.49
R2g2	1d_bc	87.70	28.34	23.88	17.82	13.97	11.37
S2d2	1d_bc	57.16	17.18	14.25	10.24	8.24	6.75
S2f2	1d_bc	92.60	28.09	23.68	17.88	14.06	11.40
S2h2	1d_bc	36.63	10.67	8.92	6.68	5.33	4.27
S2k2	1d_bc	104.33	38.16	32.31	25.68	20.17	15.10
S2k3	1d_bc	66.90	19.69	16.36	12.02	9.61	7.61
S2s6	1d_bc	170.09	44.74	37.36	27.79	22.37	18.14
S2v3	1d_bc	359.55	99.05	83.04	61.05	47.90	37.52
S13	1d_bc	180.33	16.65	13.09	9.68	6.67	3.23
C1j	1d_bc	9.22	2.93	2.04	1.43	1.17	0.97
C1k1	2d_sa	10.63	2.98	2.16	1.38	1.10	0.91
C1q	2d_sa	67.22	9.66	8.40	7.17	6.16	5.01
C1d3	2d_sa	137.17	22.59	19.33	15.81	12.09	8.76
C1r	2d_sa	21.90	4.02	3.19	2.73	2.49	1.97
C1s1	1d_bc	79.20	15.27	11.77	9.96	9.01	7.49
MPd2	1d_bc	98.45	17.31	15.04	12.68	10.48	8.66
B1d	1d_bc	40.65	18.31	15.61	12.20	9.98	8.31
B1c	1d_bc	54.40	11.13	9.65	8.20	6.77	5.58
B1e	1d_bc	37.22	14.85	12.30	8.18	6.64	5.49

TUFLOW Identifier	TUFLOW input type	PMF	100 yr ARI	50 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
C1b	1d_bc	32.56	11.26	7.39	5.74	4.71	3.94
C1p3	2d_sa	62.99	15.61	12.44	8.82	6.83	5.63

Appendix G

Calibration Results

Werribee River – Nov 1995 Storm Event



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Grid: Map Grid Of Australia, Zone 55

LEGEND

- Limits of Modelling (Main Waterways)
- Modelled Melbourne Water Underground Drains
- Hydraulic Model Boundary
- Modelled Melbourne Water Natural Waterways
- 1995 Event Observed Flood Level Location

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Melbourne Water

Melbourne Water
Baccus Marsh Flood Mapping

Hydraulic Calibration
Werribee River

Sheet 1 of 4

Job Number	31-22909
Revision	0
Date	29 Jul 2010

Figure G-1

G:\31\22909\Hydraulic Calibration.WOR

Data source: Melway Maps 333, 334, 339, 340. Created by: NBA

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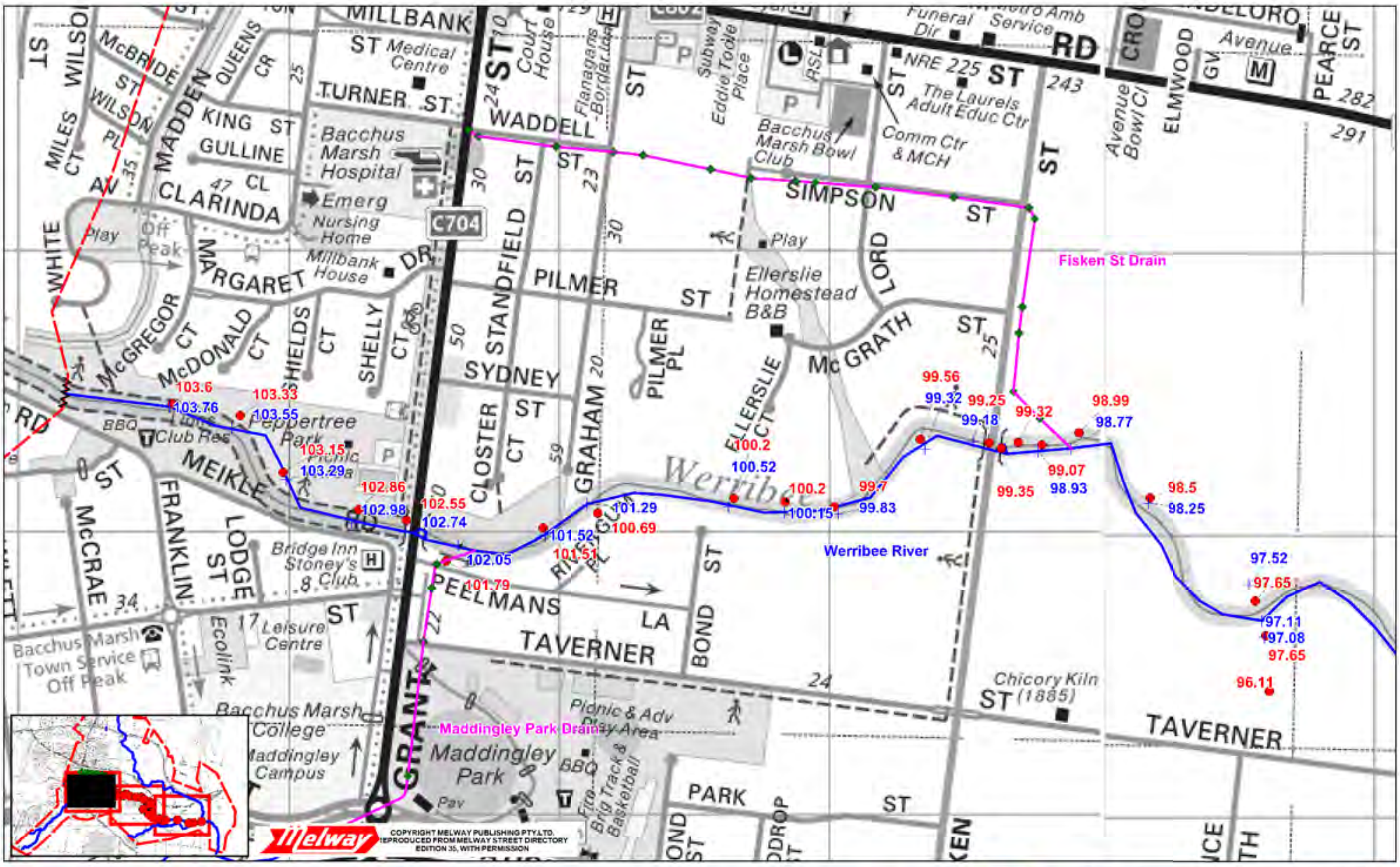

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Metres (at A3)

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Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

LEGEND

- Limits of Modelling (Main Waterways)
- Modelled Melbourne Water Underground Drains
- Hydraulic Model Boundary
- Modelled Melbourne Water Natural Waterways
- 91.89 1995 Event Observed Flood Level (mAHD)
- 91.89 TUFLOW Modelled Water Level (mAHD)

Melbourne Water
Baccus Marsh Flood Mapping

Job Number 31-22909
Revision 0
Date 29 Jul 2010

Hydraulic Calibration
Werribee River
Sheet 2 of 4

Figure G-2

8/180 Lonsdale St Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com.au W www.ghd.com.au

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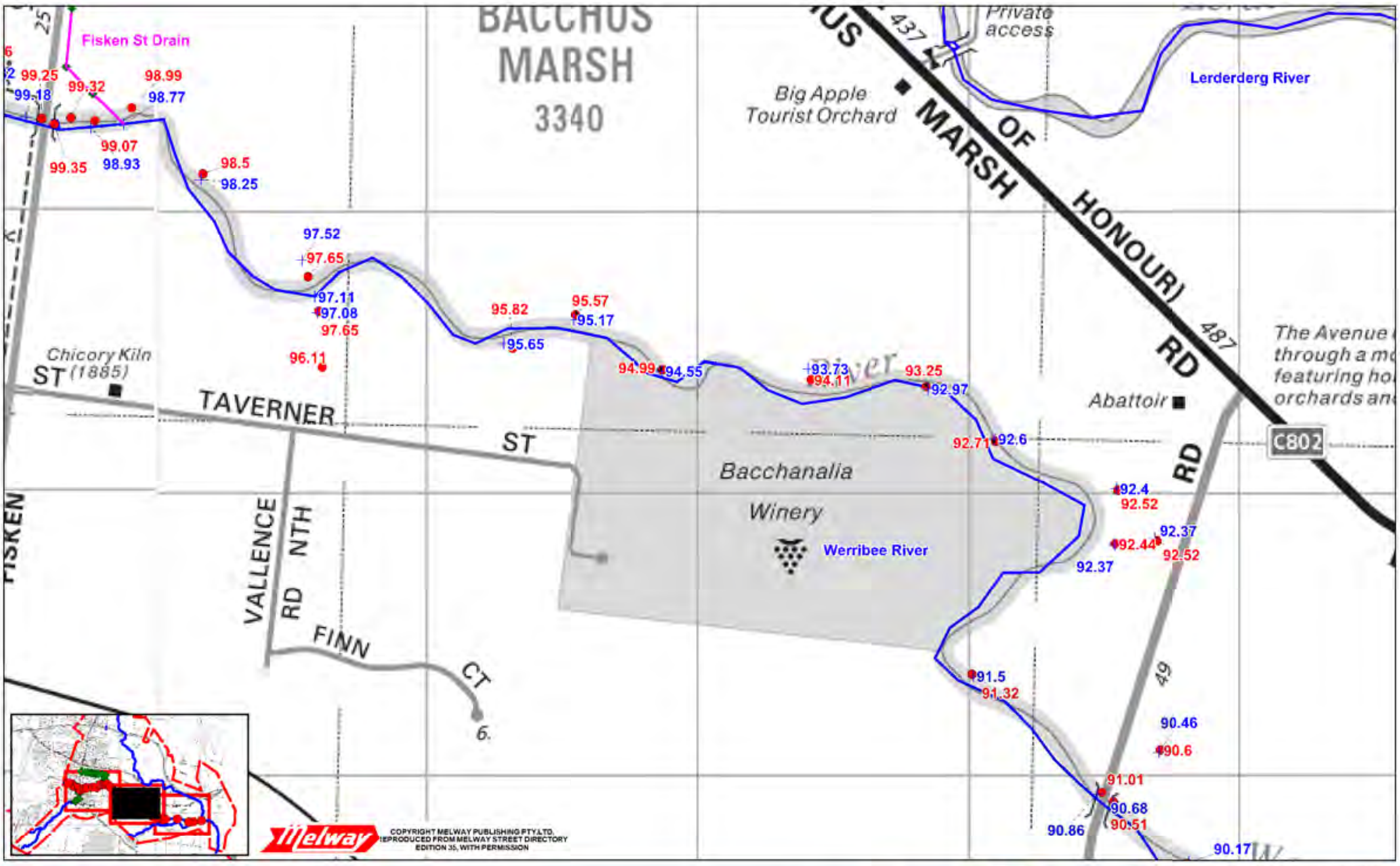

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Grid: Map Grid Of Australia, Zone 55

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Melbourne Water
Baccus Marsh Flood Mapping

Hydraulic Calibration
Werribee River
Sheet 3 of 4

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Figure G-3

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Data source: Melway Maps 333, 334. Created by: NEA

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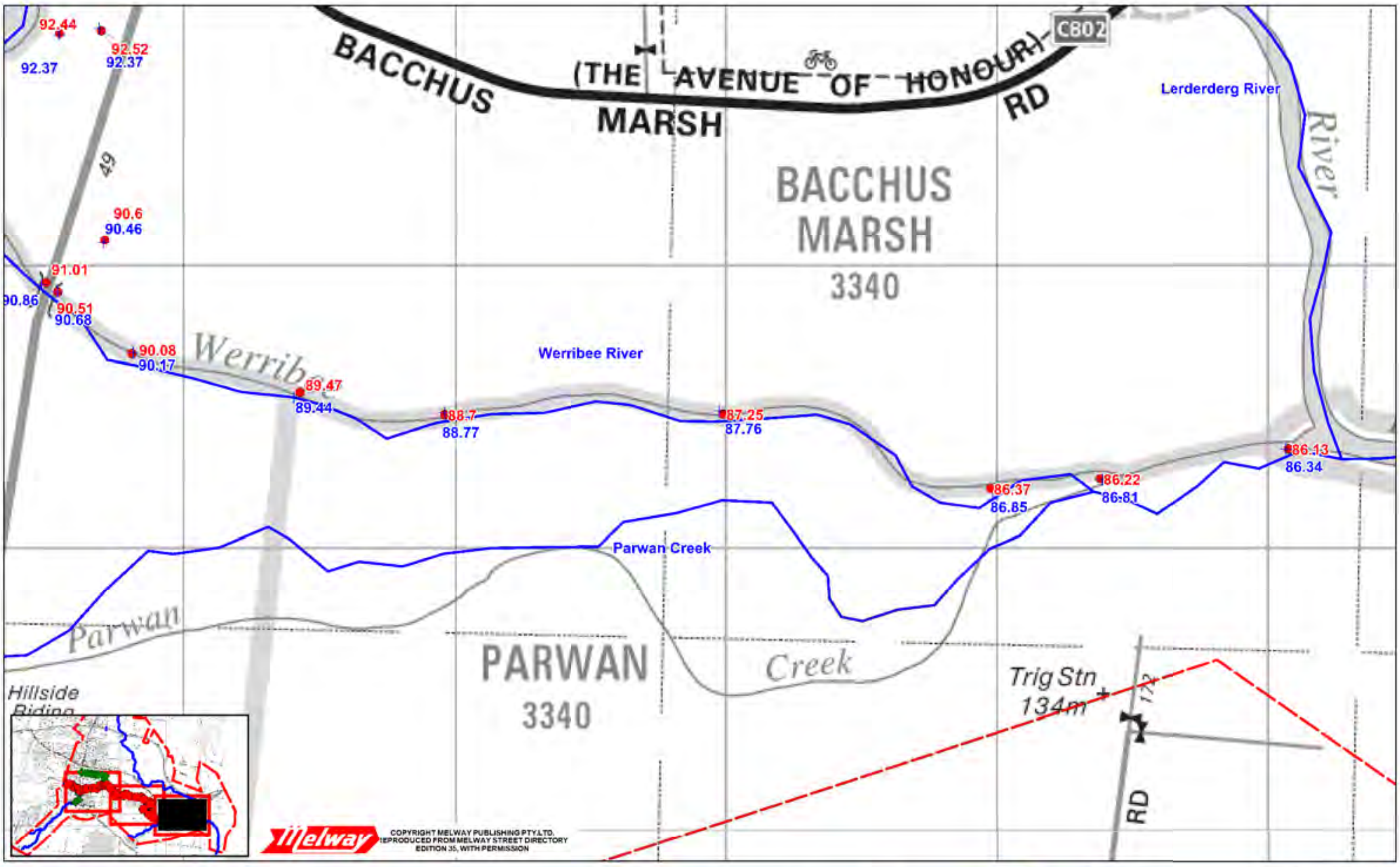

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Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

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LEGEND

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Melbourne Water
Baccus Marsh Flood Mapping

Hydraulic Calibration
Werribee River
Sheet 4 of 4

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Figure G-4

8/180 Lonsdale St Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com.au W www.ghd.com.au

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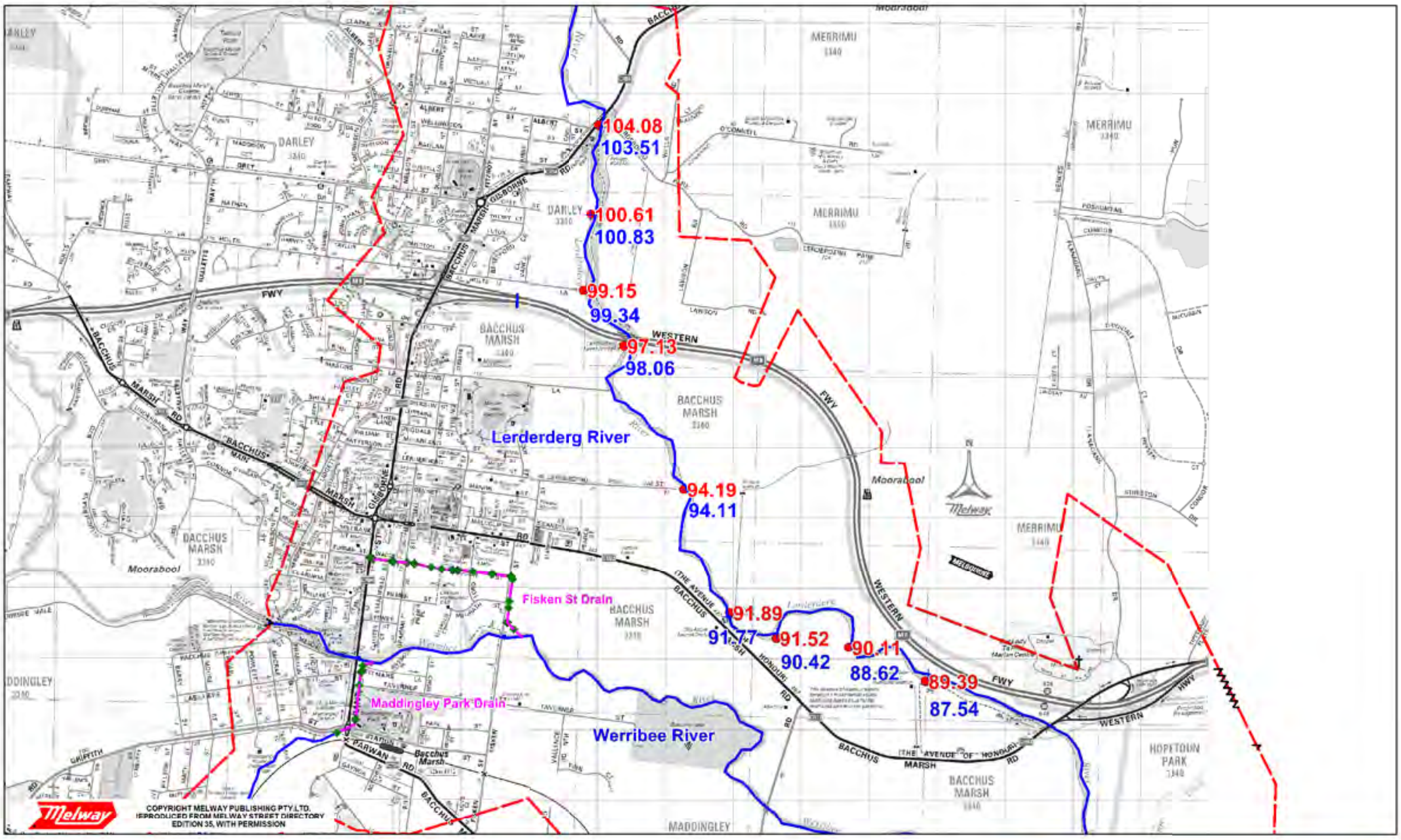
Data source: Melway Maps 333, 334, 340. Created by: NEA

Appendix H

Calibration Results

Lerderderg River – Oct 1985 Event



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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

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Hydraulic Calibration
Lerderderg River

Sheet 1 of 1

Job Number	31-22909
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Date	29 Jul 2010

Figure H-1

G:\31\22909\Hydraulic Calibration Lerderderg.WOR

Data source: Melway Maps 327, 328, 333, 334, 339, 340. Created by: NEA

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Appendix I

Results at Pre-Defined Locations

Peak Flood Levels and Flows for all Return Periods at Pre-Defined Locations within the Bacchus Marsh Area

Table I1 presents the peak flows at flow points in the Bacchus Marsh area as defined by Melbourne Water. Where flow locations cross waterways such as the Werribee River or Parwan Creek that have been modelled in the 1D domain, 'Asset Flow' represents the flow within the 1D domain and 'Overland Flow' the 2D domain. Flow point locations are presented in Appendix E.

Table I1 Peak Flows in the Bacchus Marsh Area at each flow point for each duration

Return Period		PMF			100 year ARI			50 year ARI			20 year ARI			10 year ARI			5 year ARI		
Flow Point No.	Waterway Location	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration
1	Maddingley Park Drain near Kerrs Rd	0	122	2h GSDM	0	21	9	0	18	9	0	15	9	0	12	9	0	9	9
2	Trib. of Maddingley Park Drain	0	54	1h GSDM	0	11	9	0	10	9	0	8	9	0	7	9	0	6	9
3	Maddingley Park Drain near Darcy St	0	171	2h GSDM	0	32	9	0	27	9	0	23	9	0	18	9	0	14	9
4	Maddingley Park Drain near Osborne St	0	171	2h GSDM	0	32	9	0	28	9	0	23	9	0	19	9	0	15	9
5	Werribee River downstream of gauging station 231200	434	3645	12h GSDM	0	587	24	0	478	24	0	354	24	0	271	36	0	199	48
6	Maddingley Park Drain near Tesselaar Av	23	163	2h GSDM	0	36	9	0	32	9	0	26	9	0	22	9	0	17	9
7	Werribee River D/S Grant St Bridge	60	1027	12h GSDM	0	573	24	0	478	24	0	354	24	0	271	36	0	199	48
8	Werribee River downstream of the Fisken St Bridge	3	1031	12h GSDM	0	578	24	0	483	24	0	358	24	0	274	36	0	201	48
9	Werribee River downstream of Fisken St Drain	73	1053	12h GSDM	0	577	24	0	483	24	0	358	24	0	274	36	0	201	48
10	Werribee River downstream of Woolpack Rd Bridge	611	827	12h GSDM	16	527	24	8	460	30	2	342	48	1	232	30	1	197	48

Return Period		PMF			100 year ARI			50 year ARI			20 year ARI			10 year ARI			5 year ARI		
Flow Point No.	Waterway Location	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration
11	Parwan Creek downstream of Woolpack Rd Bridge	210	99	12h GSDM	0	58	24	0	52	24	0	49	48	0	44	48	0	39	48
12	Parwan Creek near Parwan Park Rd	2526	312	6h GSDM	132	116	24	94	101	36	56	84	48	21	59	48	8	46	48
13	Werribee River after confluence with Parwan Creek	333	1660	12h GSDM	37	318	24	27	279	24	18	235	36	12	192	36	8	164	48
14	Lerderderg River near Robertsons Rd	361	3593	12h GSAM	10	611	12	7	519	18	3	403	18	1	326	18	0	260	12
15	Lerderderg River near Bacchus Marsh – Gisborne Rd	1046	3057	12h GSAM	0	624	18	0	530	18	0	409	18	0	329	18	0	270	18
16	Lerderderg River downstream of the Western Fwy	688	2417	12h GSAM	0	626	18	0	532	18	0	411	18	0	325	18	0	271	18
17	Lerderderg River near Private access Rd Bridge / Big Apple Tourist Orchard	335	785	12h GSDM	0	583	18	0	533	18	0	412	18	0	326	18	0	271	18
18	Lerderderg River downstream of Bacchus Marsh Rd Bridge	1250	592	12h GSDM	27	490	24	13	454	24	2	406	18	0	329	18	0	273	18
19	Lerderderg River near Lerderderg St	1148	1539	12h GSAM	0	629	18	0	534	18	0	412	18	0	327	18	0	272	18
20	Lerderderg River near Sewage Pumping Station	2583	1897	12h GSDM	0	633	18	0	538	18	0	416	18	0	329	18	0	273	18

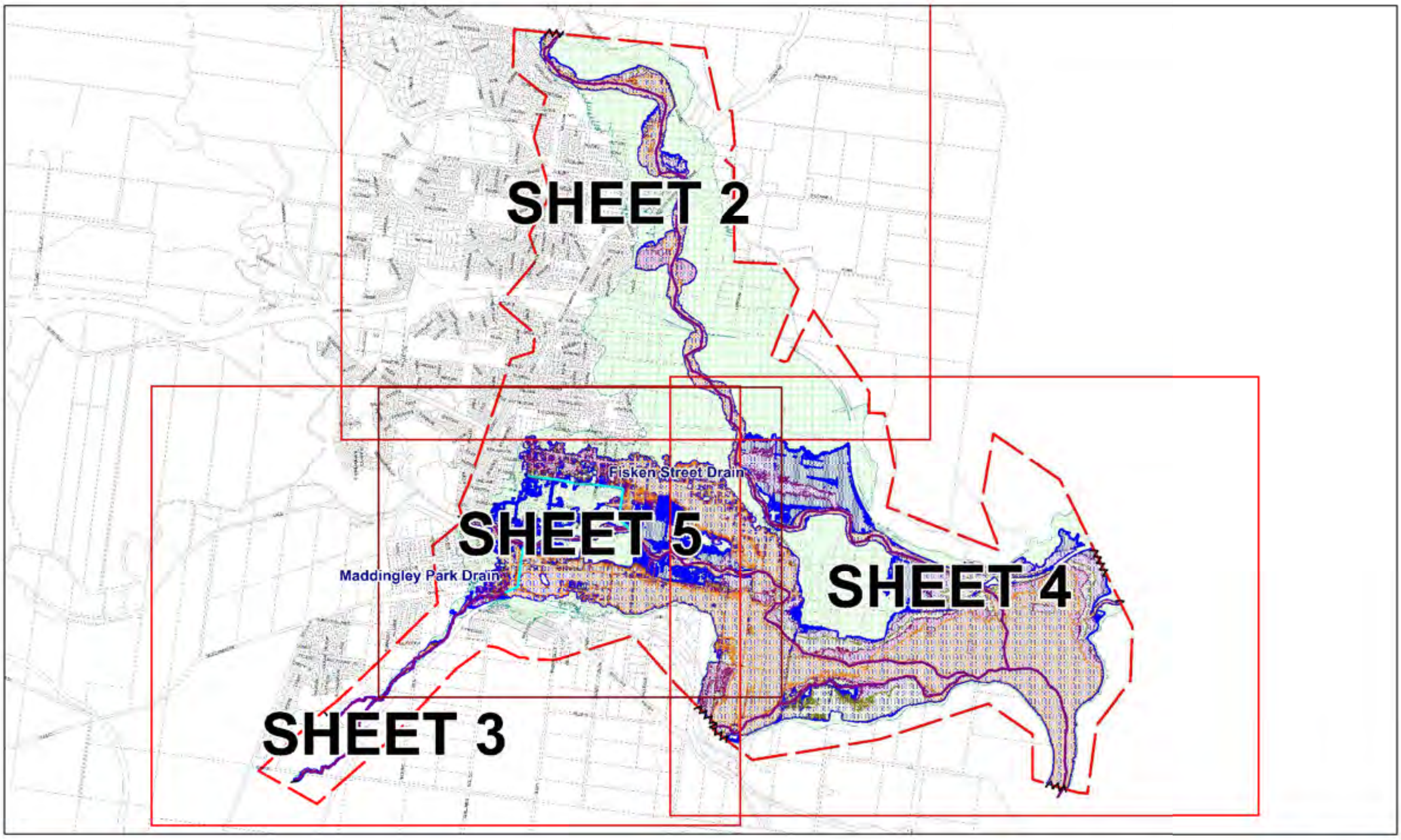
Return Period		PMF			100 year ARI			50 year ARI			20 year ARI			10 year ARI			5 year ARI		
Flow Point No.	Waterway Location	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration
21	Werribee River downstream of Maddingley Park Drain outlet	293	1330	12h GSDM	2	578	24	0	127	9	0	79	9	0	55	9	0	42	9
22	Werribee River near Whelans La and outlet of model	0	11413	12h GSDM	0	1413	24	0	1169	24	0	855	36	0	634	36	0	471	48
23	Maddingley Park Drain inlet to piped section	0	7	48h GSDM	0	8	12	0	8	12	0	8	12	0	8	12	0	8	12
24	Fisken St Drain (inlet)	0	3	1h GSDM	0	2	1.5	0	2	0.42	0	2	0.25	0	2	0.75	0	2	9
25	Werribee River before confluence with Parwan Creek	316	622	12h GSDM	27	178	24	20	175	24	11	175	36	2	169	36	2	156	48
26	Parwan Creek before confluence with Werribee River	628	478	12h GSDM	48	97	24	32	78	24	17	63	36	6	42	36	3	37	48
27	Werribee River after confluence with Lerderderg River	1071	1786	12h GSDM	128	365	24	106	334	24	79	294	36	58	264	36	41	245	48
28	Fisken St Drain outlet to Werribee River	0	4	1h GSDM	0	4	4.5	0	4	4.5	0	4	4.5	0	3	9	0	3	9
29	Maddingley Park Drain outlet to Werribee River	0	16	1h GSDM	0	13	1.5	0	12	4.5	0	10	12	0	10	12	0	9	12
30	Lerderderg River upstream of confluence with Werribee River	666	1388	12h GSDM	73	229	24	62	213	24	46	199	24	34	194	36	23	201	24

Return Period		PMF			100 year ARI			50 year ARI			20 year ARI			10 year ARI			5 year ARI		
Flow Point No.	Waterway Location	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration	Overland Flow (m^3/s)	Asset Flow (m^3/s)	Critical Storm Duration
31	Lerderderg River	46	904	12h GSDM	0	584	18	0	533	18	0	412	18	0	326	18	0	271	18
32	Werribee River downstream of Bacchanalia Winery	3698	503	12h GSDM	218	366	24	149	338	24	77	284	24	39	238	36	17	185	48
33	Overland Flow Path	2060	0	12h GSDM	40	0	9	34	0	9	27	0	9	20	0	9	13	0	9
34	Werribee River upstream of the Bacchanalia Winery	2137	1199	12h GSDM	46	553	24	39	481	24	30	358	24	22	274	36	14	201	48
35	Overland Flow Path north of Bacchanalia Winery	2137	1199	12h GSDM	9	0	9	9	0	9	8	0	9	8	0	9	6	0	9
36	Overland Flow Path east of the Bacchus Marsh town centre	73	1053	12h GSDM	7	0	6	7	0	12	7	0	12	7	0	9	6	0	9

Appendix J

Flood Extents

Extents for the PMF, 100, 50, 20, 10 & 5 year ARI events



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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- PMP Flood Extent
- 100 year ARI Flood Extent
- 50 year ARI Flood Extent
- 20 year ARI Flood Extent
- 10 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Modelled Melbourne Water Underground Drains
- Hydraulic Model Boundary
- Modelled Melbourne Water Natural Waterways

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Melbourne Water
Baccus Marsh Flood Mapping

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Base Case Scenario Flood Extents
Sheet 1 of 5

Figure J-1

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Data source: Cadastre, road names, contours supplied by Melbourne Water, May 2008. Created by: NEA

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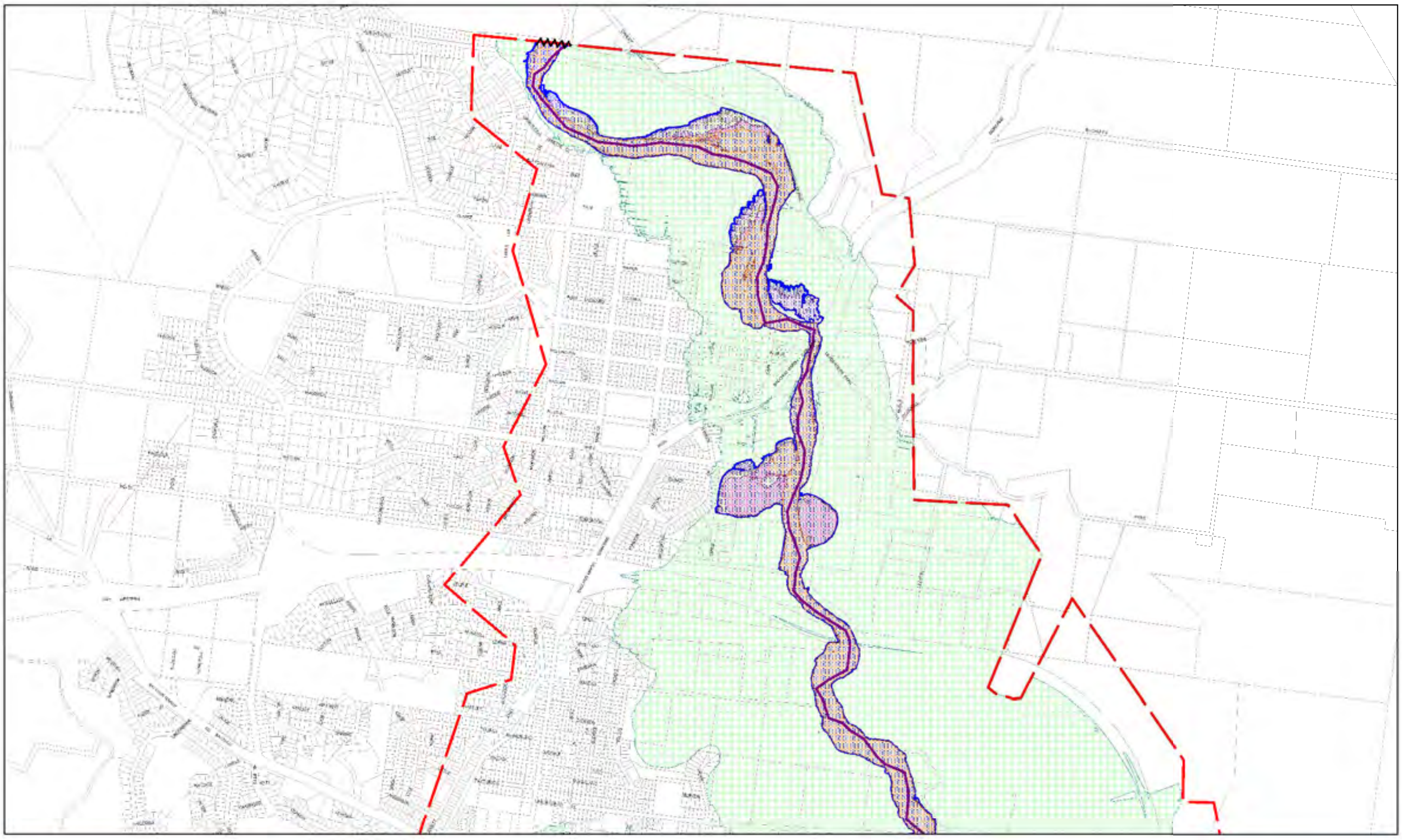

1:15,000

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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- PMP Flood Extent
- 100 year ARI Flood Extent
- 50 year ARI Flood Extent
- 20 year ARI Flood Extent
- 10 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Modelled Melbourne Water Underground Drains
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- Modelled Melbourne Water Natural Waterways

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Base Case Scenario Flood Extents

Sheet 2 of 5

Figure J-2

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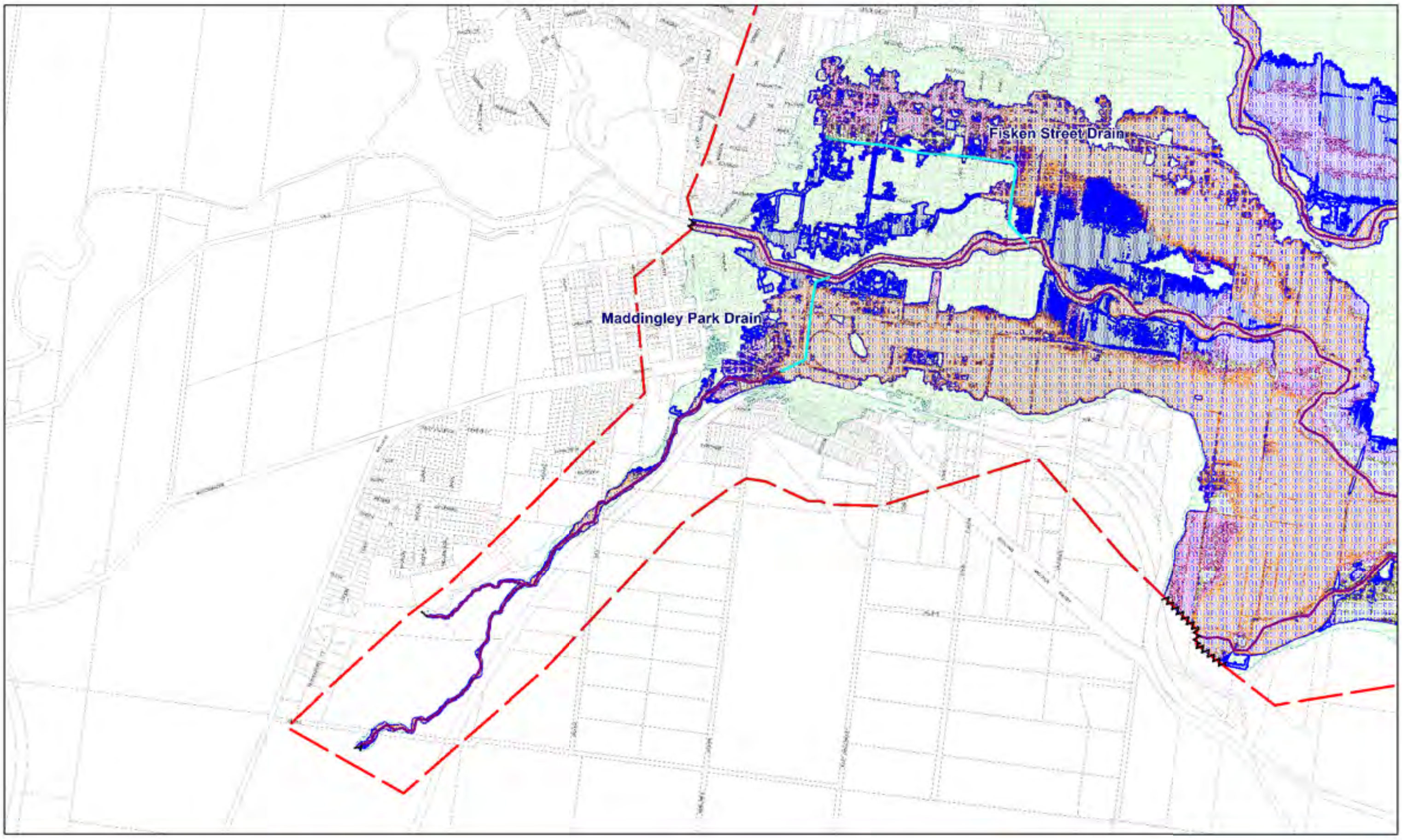

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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- PMP Flood Extent
- 100 year ARI Flood Extent
- 50 year ARI Flood Extent
- 20 year ARI Flood Extent
- 10 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Modelled Melbourne Water Underground Drains
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Base Case Scenario Flood Extents
Sheet 3 of 5

Figure J-3

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Data source: Cadastre, road names, contours supplied by Melbourne Water, May 2008. Created by: NEA

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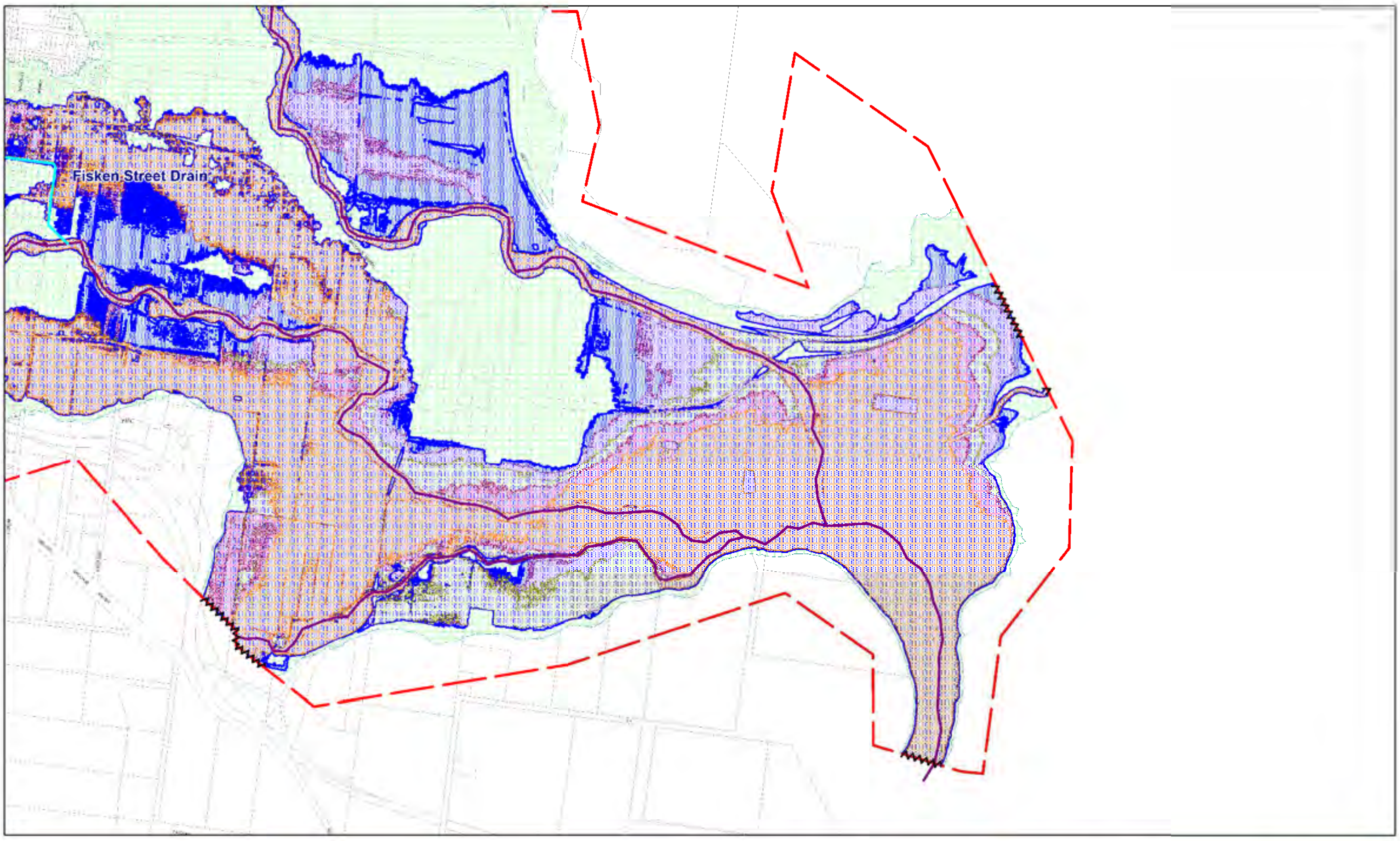

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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- PMP Flood Extent
- 100 year ARI Flood Extent
- 50 year ARI Flood Extent
- 20 year ARI Flood Extent
- 10 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Modelled Melbourne Water Underground Drains
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- Modelled Melbourne Water Natural Waterways

Melbourne Water
Baccus Marsh Flood Mapping

Job Number	31-22909
Revision	0
Date	29 Jul 2010

Base Case Scenario Flood Extents
Sheet 4 of 5

Figure J-4

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Data source: Cadastre, road names, contours supplied by Melbourne Water, May 2008. Created by: NEA

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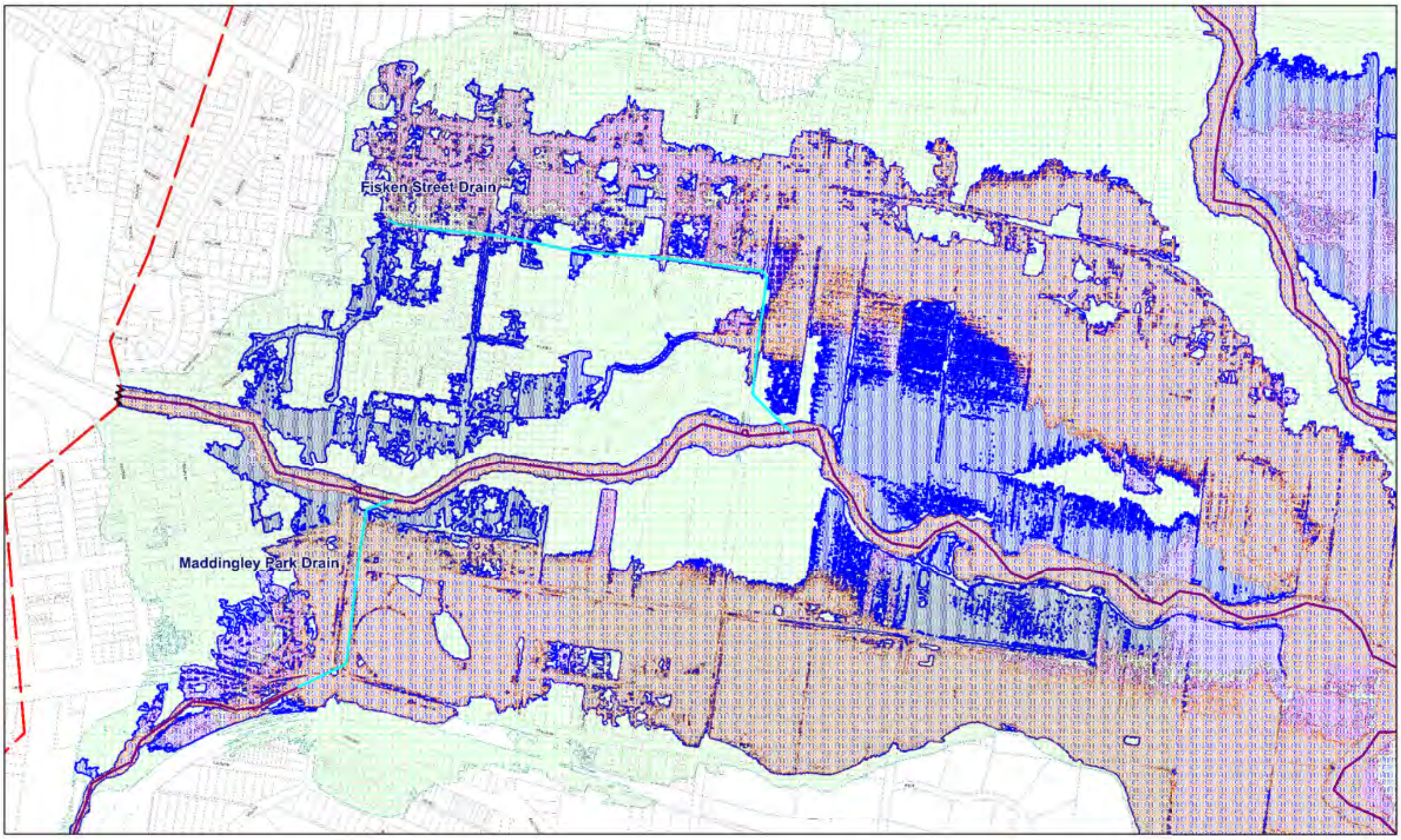

Melbourne Water
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Job Number	31-22909
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Base Case Scenario Flood Extents
Sheet 5 of 5

Figure J-5

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Appendix K

Average Annual Damage

BCA Model Inputs

BCA Spreadsheet ‘Inputs’ Worksheet – Sub Area 1

Inputs CLEAR SHEET Return to Menu

Project Name: Bacchus Marsh Flood Mapping Project

Description: Using RORB and TUFLOW to generate flood maps of the Bacchus Marsh Area for existing conditions. AREA 1

Cost of Works:

Are works expected to mitigate flood risks for all events?

If yes, press button => Zero post-works data

If no, enter post-works data.

	Pre-works					Post-works				
	Event 1	Event 2	Event 3	Event 4	Event 5	Event 1	Event 2	Event 3	Event 4	Event 5
Average Return Interval (ARI)	5	20	50	100	1E+06	5	20	50	100	1E+06
Average Level of Innundation Above Floor	0.02	0.00	0.00	0.01	2.01	0.02	0.00	0.00	0.01	2.01
Flood Warning Time (hours)	0	0	0	0	0	0	0	0	0	0
Flood Experience	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Residential Properties										
number of properties with external flooding only (flood level < floor level -0.15m)	60	103	110	110	27	60	103	110	110	27
number of single storey residential buildings affected	8	26	48	90	392	8	26	48	90	392
number of double storey residential buildings affected										
Commercial & Industrial Properties										
low value — no. buildings affected										
low value — total area of properties (sq.m.)										
medium value — no. buildings affected	19	122	145	155	249	19	122	145	155	249
medium value — total area of properties (sq.m.)	14300	55500	60400	63700	115000	14300	55500	60400	63700	115000
high value — no. buildings affected										
high value — total area of properties (sq.m.)										
Roads										
length of major roads inundated (km)	0.39	1.46	1.66	1.78	2.19	0.39	1.46	1.66	1.78	2.19
length of minor roads inundated (km)	2.48	3.5	3.85	4.9	10.15	2.48	3.5	3.85	4.9	10.15
length of unsealed roads inundated (km)	0.19	0.24	0.24	0.25	0.38	0.19	0.24	0.24	0.25	0.38

BCA Spreadsheet ‘Inputs’ Worksheet – Sub Area 2

Inputs CLEAR SHEET Return to Menu

Project Name: Bacchus Marsh Flood Mapping Project

Description: Using RORB and TUFLOW to generate flood maps of the Bacchus Marsh Area for existing conditions. AREA 2

Cost of Works:

Are works expected to mitigate flood risks for all events?

If yes, press button => Zero post-works data

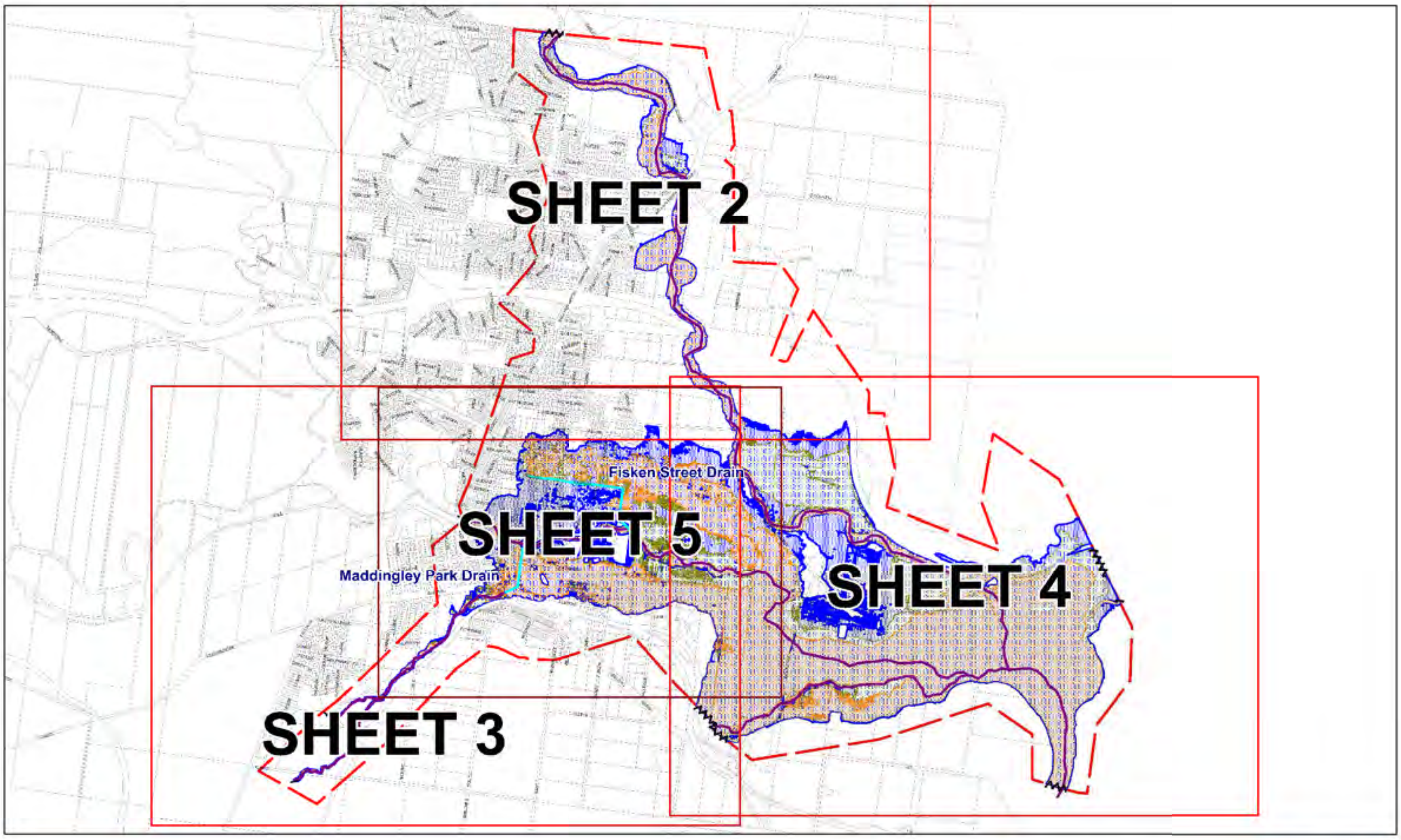
If no, enter post-works data.

	Pre-works					Post-works				
	Event 1	Event 2	Event 3	Event 4	Event 5	Event 1	Event 2	Event 3	Event 4	Event 5
Average Return Interval (ARI)	5	20	50	100	1E+06	5	20	50	100	1E+06
Average Level of Innundation Above Floor	-0.06	-0.03	0.03	0.06	2.02	-0.06	-0.03	0.03	0.06	2.02
Flood Warning Time (hours)	13	13	13	13	13	13	13	13	13	13
Flood Experience	N	N	N	N	N	N	N	N	N	N
Residential Properties										
number of properties with external flooding only (flood level < floor level -0.15m)	69	77	74	147	23	69	77	74	147	23
number of single storey residential buildings affected	27	32	43	65	795	27	32	43	65	795
number of double storey residential buildings affected										
Commercial & Industrial Properties										
low value — no. buildings affected										
low value — total area of properties (sq.m.)										
medium value — no. buildings affected	1	1	1	1	16	1	1	1	1	16
medium value — total area of properties (sq.m.)	600	600	600	600	9400	600	600	600	600	9400
high value — no. buildings affected										
high value — total area of properties (sq.m.)										
Roads										
length of major roads inundated (km)	0.91	1.92	3.74	4.68	17.21	0.91	1.92	3.74	4.68	17.21
length of minor roads inundated (km)	0.57	0.7	1.22	2.35	15.8	0.57	0.7	1.22	2.35	15.8
length of unsealed roads inundated (km)	3.06	4.39	5.13	8.59	14.62	3.06	4.39	5.13	8.59	14.62

Appendix L

Climate Change Extents

Extents for the 100, 20 & 5 year ARI events



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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- 100 year ARI Flood Extent
- 20 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Hydraulic Model Boundary
- Modelled Melbourne Water Underground Drains
- Modelled Melbourne Water Natural Waterways

Melbourne Water
Baccus Marsh Flood Mapping

Job Number	31-22909
Revision	0
Date	29 Jul 2010

Climate Change Scenario Flood Extents
Sheet 1 of 5

Figure L-1

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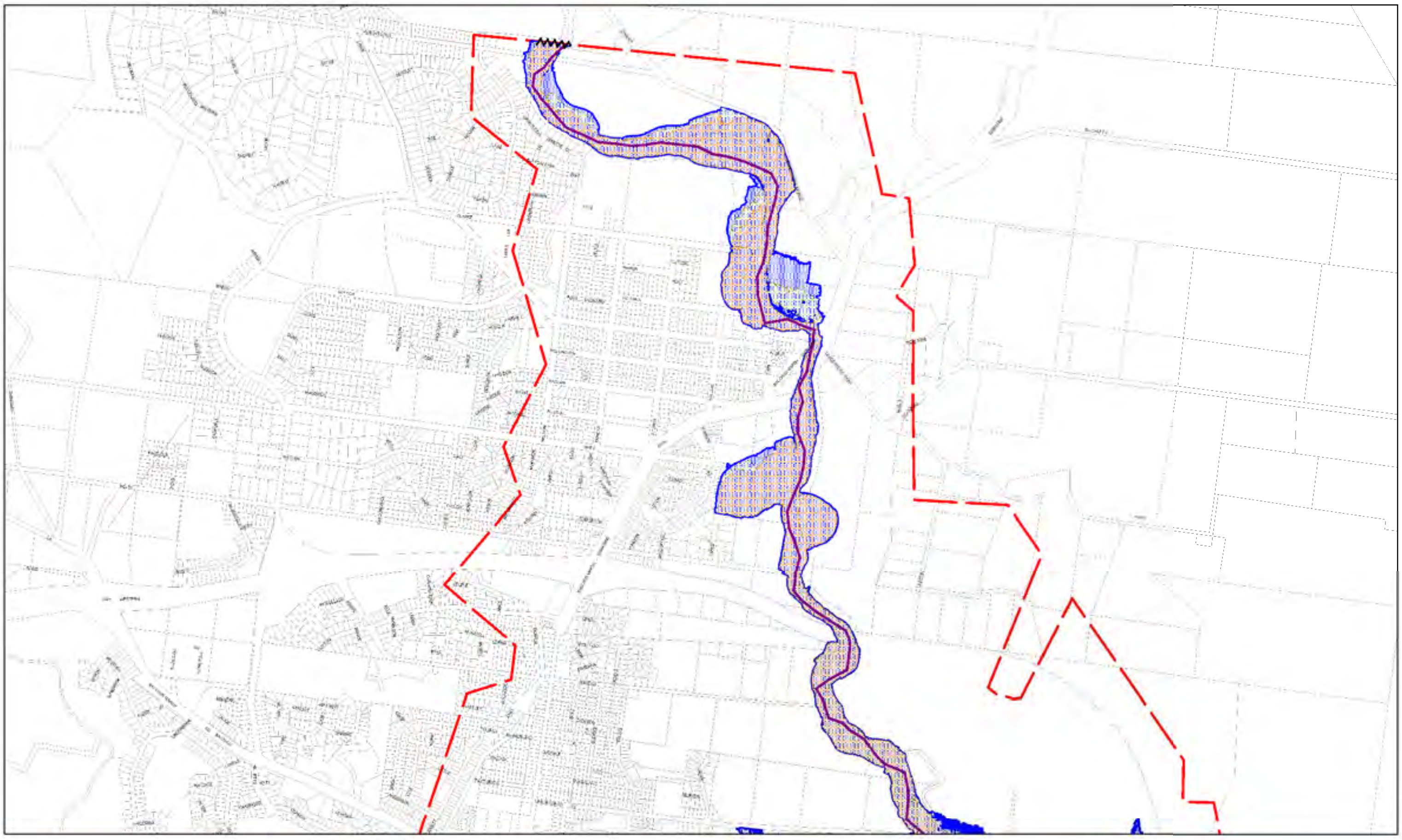

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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

100 year ARI Flood Extent
20 year ARI Flood Extent
5 year ARI Flood Extent
Limits of Modelling (Main Waterways)
Property Boundaries
Hydraulic Model Boundary
Modelled Melbourne Water Underground Drains
Modelled Melbourne Water Natural Waterways

Melbourne Water
Baccus Marsh Flood Mapping

Job Number	31-22909
Revision	0
Date	29 Jul 2010

Climate Change Scenario Flood Extents
Sheet 2 of 5

Figure L-2

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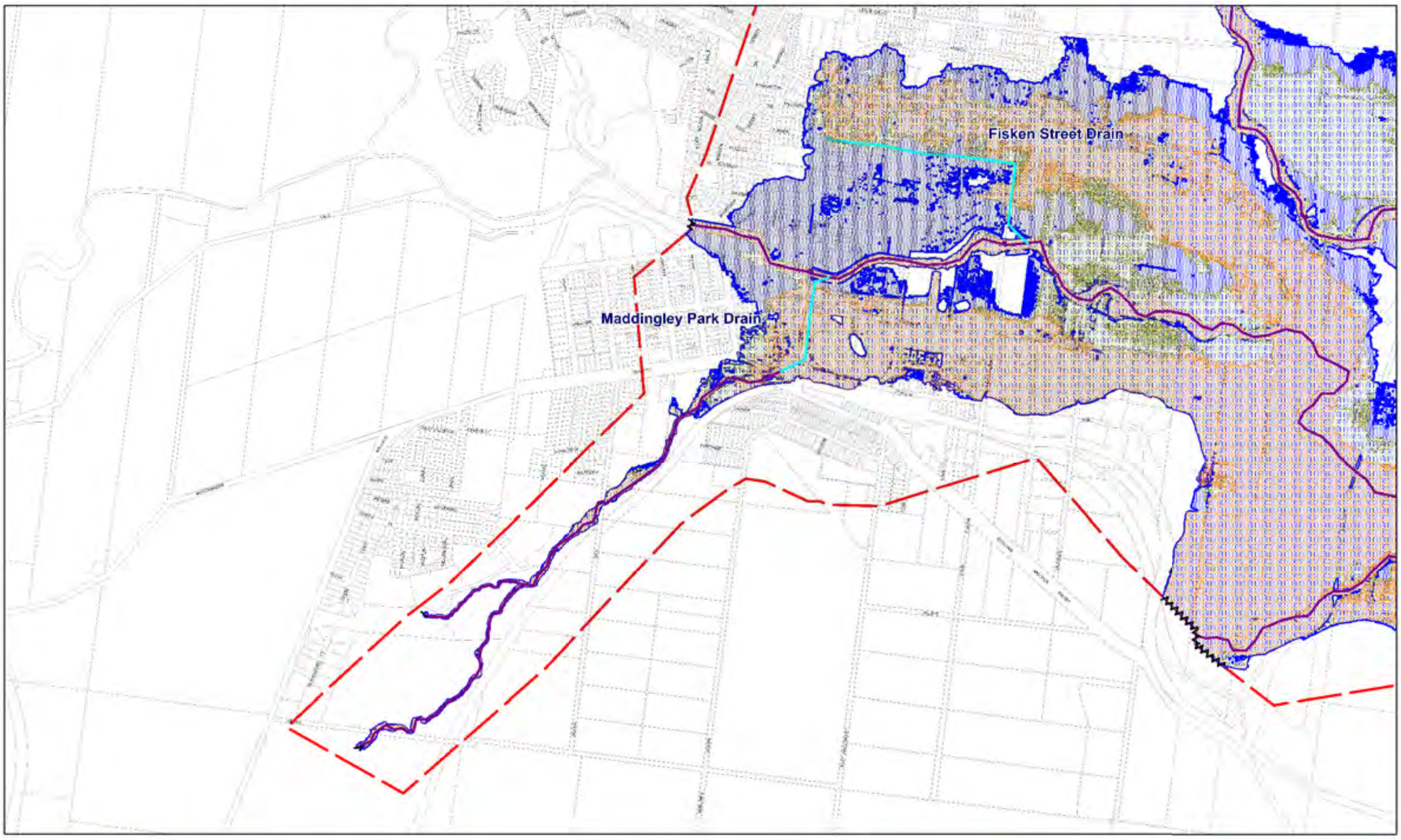

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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- 100 year ARI Flood Extent
- 20 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Hydraulic Model Boundary
- Modelled Melbourne Water Underground Drains
- Modelled Melbourne Water Natural Waterways

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Climate Change Scenario Flood Extents
Sheet 3 of 5

Figure L-3

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Data source: Cadastre, road names, contours supplied by Melbourne Water, May 2008. Created by: NEA

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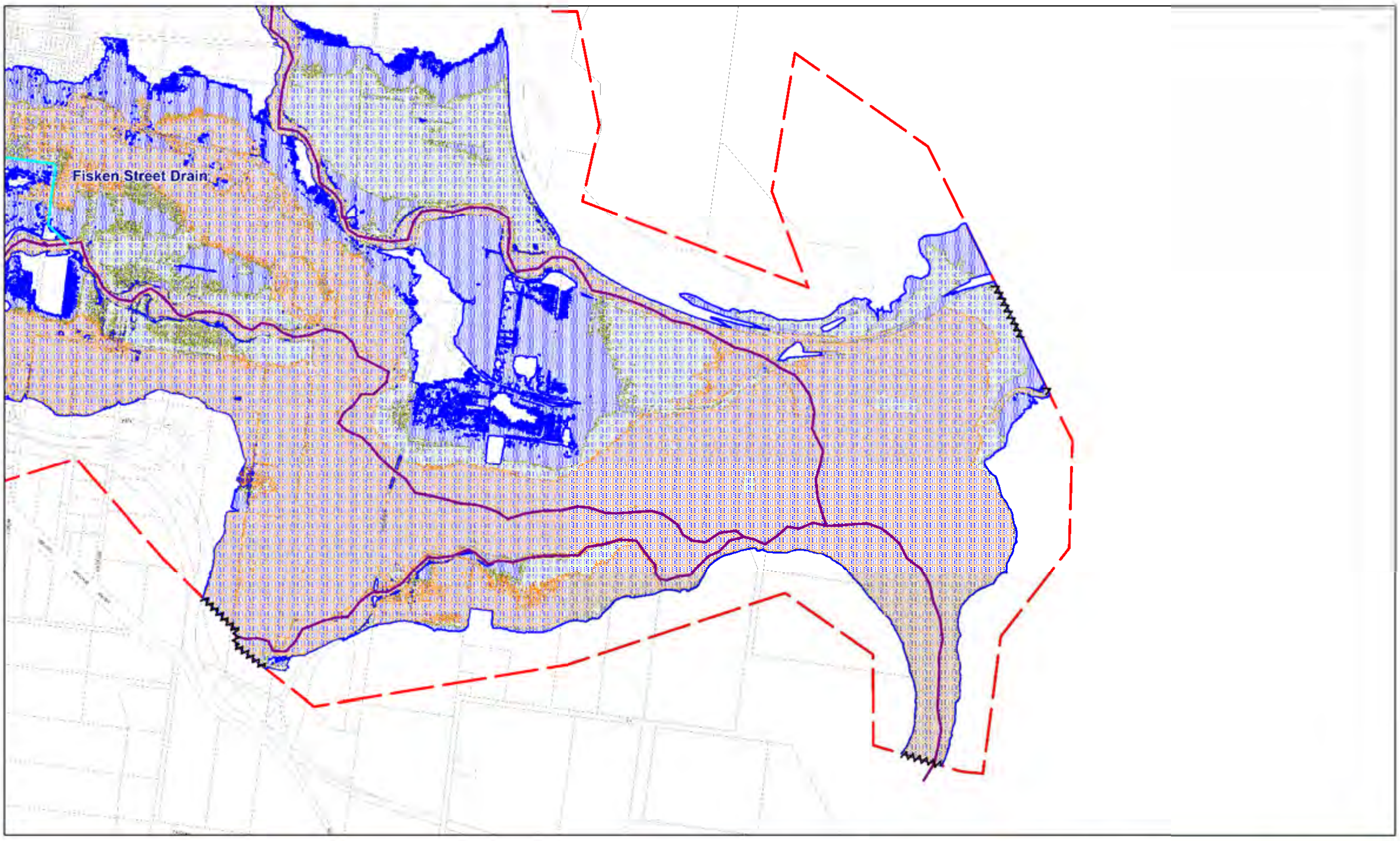

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Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

N

LEGEND

- 100 year ARI Flood Extent
- 20 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
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- Modelled Melbourne Water Natural Waterways

Melbourne Water
Baccus Marsh Flood Mapping

Job Number	31-22909
Revision	0
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Climate Change Scenario Flood Extents
Sheet 4 of 5
Figure L-4

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Data source: Cadastre, road names, contours supplied by Melbourne Water, May 2008. Created by: NEA

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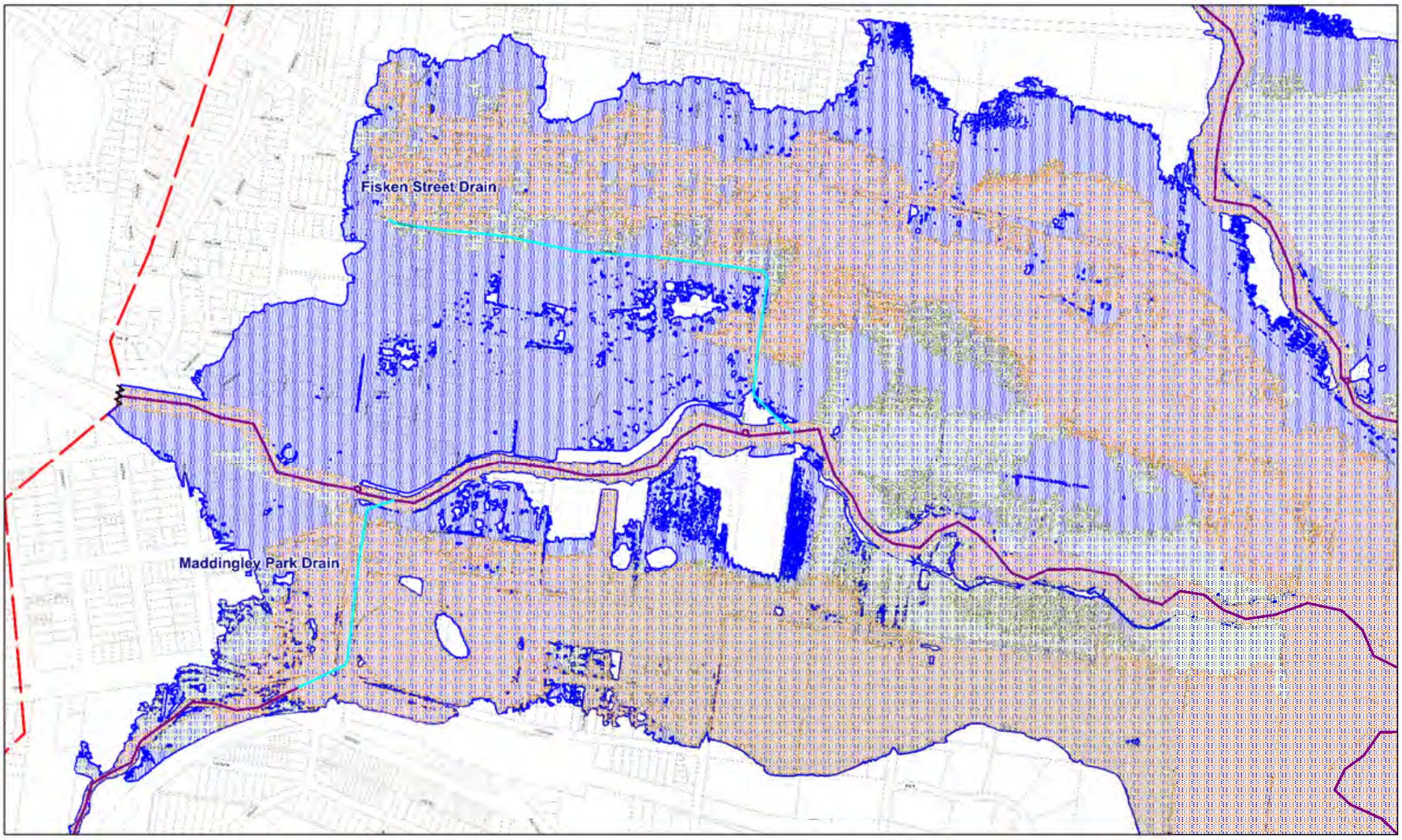

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75 0 75 150 225

Metres (at A3)

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 55

LEGEND

- 100 year ARI Flood Extent
- 20 year ARI Flood Extent
- 5 year ARI Flood Extent
- Limits of Modelling (Main Waterways)
- Property Boundaries
- Hydraulic Model Boundary
- Modelled Melbourne Water Underground Drains
- Modelled Melbourne Water Natural Waterways

Melbourne Water
Baccus Marsh Flood Mapping

Job Number	31-22909
Revision	0
Date	29 Jul 2010

Climate Change Scenario Flood Extents
Sheet 5 of 5

Figure L-5

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Data source: Cadastre, road names, contours supplied by Melbourne Water, May 2008. Created by: NEA

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