Melbourne Water Corporation
November 2011

Ballan Township Flood Study

Final Report

Halcrow Pacific Pty Ltd

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Final Report

Contents Amendment Record

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Prepared by	Checked by	Authorised by
1	0	Draft	30.11.11	AJS	DM	

Contents

List of Acronyms

1D	1 dimensional
2D	2 dimensional
AHD	Australian Height Datum
ARI	average recurrence interval
AR&R	Australian Rainfall and Runoff
CSV	comma separated values
d	depth
DTM	digital terrain model
EAF	elevation adjustment factor
f	fraction impervious (depending on source óFIôalso used)
F_{100}	frequency factor for 1 in 100yr ARI event
FI	fraction impervious (depending on source óf ôalso used)
GIS	geographical information system
GSDM	generalised short duration method
h	height (elevation)
HEC-RAS	Hydrologic Engineering Centre - River Analysis System (software application)
I_{tc}	average rainfall intensity
IFD	intensity frequency distribution
IL	initial loss
k_c	catchment co-efficient
LiDAR	light detection and ranging
m	catchment exponent
MAF	moisture adjustment factor
MD	main drain
MW	Melbourne Water
n	Manningôs ónô
PMP	probable maximum precipitation
RORB	runoff-routing-Burroughs (software application)
t_c	time of concentration
V	velocity
v X d	velocity times depth (depending on source óZ0ôalso used)
XPStorm	XP(software) - stormwater modelling (software application)
Z0	velocity times depth (depending on source óv X dôalso used)

Executive Summary

As part of Melbourne Water's ongoing flood modelling and mapping program Halcrow was commissioned to undertake an investigation into three catchments (Melbourne Water Main Drain catchments MD8143, MD8144/MD8145 and MD8146/MD8147, referred to as Catchments A, B and C respectively) within the township of Ballan. The investigation commenced in March 2008 and was completed with delivery of this report. The investigation entailed modelling, mapping of results and reporting of critical events for the 5, 10, 20, 50 and 100 year ARI and PMP under current climate conditions. The 5 20 and 100 year ARI events were also investigated under future climate conditions.

The three Ballan township catchments are located 67 kilometres west north-west of the Melbourne CBD. Land use is predominately pastoral and with some medium to low density residential properties towards the downstream end of each catchment. Reflecting the respective land uses, runoff conveyances is predominately overland and natural channels for most of the catchment area. Towards the downstream end of Catchment B an underground piped systems is present and consists of a moderately extensive network. Catchments A and C have no notable underground system with covered flow only occurring at bridges and road culverts.

For the purposes of this investigation intensity frequency data specific to the Ballan area was used to generate storm profiles for the catchment and these profiles used within the hydrological modelling application RORB. The RORB model was adjusted against Rational Method estimates for the catchment and flow data for each catchment generated. This flow data was subsequently used during the hydraulic modelling stage using the both HEC-RAS (Catchments A and C) and XPStorm (Catchment B) modelling applications. The HEC-RAS and XPStorm models were then used to model the behaviour of runoff towards the downstream end of the respective catchments.

Results from hydraulic modelling (flood levels, depths, velocity, and, depth times velocity) are then mapped using the GIS package MapInfo and the flood extents, risk ratings, and flooded properties and buildings determined.

1 Introduction and Background

1.1 Project Objective

The objective of this project was to determine flood extents and identify the risk to individual properties and roadways within the three catchments. Land-use within the catchments is rural-suburban catchments and located approximately 67 kilometres west north-west of the Melbourne CBD. Halcrow was engaged by Melbourne Water to undertake the '*Flood Mapping of the Drainage System within the Ballan Area*' study. The study area encompasses three Melbourne Water recognised catchments, i.e. MD8143, MD8144/MD8145 and MD8146/MD8147. For the purpose of this study the catchments are referred to as A, B and C respectively.

1.2 Project Scope

The project covered the following items:

- develop a hydrological model for each of the three catchments using RORB (version 6);
- develop a hydraulic model for each of the three catchments in HEC-RAS (Catchments A and C) and in XPStorm (Catchments B);
- mapping and analysing of the modelling results using MapInfo; and
- reporting on all results.

The original scope originally involved hydrological modelling of the catchments under three different land-use conditions:

- Existing development
    - Current zoning and land-use
- Ultimate development
    - Current zoning and full land-use utilisation based on zoning
- Full development
    - Future zoning and full land-use utilisation based on zoning

After discussions with Moorabool Council it was discovered that there was no foreseeable change to planning zones within any of the catchments. In turn it was agreed with Melbourne Water that the 'Full development' would not be investigated.

The later hydraulic modelling using HEC-RAS and XPStorm requires only investigating the 'Ultimate development' but under two different climate conditions:

- Base Case (normal rainfall)
- Future climate condition (or 'climate change' conditions)

The current climate assessment consisted of modelling the 5, 10, 20, 50 and 100 year Average Return Interval (ARI) and Probable Maximum Precipitation (PMP) events using current rainfall estimates. For climate change conditions only the 5, 20 and 100 year events required investigation. These events were based on current climate rainfall estimates with the rainfall intensity increased by 32% (as specified by Melbourne Water).

2 Information Used

The final hydrological and hydraulic models were created using the following information:

- Survey data (supplied by MW) – Existing Connell-Wagner site survey data included manhole and pit locations and levels, and terrain cross sections;
- LiDAR information (supplied by MW) – Received in comma separated value (CSV) format. This was used to create the digital terrain model (DTM) and this information supplemented the site survey where data not available;
- GIS Melbourne Water Asset data (supplied by MW) – Pipe locations with diameters, inverts and types. Pit locations available but invert levels were not available;
- GIS Council Asset data (supplied by Moorabool Council) – Pipe locations with diameter, inverts and type. Pit locations with inverts, entrance levels and type.
- Aerial photography (supplied by MW) – Covering all of Catchments A and B, and most of Catchment C. Site visit by Halcrow revealed the small area not covered by aerial photography was not significantly different from adjacent areas;
- Design storm data (sourced - Australian Rainfall and Runoff (AR&R) 1997) - IFD parameter for the Ballan location obtained from the AR&R Volume 2, inturn design storms generated for all storms investigated;
- Probable Maximum Precipitation (PMP) design storm data (source - Generalised Short Duration Method (GSDM) 2003) – PMP parameter for the Ballan location obtained from the GSDM, inturn design storms generated for all storms investigated
- Hydrograph records of Werribee River (supplied by MW) - Flow gauge records used to determine tailwater conditions.

3 Catchment Descriptions

3.1 Catchment Details

3.1.1 Catchment A

Catchment A (MD8143) is a relatively steep catchment (average slope 2.1%) with an area of 2.9 km². Land use is predominately for farming purposes with some low density rural residential at the downstream end. There is no significant underground stormwater network in the catchment. The reach consisted entirely of channel or culvert flow and covered the length 500 metres upstream of the Ballan-Greendale Road and running south to drain to the Werribee River. Upstream of the reach no discernable channel was evident and flow was assumed to be overland.

The main reach passes through culverts at four road crossings, including the Western Highway. Each of these locations was found to impede flow for larger events and all experienced over topping for the PMP event.

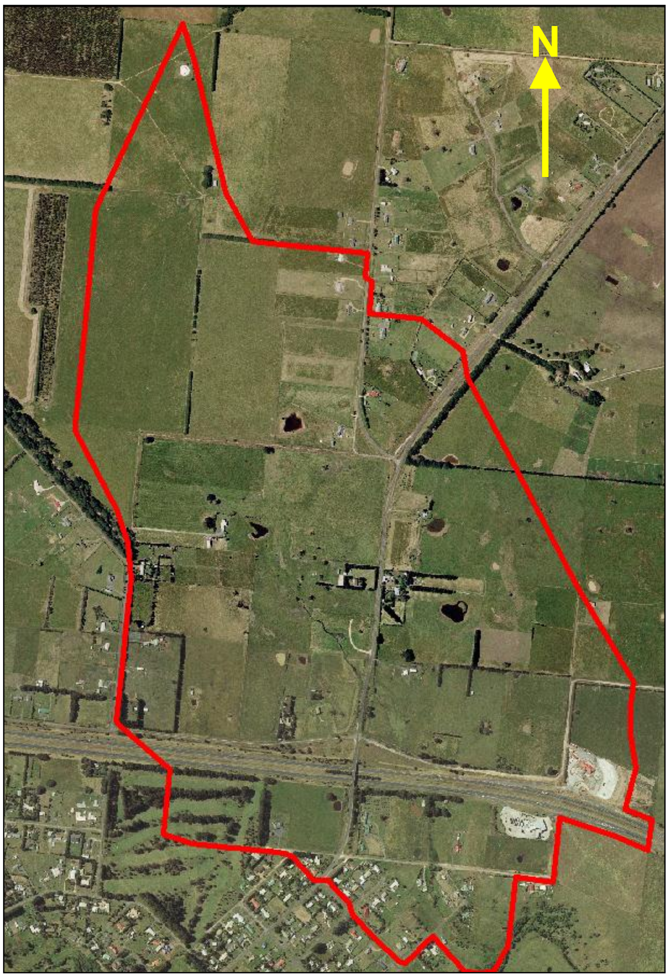

Figure 1: Catchment A aerial photograph. Extents outlined in red

3.1.2 *Catchment B*

Catchment B is a relatively flat, mixed use catchment with an area of 3.0 km^2. The main tributary, Gosling Street Drain (MD8144), is approximately 1.3 kilometres long and has an average slope of 1.4%. The drain runs from south to north and discharges into the Werribee River. A tributary of Gosling Street Drain (MD8145), is approximately 300 metres long, flows in a north-westerly direction and connects into the main drainage path about 390 metres downstream of the railway line. Catchment B was modelled using XPStorm 2009.

Catchment B is crossed by the Melbourne–Ararat train line and Old Melbourne Road, both of which were found to retard and detain flows. The road and railway line are both overtopped during the PMP event, but not in events less than or equal to the 100 year storm.

Upstream (to the south) of the rail line, the land use is predominately farming with a small area of light industrial with runoff predominately overland. Downstream of the railway line land use is mixed low to medium density residential with some farm use to the east. Towards the outlet the catchment is serviced by a mixed pipe, culvert, swale and natural watercourse system. As part of the scope of the project hydraulic modelling was limited to this northern area and the railway line modelled as a combination weir/culvert.

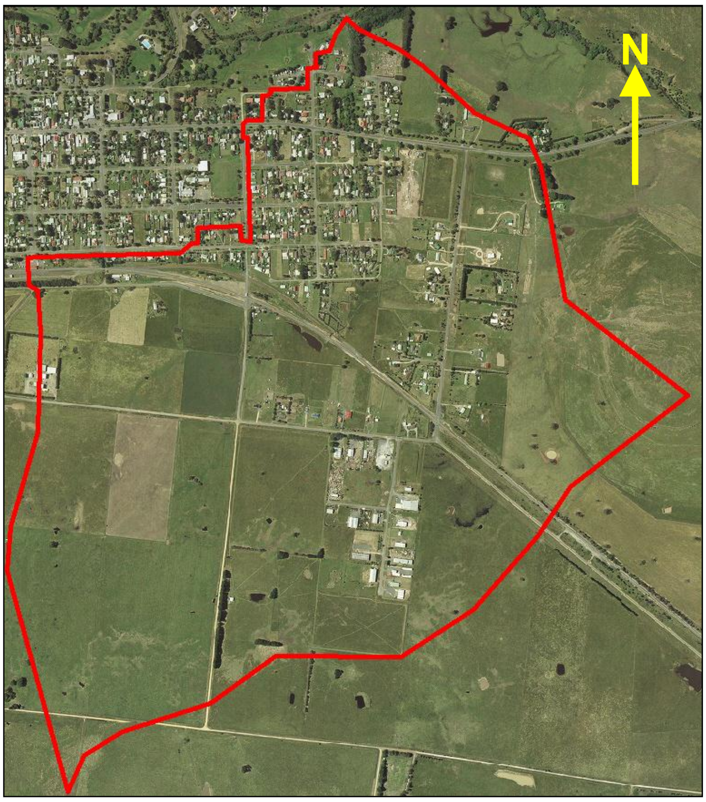

Figure 2: Catchment B aerial photograph. Extents outlined in red

3.1.3 *Catchment C*

Catchment C (MD8147/MD8148) is generally flat with land use being predominately farm or rural living. Total catchment area is 4.5 km². The modelled main tributary has an average slope of 1.1%, running from south to north and drains to the Werribee River. Catchment C was modelled using HEC-RAS software. The hydraulic model consisted entirely of channel and culvert flow and covered the reach length immediately upstream of Geelong Road and running north to the outlet at the Werribee River.

Catchment C is crossed by the Melbourne–Ararat train line, Old Melbourne Road and Geelong Road, all of which were later found to impede flow and cause significant detention. Both the train line and Old Melbourne Road experience over topping for the PMP only, whereas Geelong Road is overtopped for smaller events as well.

Figure 3: Catchment C aerial photograph. Extents outlined in red. Note aerial photography does not cover entire catchment.

4 Technical Methodology

Flood modelling and mapping of the Ballan township catchments consisted of four general stages: data preparation, hydrological assessment, hydraulic assessment and result processing/reporting. These stages are detailed below:

- Data preparation
  - Entailing compiling and processing information including drainage plans, GIS data, LiDAR, and land use. LiDAR data was processed to produce a digital terrain model (DTM); and
  - Site visit and photographic records taken.
- Hydrological assessment and modelling
  - Peak discharge estimates for 1 in 100 year event determined using Rational Method;
  - Hydrological model and design storms for catchment created using RORB;
  - RORB model adjusted to reflect Rational Method estimates;
  - RORB model modified to include underground assets; and
  - Each scenario/ARI combination/duration run and hydrograph results generated.
- Hydraulic modelling
  - HEC-RAS (Catchments A and C) and XPStorm (Catchment B) hydraulic models were created from digital terrain model, and also for Catchment B the pipe data;
  - Fraction impervious determined, large underground assets added; and
  - Hydrographs from RORB modelling, applied and modelled in either HEC-RAS or XPStorm. Outputs included flood levels, depths and flow velocities.

- Result processing/Reporting
    - Hydraulic model results processed to determine maximum depth, velocity and depth times velocity per ARI/scenario combination. Processed results then mapped and summarised in GIS and report format.

5 Hydrological Modelling

5.1 Overview

RORB, a hydrological modelling application developed and widely used within Australia, is able to simulate the runoff from user defined sub-catchments and reaches. For the Ballan township catchments, sub-catchments and overland reaches were based on available aerial photography and survey data.

5.2 RORB model development and final parameters

5.2.1 Catchment boundaries, sub-catchment boundaries, nodes and reaches

The catchment boundaries were determined from a combination of known relief contours and property boundaries. The sub-catchment boundaries were determined from ridgelines and then further divided based on contours and land (refer to **Appendix B**).

Sub-catchment values (area, reach length, node names, and sub-catchment names) were as supplied and agreed to by Melbourne Water (refer to **Appendix A**). Fraction impervious data for the 'Existing conditions' model was derived from recent aerial photography of the area. The 'Ultimate existing' (Ultimate) model fraction impervious values were as supplied by Melbourne Water. It was intended the 'Full development' (Full) model would adopt fraction impervious from the Ultimate condition except where Moorabool Council nominated areas of future re-zoning. However, after meeting with Council, it was realised that there is no foreseeable rezoning within Catchment A. As such, the Full condition would give identical results as the Ultimate condition and was not modelled.

The final RORB models consisted of 25, 39 and 28 sub-areas respectively with centrally placed nodes for each. All junction nodes were located at confluences and where reaches exits from sub-areas. All hydrographs were recorded at each of the sub-area outflows and subsequently used as input sources for the later hydraulic modelling.

5.2.2 RORB parameters

The Flood Mapping, Re-development Services Scheme and Mitigation – Technical Specifications and Requirements [3] (the 'Specification') makes recommendations on a number of RORB parameters. These recommendations are based on a history of flood modelling of catchments within the Greater Melbourne and surrounding areas. After review the parameters were considered appropriate for the Ballan township catchments.

Being the dominate parameter when adjusting the RORB for normal storm events (< 1 in 200 year) the kc value was adjusted until model discharges closely matched the Rational Method estimates.

Table 1: RORB Parameters

Parameter	Selected Value	Explanation
Storm events – Current Climate Conditions	PMP, 100, 50, 20, 10 & 5yr ARI	Standard ARI storm events automatically generated (RORB) / PMP manual (GSDM)
Storm events – Future Climate Conditions	100, 20 & 5yr ARI	Design storms generated using IFD parameters for the Ballan township catchments
Routing method	Single routing parameters	For small catchments single set of parameters sufficient to model conditions
Loss modelling method	Runoff co-efficient model	Suitable method of loss estimation for urban catchments, alternative 'constant loss' method better suited to rural.
Storm Location Details (IFD)	Ballan (AR&R Vol.2)	Design storms generated using IFD parameters for the Ballan township catchments
Temporal Pattern details	Filtered	Design rainfall pattern without storm burst exceeding the ARI being investigated
Areal Pattern details	Uniform	No manual modification to design rainfall distributions by sub-catchment required
Areal reduction Factors details	Siriwardena and Weinmann	Provides a method of areal reduction representative of local conditions (Victorian) as opposed to the alternative AR&R
Loss Factor details	Constant losses	Variable loss only suitable when a detailed study has been performed of the catchments loss behaviour with storm duration or return interval.
RoC - PMP, 100, 50, 20, 20, 10 & 5yr ARI	0.65, 0.60, 0.45, 0.40, 0.30 & 0.22 (respectively)	Values provided in Specifications deemed appropriate for this study.
m	0.8 (1.0 for PMP)	Appropriate value for small to large storm events (<200yr ARI).
Initial Loss	15 mm	Losses through ground permeation considered low given medium density land use and clayey soil.
k_c	2.11 – Catchment A 2.29 – Catchment B 4.27 – Catchment C	k_c value modified to match peak discharge to Rational Method estimates. Final value adjusted to accommodate piped flow not otherwise considered by the Rational Method.

5.3 *Design Storm Models - 5yr, 10yr, 20yr, 50yr and 100yr ARI*

Storm files were generated using the Australian Rainfall and Runoff IFD Parameter function within RORB. This function has a list of important Australian locations incorporated by default, including Melbourne and Ballarat. Provision is also made for unlisted locations to be created manually using the parameters obtained from the Australian Rainfall and Runoff (AR&R) Volume 2 (refer **Table 2**). From this information, the Ballan design storms for were generated for all standard ARI's and durations.

Table 2: Ballan IFD data (AR&R Volume 2)

IFD Data	Ballarat	Ballan	Melbourne	Sydney
2yr1hr (mm/hr)	19.50	**19.17**	18.90	41.90
2y12hr (mm/hr)	4.00	**4.03**	3.81	8.27
2y72hr (mm/hr)	1.10	**1.14**	1.13	2.55
50yr1hr (mm/hr)	40.20	**40.42**	38.70	87.00
50yr12hr (mm/hr)	8.00	**7.96**	7.09	16.80
50yr72hr (mm/hr)	2.10	**2.34**	2.21	5.19
Skew	0.33	**0.35**	0.35	0
F2 (mm/hr)	4.32	**4.31**	4.29	4.29
F50 (mm/hr)	14.85	**14.83**	14.90	15.90
Zone	1	**1**	1	1

A check was performed on the IFD parameters by comparing to those for Melbourne and Ballarat (refer **Table 2**). The close proximity of these locations giving similar values, and to contrast, Sydney was also compared. A comparison confirmed the validity of the parameters used.

Note, the Brief requests that rainfall be expressed in Annual Exceedance Probability (AEP) and not Average Return Interval (ARI). However, RORB and the AR&R supply information in terms of standard ARI. As such, all modelling and calculations have been done in terms of ARI. Final deliverables will be in terms of AEP using the nearest equivalent ARI (refer **Table 3**)

Table 3: AEP and ARI comparison

AEP	Equiv. ARI	ARI Used
20%	4.5 year	5 year
10%	9.5 year	10 year
5%	19.5 year	20 year
2%	50.0 year	50 year
1%	100.0 year	100 year

5.4 Design Storm Models - Probable Maximum Precipitation (PMP)

The Probable Maximum Precipitation (PMP) for the Ballan location was determined for all standard durations between 0.5 hours and 36 hours. The method employed was as prescribed by both the Bureau of Meteorology's Generalised Short Duration Method (GSDM) (October 2006) and the Generalised Southeast Australian Method (GSAM) (June 2003).

For a small (<1000 km^2) catchment located in the intermediate zone, the GSDM was used to calculate rainfall depth for durations between 0 and 3 hours and the GSAM used for durations between 24 and 72 hours. As outlined in the GSAM, rainfall depths for durations between 3 and 24 hours were interpolated using the results from both the GSDM and GSAM.

Preliminary RORB runs for 100 year ARI indicated the PMP event was likely to have a critical duration significantly below 9 hours, i.e. a short duration. This being the case, the GSDM temporal pattern method was used in the final model.

5.5 Climate Change Conditions

For the climate change condition, a 32% increase in current rainfall intensity was used, as per Section 4.2.2 of the Brief.

Each climate change design storm was based on the corresponding automatically generated storm event using RORB. Intensity was increased by a factor of 1.32 while all other values, including temporal pattern, remained the same.

5.6 Determination of the parameter kc

Initial investigation of k_c values were limited to standard RORB values applicable for Victorian catchments, as well as the RORB default (refer to **Table 4**). The wide range of values was found to give a correspondingly wide range of peak discharges.

Table 4: kc values investigated

k_c	Source
0.97	Victorian location with MAR < 800mm (ARR Vol 1)
2.00	Victorian data (Pearse et. al)
3.73	RORB default, where kc = 2.2*A0.5 * (Qp/2)0.8-m

Model runs were performed in RORB using the three kc values for each standard ARI/duration combination, with ARI's ranging from 5 to 100 years and duration's from 0.5 to 72 hours (refer **Figure 4**). The peak discharges for each ARI were then compared to the discharges calculated using the Rational Method. For higher ARI's, including 100 year, a kc value of 2.00 was found to give the most accurate indication of maximum discharge.

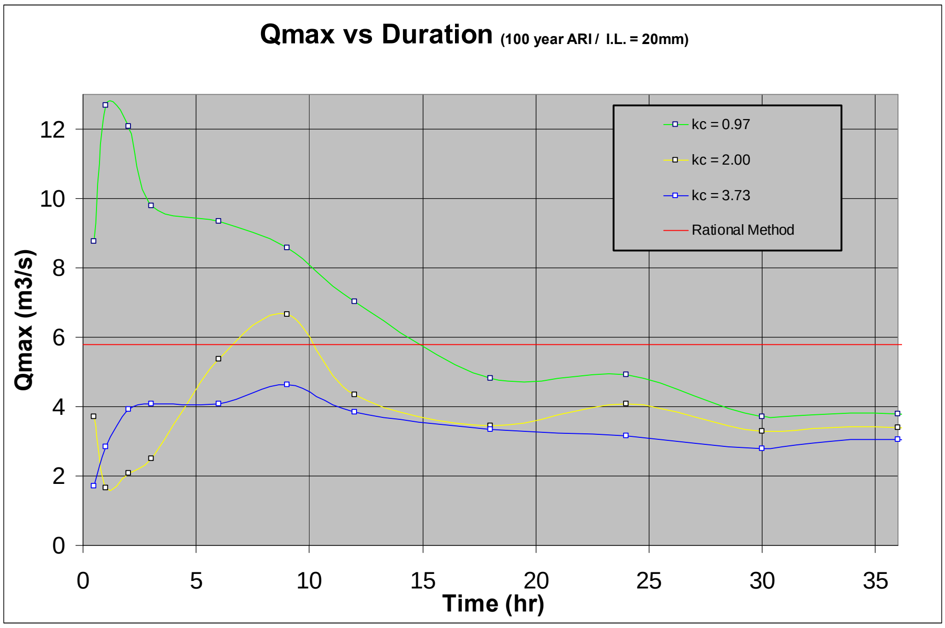

Figure 4: Change in Peak Discharge with kc

5.7 *Flow Estimate*

Given the lack of pluviograph and hydrograph data for calibration, the method outlined in **Sections 2.7** and **2.8** of the Specification was used to estimate the catchment behaviour.

As an undiverted model, each catchment under 'Existing' conditions was considered in two parts; that part drained by a Melbourne Water asset and that part upstream of the Melbourne Water asset. The extents of the asset were deemed between the Werribee River and the point at which no sub-catchment upstream was greater than 60 hectares. This corresponds with the final RORB model where the area upstream and the main reach were treated as the Melbourne Water asset.

Time of concentration (t_c) was the sum of both the t_c for the upstream area (using the Adams Method) and the t_c for the asset derived from the average velocity under top of bank conditions (modelled using HEC-RAS). The peak discharge (Q_{max}) for a 100 year ARI was then determined using the Rational Method.

5.8 RORB model

5.8.1 *Initial Loss (IL)*

Given the low permeability of the soil, a relatively low initial loss (I.L.) was chosen for all catchments, i.e. 15mm. During adjustment of the model it was found the calculated discharge, critical duration and time of concentration tended to be longer than anticipated while the lower I.L. will tend to reduce this effect. As is common practice, I.L. = 0mm was adopted for the PMP event.

- I.L. = 15 mm (ARI ≤ 100)
- I.L. = 0 mm (PMP)

5.8.2 *m*

As outlined in the Specification, m = 0.8 was adopted for all standard return intervals. Choice of PMP is undocumented in the Specification but as is common practice, m = 1.0 was adopted for the PMP event.

- m = 0.8
- m = 1.0 (PMP)

5.8.3 *Run-off Coefficients (RoC)*

Values for Run-off Coefficient (RoC) were supplied in the Specification in terms of standard duration/ARI, with a maximum duration of 2 hours. However, the preliminary model runs indicated the storm duration for each of the return intervals was greater than 2 hours, well outside of the values supplied by Melbourne Water. Without further information, the RoC for 2 hours was used for each case. For the calibration model (100 year) RoC = 0.6.

No RoC was supplied in the Specification for a PMP event, and by nature little observational data is available. Based on two earlier studies for Melbourne Water were referred to each giving approximations of RoC of 0.60 and 0.68. As a reasonable estimate RoC = 0.65 was selected.

- RoC100yr = 0.60
- RoC50yr = 0.45
- RoC20yr = 0.40
- RoC10yr = 0.30
- RoC5yr = 0.22

5.8.4 k_c

Given that calibration data was limited to one peak discharge for a single ARI; the model was insensitive to I.L.; and, other parameters are arbitrarily set by the specifications, the process of fitting the model was largely limited to adjusting k_c.

- k_c = 2.11 Catchment A (MD8143)
- k_c = 2.29 Catchment B (MD8144/8145)
- k_c = 4.27 Catchment C(MD8146/8147)

5.9 Hydrological Results

All flow estimates showed a consistent trend of increasing with storm intensity. The flow estimates also showed a trend of increasing with an increase in fraction impervious (i.e. Existing to Ultimate) and storm intensity (Ultimate to Climate Change).

5.10 Hydrological Modelling Discussion

All RORB parameters except for I.L. and k_c was outlined in the Specifications and used in the final model. Of these two parameters, I.L. was limited to a range of 15 to 20mm. Sensitivity analysis showed that the influence of I.L. on final results was minor.

Manual adjustment of the remaining parameter, k_c, allowed for the peak discharge to be matched to the Rational Method flow estimates relatively easily. However, against t_c (determined using the Adams Method) both time to peak and critical duration were conspicuously high in RORB. With effectively only k_c to adjust the model for fit, only the magnitude of the flow distribution curve could be adjusted. The shape of the curve remained relatively unchanged.

The PMP events modelled were found to be 5.2 and 5.3 times greater than the respective 100 year ARI events. Typically, PMP results are approximately 2.5 to 6 times greater than for a 100 year ARI suggesting the model were a good indictor of PMP

6 Hydraulic Modelling

6.1 *Modelling Overview*

HEC-RAS is a 1D hydraulic package typically used for modelling flow open channel of varying cross sections. XP Storm is also a 1D hydraulic package capable of modelling open channel flow but with the added ability of simultaneously modelling underground piped networks. As such, the hydraulic modelling was undertaken using HEC-RAS for Catchment A and Catchment C and XP Storm for Catchment B.

6.2 *HEC-RAS Overview*

HEC-RAS is a 1-dimensional hydraulic calculation software that has the primary function of modelling channel and overbank flow. HEC-RAS also has the capacity to model covered flow such as culverts, bridges and other structures where required as was the case with Catchment A and Catchment C, with no significant differences in methodology between the two. Version 4.0.0 of the HEC-RAS software was used throughout the project, the latest version available during the term of the project.

6.3 *HEC-RAS Model Description*

The main reach for each catchment was determined from aerial photography as supplied by Melbourne Water. The length the reaches extended from the outlet at the Werribee River (CH 0m) and to the upper extents as defined in the earlier RORB model (**Section 3.1**).

Cross section location was determined initially by available survey data, i.e. immediately upstream and downstream of culverts. Where these cross sections were later found to be exceeded by the flood levels, LiDAR data was also used. Where no survey data was available cross sections were created at a maximum of 50 metre intervals based on available LiDAR data. Finally, using HEC-RAS the cross sections were then interpolated at a minimum of 20 metre intervals.

During the course of model construction, the quality of the supplied survey data was found to be variable. It was discovered during the model build that the latest source of survey data was found to be geo-referenced incorrectly. As a solution it was agreed with Melbourne Water that the earlier recorded survey data from Connell-Wagner would be used were available. LiDAR information was found to be generally adequate for over banks but sampling appeared to be inadequate upstream of the railway line within Catchment C. For instance the defined man-made channel upstream of the railway line (modelled using survey field survey data) appeared near flat from LiDAR data.

All culverts along the reaches were included with elevations and lengths based on survey data with the exception of the multiple culverts installed at the Lay Street extension within Catchment B. At this location a new development had commenced between the time of the survey data being collected and the model/s being constructed. As a solution the dimension of this culvert was measured on site and elevations estimated from the LiDAR information.

6.4 XP Storm Overview (Catchment B)

The hydraulic modelling software used for Catchment B was XP Storm 2009 (Version 11.0). The model was set up as a one-dimensional hydraulic model to predict the flooding from overland flows based on a storm water network that included a combination of pipes, manholes, open channels and culverts. It was only necessary to use the Hydraulics Mode of XP Storm as the catchment hydrology, normally modelled with the Runoff Mode, was accounted for by the earlier RORB modelling. No historical flow data was available for the models to be calibrated.

The downstream limit of the hydraulic model for Catchment B is at the junction between Werribee River and Gosling Street Drain (MD 8144). The upstream limit is the northern side of the Melbourne-Ararat railway line.

The model contains two key drainage crossings of the railway line in Catchment B. At each of these locations, one dummy link was modelled further upstream (south) of the railway line in order to better simulate the approach flow to the culverts and potential storage behind the railway embankment (i.e. the boundary conditions). However, the predicted flood extents are only considered to be valid from the downstream (northern) side of the railway line.

There are issues with satisfactory operation of the Scenario Manager in XP Storm (Version 11), a matter which has been acknowledged by XP Software technical support following Halcrow's consultation with them. (The problem relates to data corruption when using Scenario Manager). To work around this, a separate model for each design storm event was created. A base model for the 1 in 100 year event was first established and then used as a template for the other storm events whereby the inflow hydrograph data was simply changed. This helped to build consistency into the modelling process.

Dummy weir links were modelled at particular locations in Catchment B to allow for potential connectivity of flowpaths/floodplains that may occur given the topography and certain flow conditions. For example, spill-over of flows between the east and west tributaries that pond upstream of the railway line.

Adjustments to the various model parameters and controls, (e.g. time step, tolerance, level, gradient, roughness) were made during the model development process to improve the model stability. Spill crest levels at nodes must be specified at least as high as the top of a connecting channel to maintain flow continuity. These changes do not adversely affect the accuracy of the model results.

6.5 XP Storm inflow hydrographs

Hydrological flows at relevant node locations for each of the design storm events were derived from RORB. This data was entered into model as a time series inflow within the User Inflow section of the node data. Care was taken to ensure that the inflow hydrographs were used to simulate the additional flow entering the system, as opposed to a total flow hydrograph at a given point. Hydrographic data was based on the critical duration storm event for each ARI, as determined from RORB modelling.

6.6 Survey and Cross Sections

Similar to the HEC-RAS model, priority was given to using the (Connell Wagner) site survey data where available and then the LiDAR data. The Connell Wagner manhole survey was also utilized. This data was mostly used to help develop the network of nodes, conduits/links and cross sections that define the main structure of the XP Storm model. XP Storm allows only one cross section to define each natural channel between two given nodes. Dummy nodes and additional cross sections were entered into the model to make the model more representative of the site conditions.

Cross sections were extended to be sufficient for the PMF modelling scenario. Where the extent of detailed survey was limited, LiDAR was used to extrapolate the cross section extents.

6.7 Boundary Conditions

Boundary conditions at the outlet were based on Werribee River stage hydrographs for the 10 and 100 year ARI events. River stage (AHD) was determined from the HEC-RAS model of the Werribee River supplied by Melbourne Water. For modelling the PMP events for all three catchments, the Werribee River water surface elevation for a 1 in 100 year events was used as a tailwater condition and the 1 in 10 year ARI for all other events (refer to Table 5).

Table 5: Werribee River flood surface elevations

Scenario	Storm Event	Werribee River Surface Elev.
Reach A		
Probable Maximum Flooding (PMF)	**100yr**	**477.36m**
Normal climate - 1, 2, 5,10 & 20% events	**10yr**	**476.68m**
Climate change - 1, 5 & 20% events	**10yr**	**476.68m**
Reach B		
Probable Maximum Flooding (PMF)	**100yr**	**480.11m**
Normal climate 1, 2, 5,10 & 20% events	**10yr**	**479.53m**
Climate change 1, 5 & 20% events	**10yr**	**479.53m**
Reach C		
Probable Maximum Flooding (PMF)	**100yr**	**490.50m**
Normal climate 1, 2, 5,10 & 20% events	**10yr**	**489.81m**
Climate change 1, 5 & 20% events	**10yr**	**489.81m**

Lateral inflow hydrographs (from previous hydrological model stage) was used along the length of the reach with the location corresponding to the hydrological model.

6.8 Manning's 'n

Manning's n values for each of the models are outlined in **Table 6** below with surface roughness based on site observation and aerial photography.

Table 6: Manning's 'n'

Surface Type	Manning's 'n'
MAIN CHANNEL	
Straight, uniform and relatively clean	0.035 - 0.050
Some weeds, heavy brush on banks	0.050 - 0.070
Sluggish weedy reaches with deep pools	0.050 - 0.080
Trees within channel, branches submerged at high stage	+0.010 - 0.020
Irregular Sections, with pools, slight channel meander	+0.010 - 0.020
OVERBANKS	
Long grass, no bush	0.035 - 0.060
Irregular and rough section	0.035 - 0.100
Residential 1 Zone (R1Z) ï Ultimate conditions	0.100 - 0.200
Low Density Residential Zone (LDRZ) ï Ultimate conditions	0.080 ï 0.100

6.9 Assumptions

6.9.1 General

- 'Ultimate Development' conditions, i.e. land use within each catchment is fully developed in accordance with current land use zoning;

- Maximum seasonal vegetation growth;

- With the exception of the above two assumptions all other land use/conditions remain unchanged from the time of site visit;

- For PMP events, the tail water conditions will be taken from the Melbourne Water's estimate of the Werribee River for the 100 year event;

- For all other events, the tail water conditions will be taken from the Melbourne Water's estimate of the Werribee River for the 100 year event; and

- Manning's 'n' values determined from aerial photographs and site visits in conjunction with **Table 6**.

6.9.2 HEC-RAS

- Default values used unless otherwise stated;

- Cross section samples taken at 50 metre intervals along the main reach with interpolated cross sections no greater than 20 metres as indicative of the reach; and

- Simulation time window covers beginning of storm event, peak flow and a minimum reduction of 50% in peak flow.

6.9.3 XP Storm

- Pit entry capacities were calculated based on approach depth-captured flow relationships;

- Outfall node (619) has a "Type 2, Fixed Backwater" control for tail water conditions;

- Hydraulics Job Control data: Routing Control Time step = 1 second, model run time for 15 hour duration, save results every 120 seconds;

- Hydraulics Job Control – simulation tolerances: flow tolerance = 0.005, head tolerance = 0.005; and

- Hydraulics Job Control – Routing Control data: under-relaxation parameter = 0.85, time weighting factor = 0.95, minimum Courant time step factor = 1.0, maximum time step iterations = 500, hydrograph method = Dynamic Wave.

6.10 Discussion

Without historical hydrograph data, direct verification of the hydraulic models is not possible. As an alternative to direct verification the models were checked for consistency across events (e.g. increase in surface elevation with increasing discharge).

Model output errors were found to be limited to very low flows towards the start and finish of the model runs. However this would occur significantly before and after the peak flow and in turn did not affect final flood extents.

7 Flood Mapping

7.1 *Overview and Methodology*

The results presented within this section provide modelled estimates for flood extents, flood safety risk and flooded properties. These results will allow for planning approvals to new developments with reasonable confidence that flooding will not occur with unacceptable frequency. Furthermore, these results will also assist in determining which properties that are prone to flooding and in studying mitigation measures, if required.

Both the HEC-RAS and XP Storm packages are able to produce a geographically referenced set of outputs at regular time intervals during the running of the model. These results include flood level elevation, depth, velocity and discharges at each cross section locations. The results are interpolated and a contiguous region is produced.

7.2 *Flood Extents*

Flood extents were taken as that area where flood levels exceeded the terrain level after interpolation between cross sections. Flood extents were mapped for all Scenario/ARI combinations modelled. Refer to **Figure 5**, **Figure 6** and **Figure 7** for the 1 in 100 year current climate flood extent.

7.3 *Safety Risks in Roads*

Safety risk in roads is a measure of safety along roadways on the depth times velocity (v X d) for a 100 year ARI event. For any given location, the maximum v X d and d over the storm event has been taken. The results are based on the following definitions:

High Risk = v X d >0.8 m²/sec OR d > 0.8 m

Moderate Risk = v X d 0.4-0.8 m²/sec OR 0.4m < d < 0.8m

Low Risk = v X d < 0.4 m2/sec OR 0m < d < 0.4 m

7.4 *Properties and Buildings Flooded*

Each property within the PMP flood extents, under current climate conditions, was mapped, and, depth and the depth times velocity for each event at every affected property recorded.

Figure 5: Catchment A 100 year flood extents

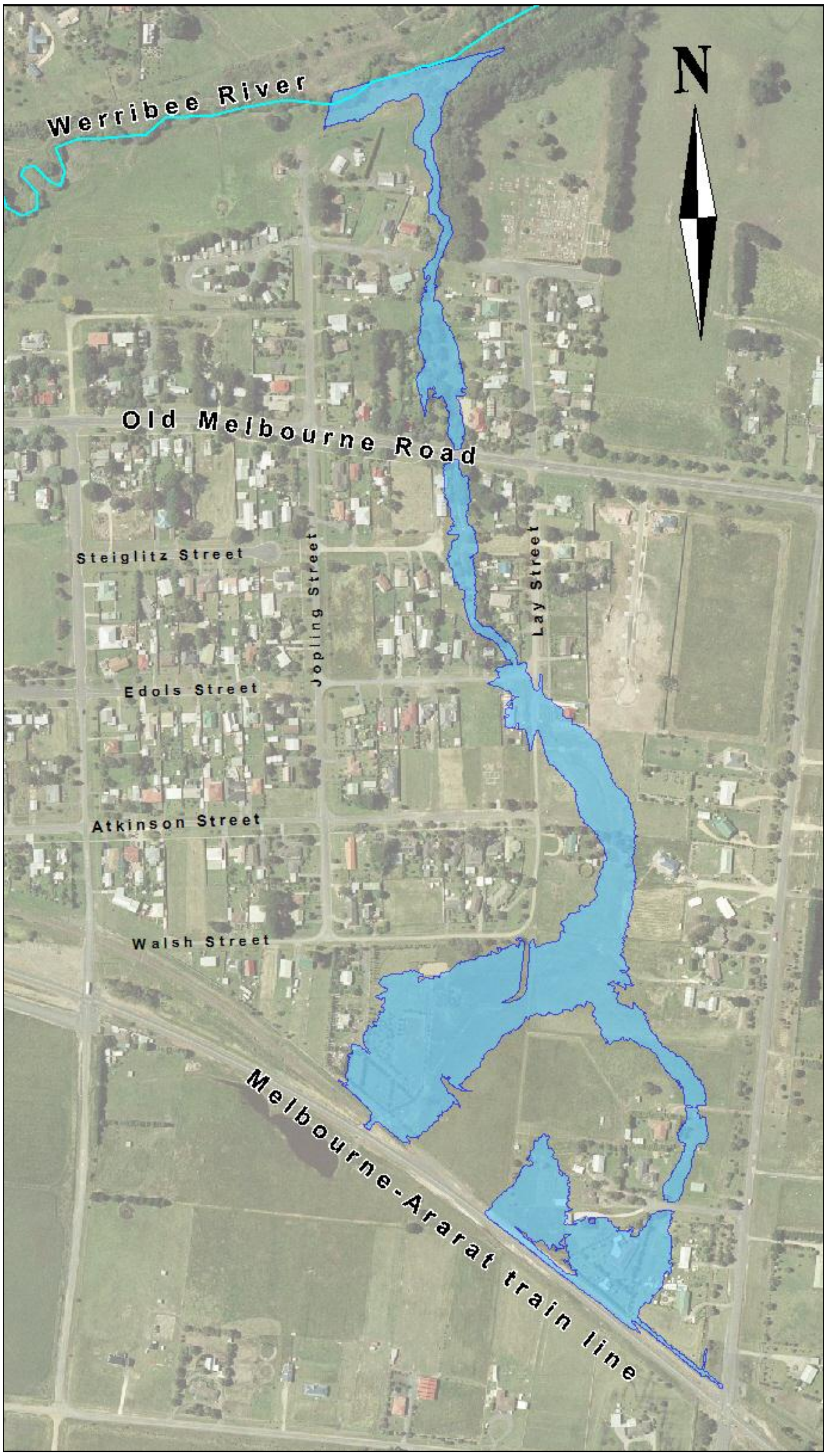

Figure 6: Catchment B 100 year flood extents

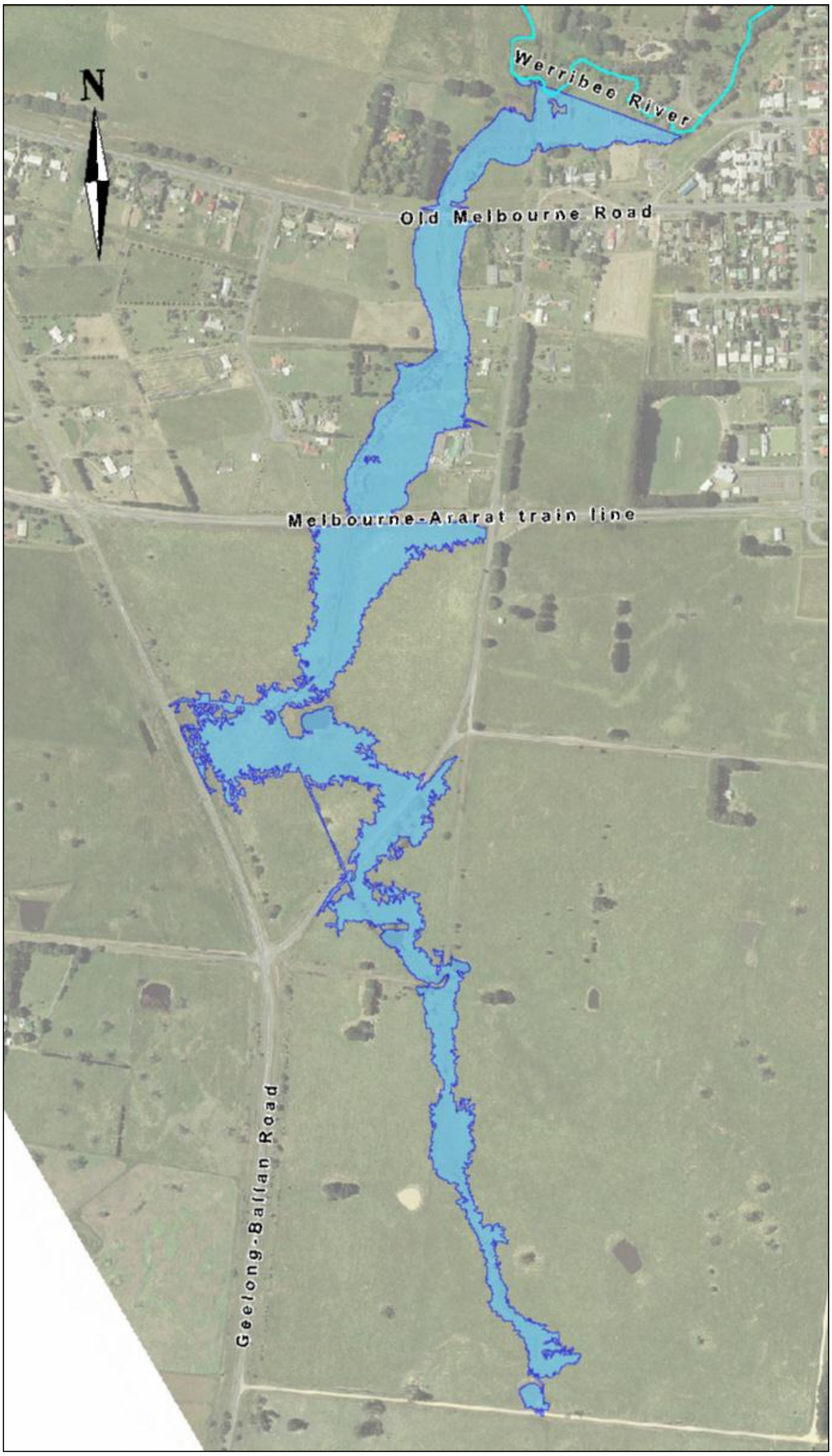

Figure 7: Catchment C 100 year flood extents

Each of the properties flooded was assessed for flooding of the most significant habitable building within the property, e.g. main residence but not garage. This assessment was then rated from 0 to 6 for flood risk. Each of the ratings is as follows:

- Category 1 = Property (but not floor) floor flooded by 1% AEP
- Category 2 = 50yr ARI level <floor level < 100yr ARI level
- Category 3 = 20yr ARI level <floor level < 50yr ARI level
- Category 4 = 10yr ARI level <floor level < 20yr ARI level
- Category 5 = 5yr ARI level <floor level < 10yr ARI level
- Category 6 = floor level < 5yr ARI level

8 Conclusions

Each of the Ballan Township Main Drain Catchments (Catchments A, B and C) was investigated for the 5, 10, 20, 50, 100 year ARI and PMP events under 'Ultimate' land-use and current climate conditions. Further investigation was also undertaken for the 5, 20 and 100 year ARI events under 'Ultimate' land-use and climate change conditions. Findings are in the form of flood extents, flood contours and safety risk. Also, a summary of both properties and habitable buildings flooded is available for Melbourne Water when considering mitigation works.

Methodology and technological improvements developed since the previous studies has allowed for higher confidence of results in a format that that is more flexible and accessible to those without direct modelling experience. Given the lack of historical flow recordings available calibration of the models was not possible, however, by comparing the model results to Rational Method estimates and previous modelling results (with consideration to improvements since the time of creation) a satisfactory level of robustness was achieved.

References

[1] Melbourne Water*, Flood Mapping of the Drainage System Within the Ballan Area*, 2008

[2] Engineers Australia, *Australian Rainfall and Runoff* Volume 1, 2003.

[3] Melbourne Water, *Flood Mapping, Re-development Services Scheme and Mitigation – Technical Specifications and Requirements*, July 2009.

[4] Bureau of Meteorology, *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method*, June 2003.

Appendix A PMP Calculations

A.1 Catchment A (MD8143)

GSDM CALCULATION SHEET – KMWHAC Ballan Township MD 8143

LOCATION INFORMATION

Catchment:	Ballan township ï MD8143			Area:	2.9	km^2
State:	Victoria			Duration Limit:	4	hrs
Latitude:	37.60	°S	144.23	°E		

Proportion of Area Considered:

Smooth, **S** =	1.00	(0.0-1.0)	Rough, **R** =	0.0	(0-1)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 510 m AHD

Adjustment for Elevation (-0.05 per 300m above 1500m) = 0

EAF = 1 (0.85-1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = 0.55 (0.40- 1.00)

PMP VALUES (mm)

Duration (hours)	Initial Depth - Smooth (D_s)	Initial Depth - Rough (D_r)	PMP Estimate (D_SxS+D_RxR)xMAFxEAF)	Rounded PMP Estimate (nearest 10mm)
0.25	235	0	129	130
0.50	330	0	182	180
0.75	415	0	228	230
1.0	485	0	267	270
1.5	555	0	305	310
2.0	620	0	341	340
2.5	660	0	363	360
3.0	695	0	382	380
4.0	760	0	N.A.	N.A.

A.2 Catchment B (MD8144/8145)

GSDM CALCULATION SHEET - KMWHAC Ballan Township MD 8144/8145

LOCATION INFORMATION

Catchment:	Ballan township ï MD8143			Area:	3.0	km^2
State:	Victoria			Duration Limit:	4	hrs
Latitude:	37.60	°S	144.23	°E		
Proportion of Area Considered:						
Smooth, **S** =	1.00		(0.0-1.0)	Rough, **R** =	0.0	(0-1)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 510 m AHD

Adjustment for Elevation (-0.05 per 300m above 1500m) = 0

EAF = 1 (0.85-1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = 0.55 (0.40- 1.00)

PMP VALUES (mm)

Duration (hours)	Initial Depth - Smooth (D_s)	Initial Depth - Rough (D_r)	PMP Estimate (D_SxS+D_RxR)xMAFxEAF)	Rounded PMP Estimate (nearest 10mm)
0.25	235	0	129	130
0.50	335	0	184	180
0.75	425	0	234	230
1.0	490	0	270	270
1.5	565	0	311	310
2.0	630	0	347	350
2.5	670	0	369	370
3.0	705	0	388	390
4.0	765	0	N.A.	N.A.

A.3 Catchment C (MD8146/8147)

GSDM CALCULATION SHEET - KMWHAC Ballan Township MD 8146/8147

LOCATION INFORMATION

Catchment:	Ballan township ï MD8146/8147		Area:	4.5	km^2
State:	Victoria		Duration Limit:	3	hrs
Latitude:	37.60	°S	144.23	°E	
Proportion of Area Considered:					
Smooth, **S** =	1.00	(0.0-1.0)	Rough, **R** =	0.0	(0-1)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 510 m AHD

Adjustment for Elevation (-0.05 per 300m above 1500m) = 0

EAF = 1 (0.85-1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = 0.55 (0.40- 1.00)

PMP VALUES (mm)

Duration (hours)	Initial Depth - Smooth (D_s)	Initial Depth - Rough (D_r)	PMP Estimate (DSxS+DRxR)xMAFxEAF)	Rounded PMP Estimate (nearest 10mm)
0.25	220	0	121	120
0.50	325	0	179	180
0.75	410	0	226	230
1.0	480	0	264	260
1.5	545	0	300	300
2.0	610	0	336	340
2.5	650	0	358	360
3.0	680	0	374	370
4.0	750	0	N.A.	N.A.

Appendix B RORB Sub-catchment Values and Channel Reaches

B.1 Catchment A (MD8143)

Sub-area details

Sub-area	Area (km^2)	Frac. Imperv.
A	0.110	0.189
B	0.238	0.077
C	0.337	0.054
D	0.161	0.2
E	0.131	0.191
F	0.136	0.2
G	0.159	0.201
H	0.118	0.232
I	0.073	0.216
J	0.133	0.245
K	0.112	0.059
L	0.119	0.05
M	0.067	0.073
N	0.151	0.103
O	0.119	0.096
P	0.120	0.109
Q	0.118	0.687
R	0.055	0.666
S	0.124	0.508
T	0.094	0.32
U	0.052	0.481
V	0.047	0.461
W	0.032	0.42
X	0.025	0.357
Y	0.050	0.11
TOTAL	2.881	--
Average	0.115	--

Reach details

Reach	Length (m)	Slope (%)
A-A1	0.215	natural
A1-B1	0.185	natural
B-B1	0.358	natural
B1-E1	0.433	1.78
C-C1	0.66	natural
C1-E1	0.584	natural
D1-E1	0.393	natural
E-E1	0.31	natural
E1-I1	0.451	1.74
F-F1	0.31	natural
F1-I1	0.388	natural
G-I1	0.453	natural
H-I1	0.331	natural
I-I1	0.249	natural
I1-P1	0.273	2.33
J-J1	0.171	natural
J1-K1	0.33	natural
K-K1	0.249	natural
K1-M1	0.311	natural
L-M1	0.308	natural
M-M1	0.28	natural
M1-P1	0.337	natural
N-O1	0.413	natural
O-O1	0.292	natural
O1-P1	0.142	natural
P-P1	0.241	natural
P1-R1	0.162	1.85
Q-R1	0.291	natural
R-R1	0.279	natural
R1-U1	0.195	1.79
S-S1	0.303	natural
S1-U1	0.294	natural
T-U1	0.346	natural
U-U1	0.184	natural
U1-V1	0.102	2.75
V-V1	0.226	Natural
V1-X1	0.109	1.01
W-X1	0.164	natural
X-X1	0.102	natural
X1-Y1	0.132	4.39
Y-Y1	0.093	natural
Y1-out	0.075	0.40

B.2 Catchment B (MD8144/8145)

Sub-area details

Sub-area	Area (km^2)	Frac. Imperv.
A	0.125	0.747
B	0.132	0.579
C	0.164	0.188
D	0.05	0.076
E	0.065	0.176
F	0.089	0.197
G	0.155	0.085
H	0.175	0.223
I	0.225	0.05
J	0.129	0.05
K	0.189	0.05
L	0.202	0.05
M	0.185	0.05
N	0.222	0.222
O	0.102	0.117
P	0.068	0.149
Q	0.041	0.474
R	0.027	0.45
S	0.073	0.221
T	0.015	0.45
U	0.049	0.451
V	0.029	0.45
W	0.016	0.45
X	0.072	0.133
Y	0.014	0.45
Z	0.053	0.45
AA	0.028	0.45
AB	0.021	0.45
AC	0.057	0.3
AD	0.015	0.492
AE	0.023	0.507
AF	0.061	0.194
AG	0.037	0.427
AH	0.011	0.492
AI	0.028	0.49
AJ	0.02	0.479
AK	0.014	0.451
AL	0.011	0.422
AM	0.022	0.501
TOTAL	3.014	--
Average	0.077	--

Reach details

Reach	Length (m)	Slope (%)
A-A1	0.278	natural
A1-B1	0.231	natural
B-B1	0.228	natural
B1-E1	0.106	natural
C-C1	0.252	natural
C1-E1	0.317	natural
D-E1	0.163	natural
E-E1	0.292	natural
E1-G2	0.09	natural
F-G1	0.151	natural
G-G1	0.356	natural
G1-G2	0.211	natural
G2-H1	0.161	natural
H-H1	0.292	natural
H1-R1	0.178	natural
I-I1	0.334	natural
I1-K1	0.469	natural
J-K1	0.358	natural
K-K1	0.421	natural
K1-O1	0.345	natural
L-L1	0.511	natural
L1-M1	0.476	natural
M-M1	0.308	natural
M1-01	0.362	natural
N-01	0.406	natural
O-O1	0.193	natural
O1-P1	0.222	natural
P-P1	0.104	natural
P1-Q1	0.242	0.68
Q-Q1	0.125	natural
Q1-R1	0.087	0.02
R-R1	0.109	natural
R1-S1	0.12	0.83
S-S1	0.16	natural
S1-Z1	0.171	0.714
T-T1	0.111	natural
T1-U1	0.194	natural
U-U1	0.122	natural
U1-W1	0.136	natural
Reach	Length (m)	Slope (%)
V-W1	0.135	natural
W-W1	0.093	natural
W1-Z1	0.195	natural
X-X1	0.222	natural
X1-Z1	0.243	natural
Y-Z1	0.066	natural
Z-Z1	0.153	natural
Z1-AB1	0.149	1.63
AA-AA1	0.131	natural
AA1-AB1	0.146	natural

AB-AB1	0.083	natural
AB1-AE1	0.07	1
AC-AC1	0.217	natural
AC1-AE1	0.231	natural
AD-AE1	0.074	natural
AE-AE1	0.123	natural
AE1-AH1	0.146	1.54
AF-AF1	0.189	natural
AF1-AH1	0.193	natural
AG-AH1	0.112	natural
AH-AH1	0.08	natural
AH1-AK1	0.1	3
AI-AI1	0.126	natural
AI1-AJ1	0.178	natural
AJ-AJ1	0.148	natural
AJ-AJ1	0.148	natural
AJ1-AK1	0.127	natural
AK-AK1	0.106	natural
AK1-out	0.161	3.5
AL-out	0.114	natural
AM-out	0.161	natural
AJ-AJ1	0.148	natural
AJ1-AK1	0.127	natural
AK-AK1	0.106	natural
AK1-out	0.161	3.5
AL-out	0.114	natural
AM-out	0.161	natural

B.3 MD 8146/8147 (Catchment CB)

Sub-area details

Sub-area	Area (km^2)	Frac. Imperv.
A	0.317	0.109
B	0.239	0.089
C	0.334	0.05
D	0.157	0.102
E	0.155	0.182
F	0.218	0.117
G	0.675	0.05
H	0.335	0.05
I	0.193	0.05
J	0.087	0.05
K	0.049	0.06
L	0.057	0.074
M	0.122	0.05
N	0.101	0.05
O	0.039	0.05
P	0.113	0.05
Q	0.036	0.05
R	0.066	0.188
S	0.047	0.102
T	0.068	0.298
U	0.074	0.459
V	0.327	0.397
W	0.228	0.483
X	0.027	0.487
Y	0.086	0.47
Z	0.065	0.416
AA	0.189	0.275
AB	0.095	0.222
TOTAL	3.014	--
Average	0.077	--

Reach details

Reach	Length (m)	Slope (%)
A-A1	0.506	natural
A1-B1	0.537	natural
B-B1	0.537	natural
B1-D1	0.219	natural
C-C1	0.332	natural
C1-D1	0.528	natural
D-D1	0.335	natural
D1-F1	0.213	natural
E1-F1	0.686	natural
F-F1	0.301	natural
F1-J1	0.181	0.43
G-G1	0.42	natural
G1-H1	0.552	1.36
H-H1	0.358	natural
H1-I1	0.315	1.14
I-I1	0.262	natural
I1-J1	0.246	0.89
J-J1	0.119	natural
J1-L1	0.284	0.63
K-L1	0.2	natural
L-L1	1	0.177
L1-X1	0.234	1.15
M-M1	0.259	natural
M1-N1	0.227	natural
N-N1	0.194	natural
Reach	**Length (m)**	**Slope (%)**
N1-Q1	0.251	natural
O-O1	0.17	natural
O1-Q1	0.195	natural
P-Q1	0.228	natural
Q-Q1	0.141	natural
Q1-S1	0.156	0.64
R-S1	0.254	natural
S-S1	0.135	natural
S1-T1	0.091	1.26
T-T1	0.187	natural
T1-U1	0.197	1.32
U-U1	0.106	natural
U1-X1	0.161	0.68
V-V1	0.296	natural
V1-X1	0.383	natural
W-X1	0.256	natural
X-X1	0.126	natural
X1-Z1	0.297	0.97
Y-Y1	0.161	natural
Y1-Z1	0.209	natural
Z-Z1	0.12	natural
Z1-AB1	0.083	1.36
AA-AA1	0.392	natural
AA1-AB1	0.458	natural

AB-AB1	0.288	natural
AB1-out	0.185	1.3

Appendix C RORB Catchment file (*.cat/*.catg)

C.1 MD 8143 (Catchment A)

```
0
1, 1, .215,  -99  ,  Reach 1 node 1      Sub-area A, Reach A-A1 Rainfall excess h'graph and route d.s.
5, 1, .185,  -99  ,  Reach 2           Reach A1-B1 - Route running h'graph downstream
3  ,                          Store running hydrograph
1, 1, .358,  -99  ,  Reach 3 node 4      Sub-area B, Reach B-B1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
5, 2, .433, 1.780,  -99  ,  Reach 4      Reach B1-E1 - Route running h'graph downstream
3  ,                          Store running hydrograph
1, 1, .660,  -99  ,  Reach 5 node 6      Sub-area C, Reach C-C1 Rainfall excess h'graph and route d.s.
5, 1, .584,  -99  ,  Reach 6           Reach C1-E1 - Route running h'graph downstream
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .393,  -99  ,  Reach 7 node 8      Sub-area D, Reach D1-E1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .310,  -99  ,  Reach 8 node 9      Sub-area E, Reach E-E1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
7  ,                          PRINT
F1
5, 2, .451, 1.740,  -99  ,  Reach 9      Reach E1-I1 - Route running h'graph downstream
3  ,                          Store running hydrograph
1, 1, .310,  -99  ,  Reach 10 node 11   Sub-area F, Reach F-F1 Rainfall excess h'graph and route d.s.
5, 1, .388,  -99  ,  Reach 11          Reach F1-I1 - Route running h'graph downstream
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .453,  -99  ,  Reach 12 node 13   Sub-area G, Reach G-I1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .331,  -99  ,  Reach 13 node 14   Sub-area H, Reach H-I1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .249,  -99  ,  Reach 14 node 15   Sub-area I, Reach I-I1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
7  ,                          PRINT
I1
5, 2, .273, 2.330,  -99  ,  Reach 15     Reach I1-P1 - Route running h'graph downstream
3  ,                          Store running hydrograph
1, 1, .171,  -99  ,  Reach 16 node 17   Sub-area J, Reach J-J1 Rainfall excess h'graph and route d.s.
5, 1, .330,  -99  ,  Reach 17          Reach J1-K1 - Route running h'graph downstream
3  ,                          Store running hydrograph
1, 1, .249,  -99  ,  Reach 18 node 20   Sub-area K, Reach K-K1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
5, 1, .311,  -99  ,  Reach 19          Reach K1-M1 - Route running h'graph downstream
3  ,                          Store running hydrograph
1, 1, .308,  -99  ,  Reach 20 node 22   Sub-area L, Reach L-M1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .280,  -99  ,  Reach 21 node 23   Sub-area M, Reach M-M1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
5, 1, .337,  -99  ,  Reach 22          Reach M1-P1 - Route running h'graph downstream
4  ,                          Add running h'graph to last stored h'graph
3  ,                          Store running hydrograph
1, 1, .413,  -99  ,  Reach 23 node 24   Sub-area N, Reach N-O1 Rainfall excess h'graph and route d.s.
3  ,                          Store running hydrograph
1, 1, .292,  -99  ,  Reach 24 node 25   Sub-area O, Reach O-O1 Rainfall excess h'graph and route d.s.
4  ,                          Add running h'graph to last stored h'graph
```

```
5, 1, .142,  -99  ,  Reach 25           Reach O1-P1 - Route running h'graph downstream
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .241,  -99  ,  Reach 26 node 26    Sub-area P, Reach P-P1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
P1
5, 3, .162, 1.850,  -99  ,  Reach 27     Reach P1-R1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .291,  -99  ,  Reach 28 node 28    Sub-area Q, Reach Q-R1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .279,  -99  ,  Reach 29 node 29    Sub-area R, Reach R-R1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
R1
5, 2, .195, 1.790,  -99  ,  Reach 30     Reach R1-U1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .303,  -99  ,  Reach 31 node 31    Sub-area S, Reach S-S1 Rainfall excess h'graph and route d.s.
5, 1, .294,  -99  ,  Reach 32           Reach S1-U1 - Route running h'graph downstream
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .346,  -99  ,  Reach 33 node 33    Sub-area T, Reach T-U1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .184,  -99  ,  Reach 34 node 34    Sub-area U, Reach U-U1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
U1
5, 2, .102, 2.750,  -99  ,  Reach 35     Reach U1-V1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .226,  -99  ,  Reach 36 node 36    Sub-area V, Reach V-V1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
V1
5, 2, .109, 1.010,  -99  ,  Reach 37     Reach V1-X1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .164,  -99  ,  Reach 38 node 38    Sub-area W, Reach W-X1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .102,  -99  ,  Reach 39 node 39    Sub-area X, Reach X-X1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
X1
5, 2, .132, 4.390,  -99  ,  Reach 40     Reach X1-Y1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .093,  -99  ,  Reach 41 node 41    Sub-area Y, Reach Y-Y1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
Y1
5, 2, .075, .400,  -99  ,Reach 42        Reach Y1-out - Route running h'graph downstream
7.2  ,  PRINT
out
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
   0.110,   0.238,   0.337,   0.161,   0.131,   0.136,   0.159,   0.118,   0.073,   0.133,
   0.112,   0.119,   0.067,   0.151,   0.119,   0.120,   0.118,   0.055,   0.124,   0.094,
   0.052,   0.047,   0.032,   0.025,   0.050,  -99
C Impervious Fraction Data
 1 ,
   0.074,   0.003,   0.005,   0.064,   0.026,   0.040,   0.008,   0.062,   0.051,   0.108,
   0.022,   0.000,   0.082,   0.199,   0.025,   0.019,   0.266,   0.295,   0.030,   0.244,
   0.180,   0.292,   0.168,   0.221,   0.020,  -99
```

C.2 MD8144/8145 (Catchment B)

```
0
1, 1, .278,  -99  ,  Reach 17 node 60    Sub-area A, Reach A-A1 Rainfall excess h'graph and route d.s.
7  ,                              PRINT
A
5, 1, .231,  -99  ,  Reach 18            Reach A1-B1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .228,  -99  ,  Reach 19 node 59    Sub-area B, Reach B-B1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
B
5, 1, .106,  -99  ,  Reach 20            Reach B1-E1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .252,  -99  ,  Reach 21 node 61    Sub-area C, Reach C-C1 Rainfall excess h'graph and route d.s.
5, 1, .317,  -99  ,  Reach 22            Reach C1-E1 - Route running h'graph downstream
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .163,  -99  ,  Reach 24 node 56    Sub-area D, Reach D-E1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .292,  -99  ,  Reach 23 node 58    Sub-area E, Reach E-E1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
E1
5, 1, .090,  -99  ,  Reach 25            Reach E1-G2 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .151,  -99  ,  Reach 27 node 55    Sub-area F, Reach F-G1 Rainfall excess h'graph and route d.s.
3  ,                              Store running hydrograph
1, 1, .356,  -99  ,  Reach 26 node 57    Sub-area G, Reach G-G1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
5, 1, .211,  -99  ,  Reach 28            Reach G1-G2 - Route running h'graph downstream
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
G1
5, 1, .161,  -99  ,  Reach 29            Reach G2-H1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .292,  -99  ,  Reach 30 node 53    Sub-area H, Reach H-H1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
7  ,                              PRINT
H1
5, 1, .178,  -99  ,  Reach 31            Reach H1-R1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .334,  -99  ,  Reach 5 node 66     Sub-area I, Reach I-I1 Rainfall excess h'graph and route d.s.
5, 1, .469,  -99  ,  Reach 6             Reach I1-K1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .358,  -99  ,  Reach 8 node 64     Sub-area J, Reach J-K1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .421,  -99  ,  Reach 7 node 65     Sub-area K, Reach K-K1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
5, 1, .345,  -99  ,  Reach 9             Reach K1-O1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .511,  -99  ,  Reach 1 node 67     Sub-area L, Reach L-L1 Rainfall excess h'graph and route d.s.
5, 1, .476,  -99  ,  Reach 2             Reach L1-M1 - Route running h'graph downstream
3  ,                              Store running hydrograph
1, 1, .308,  -99  ,  Reach 3 node 68     Sub-area M, Reach M-M1 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
5, 1, .362,  -99  ,  Reach 4             Reach M1-01 - Route running h'graph downstream
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .406,  -99  ,  Reach 10 node 62    Sub-area N, Reach N-01 Rainfall excess h'graph and route d.s.
4  ,                              Add running h'graph to last stored h'graph
3  ,                              Store running hydrograph
1, 1, .193,  -99  ,  Reach 11 node 63    Sub-area O, Reach O-O1 Rainfall excess h'graph and route d.s.
```

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4 ,                           Add running h'graph to last stored h'graph
5, 1, .222,  -99  ,  Reach 12         Reach O1-P1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .104,  -99  ,  Reach 13 node 54    Sub-area P, Reach P-P1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
7 ,                           PRINT
P1
5, 2, .242, .680,  -99  ,Reach 14       Reach P1-Q1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .125,  -99  ,  Reach 15 node 52    Sub-area Q, Reach Q-Q1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
7 ,                           PRINT
Q1
5, 2, .087, .020,  -99  ,Reach 16       Reach Q1-R1 - Route running h'graph downstream
4 ,                           Add running h'graph to last stored h'graph
3 ,                           Store running hydrograph
1, 1, .109,  -99  ,  Reach 32 node 30    Sub-area R, Reach R-R1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
7 ,                           PRINT
R1
5, 2, .120, .830,  -99  ,Reach 33       Reach R1-S1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .160,  -99  ,  Reach 34 node 51    Sub-area S, Reach S-S1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
7 ,                           PRINT
S1
5, 2, .171, .714,  -99  ,Reach 35       Reach S1-Z1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .111,  -99  ,  Reach 36 node 49    Sub-area T, Reach T-T1 Rainfall excess h'graph and route d.s.
5, 1, .194,  -99  ,  Reach 37         Reach T1-U1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .122,  -99  ,  Reach 38 node 50    Sub-area U, Reach U-U1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
5, 1, .136,  -99  ,  Reach 39         Reach U1-W1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .135,  -99  ,  Reach 40 node 44    Sub-area V, Reach V-W1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
3 ,                           Store running hydrograph
1, 1, .093,  -99  ,  Reach 41 node 45    Sub-area W, Reach W-W1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
5, 1, .195,  -99  ,  Reach 42         Reach W1-Z1 - Route running h'graph downstream
4 ,                           Add running h'graph to last stored h'graph
3 ,                           Store running hydrograph
1, 1, .222,  -99  ,  Reach 43 node 48    Sub-area X, Reach X-X1 Rainfall excess h'graph and route d.s.
5, 1, .243,  -99  ,  Reach 44         Reach X1-Z1 - Route running h'graph downstream
4 ,                           Add running h'graph to last stored h'graph
3 ,                           Store running hydrograph
1, 1, .066,  -99  ,  Reach 46 node 46    Sub-area Y, Reach Y-Z1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
3 ,                           Store running hydrograph
1, 1, .153,  -99  ,  Reach 45 node 47    Sub-area Z, Reach Z-Z1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
7 ,                           PRINT
Z1
5, 2, .149, 1.630,  -99  ,  Reach 47     Reach Z1-AB1 - Route running h'graph downstream
3 ,                           Store running hydrograph
1, 1, .131,  -99  ,  Reach 48 node 43    Sub-area AA, Reach AA-AA1 Rainfall excess h'graph and route d.s.
5, 1, .146,  -99  ,  Reach 49         Reach AA1-AB1 - Route running h'graph downstream
4 ,                           Add running h'graph to last stored h'graph
3 ,                           Store running hydrograph
1, 1, .083,  -99  ,  Reach 50 node 42    Sub-area AB, Reach AB-AB1 Rainfall excess h'graph and route d.s.
4 ,                           Add running h'graph to last stored h'graph
7 ,                           PRINT
AB1
5, 2, .070, 1.000,  -99  ,  Reach 51     Reach AB1-AE1 - Route running h'graph downstream
3 ,                           Store running hydrograph
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1, 1, .217,  -99  ,  Reach 52 node 41    Sub-area AC, Reach AC-AC1 Rainfall excess h'graph and route d.s.
5, 1, .231,  -99  ,  Reach 53            Reach AC1-AE1 - Route running h'graph downstream
4  ,                            Add running h'graph to last stored h'graph
3  ,                            Store running hydrograph
1, 1, .074,  -99  ,  Reach 55 node 39    Sub-area AD, Reach AD-AE1 Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
3  ,                            Store running hydrograph
1, 1, .123,  -99  ,  Reach 54 node 40    Sub-area AE, Reach AE-AE1 Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
7  ,                            PRINT
AE1
5, 2, .146, 1.540,  -99  ,  Reach 56     Reach AE1-AH1 - Route running h'graph downstream
3  ,                            Store running hydrograph
1, 1, .189,  -99  ,  Reach 57 node 37    Sub-area AF, Reach AF-AF1 Rainfall excess h'graph and route d.s.
5, 1, .193,  -99  ,  Reach 58            Reach AF1-AH1 - Route running h'graph downstream
4  ,                            Add running h'graph to last stored h'graph
3  ,                            Store running hydrograph
1, 1, .112,  -99  ,  Reach 59 node 35    Sub-area AG, Reach AG-AH1 Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
3  ,                            Store running hydrograph
1, 1, .080,  -99  ,  Reach 60 node 36    Sub-area AH, Reach AH-AH1 Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
7  ,                            PRINT
AH1
5, 2, .100, 3.000,  -99  ,  Reach 61     Reach AH1-AK1 - Route running h'graph downstream
3  ,                            Store running hydrograph
1, 1, .126,  -99  ,  Reach 62 node 38    Sub-area AI, Reach AI-AI1 Rainfall excess h'graph and route d.s.
5, 1, .178,  -99  ,  Reach 63            Reach AI1-AJ1 - Route running h'graph downstream
3  ,                            Store running hydrograph
1, 1, .148,  -99  ,  Reach 64 node 33    Sub-area AJ, Reach AJ-AJ1 Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
5, 1, .127,  -99  ,  Reach 65            Reach AJ1-AK1 - Route running h'graph downstream
4  ,                            Add running h'graph to last stored h'graph
3  ,                            Store running hydrograph
1, 1, .106,  -99  ,  Reach 66 node 34    Sub-area AK, Reach AK-AK1 Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
7  ,                            PRINT
AK1
5, 2, .161, 3.500,  -99  ,  Reach 67     Reach AK1-out - Route running h'graph downstream
3  ,                            Store running hydrograph
1, 1, .114,  -99  ,  Reach 69 node 31    Sub-area AL, Reach AL-out Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
3  ,                            Store running hydrograph
1, 1, .161,  -99  ,  Reach 68 node 32    Sub-area AM, Reach AM-out Rainfall excess h'graph and route d.s.
4  ,                            Add running h'graph to last stored h'graph
7.2  ,                          PRINT
out
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
  0.125,   0.132,   0.163,   0.050,   0.065,   0.089,   0.155,   0.175,   0.225,   0.129,
  0.189,   0.202,   0.185,   0.222,   0.102,   0.068,   0.041,   0.027,   0.073,   0.015,
  0.049,   0.029,   0.015,   0.072,   0.014,   0.053,   0.028,   0.021,   0.057,   0.015,
  0.023,   0.061,   0.037,   0.011,   0.028,   0.020,   0.014,   0.011,   0.022,  -99
C Impervious Fraction Data
 1 ,
  0.110,   0.132,   0.005,   0.093,   0.016,   0.096,   0.006,   0.053,   0.020,   0.028,
  0.005,   0.005,   0.048,   0.015,   0.011,   0.094,   0.049,   0.274,   0.085,   0.309,
  0.390,   0.412,   0.360,   0.061,   0.138,   0.205,   0.066,   0.258,   0.058,   0.363,
  0.368,   0.030,   0.321,   0.157,   0.356,   0.300,   0.281,   0.136,   0.112,  -99
```

C.3 MD 8146/8147 (Catchment C)

```
0
1, 1, .506,  -99  ,  Reach 1 node 1      Sub-area A, Reach A-A1 Rainfall excess h'graph and route d.s.
5, 1, .537,  -99  ,  Reach 2             Reach A1-B1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .537,  -99  ,  Reach 3 node 2      Sub-area B, Reach B-B1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
5, 1, .219,  -99  ,  Reach 4             Reach B1-D1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .332,  -99  ,  Reach 5 node 3      Sub-area C, Reach C-C1 Rainfall excess h'graph and route d.s.
5, 1, .528,  -99  ,  Reach 6             Reach C1-D1 - Route running h'graph downstream
4  ,                         Add running h'graph to last stored h'graph
3  ,                         Store running hydrograph
1, 1, .335,  -99  ,  Reach 7 node 4      Sub-area D, Reach D-D1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
5, 1, .213,  -99  ,  Reach 8             Reach D1-F1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .686,  -99  ,  Reach 9 node 5      Sub-area E, Reach E1-F1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
3  ,                         Store running hydrograph
1, 1, .301,  -99  ,  Reach 10 node 6     Sub-area F, Reach F-F1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
5, 2, .181, .430,  -99  ,Reach 11        Reach F1-J1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .420,  -99  ,  Reach 12 node 7     Sub-area G, Reach G-G1 Rainfall excess h'graph and route d.s.
7  ,                         PRINT
G1
5, 2, .552, 1.360,  -99  ,  Reach 13     Reach G1-H1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .358,  -99  ,  Reach 14 node 8     Sub-area H, Reach H-H1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
7  ,                         PRINT
H1
5, 2, .315, 1.140,  -99  ,  Reach 15     Reach H1-I1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .262,  -99  ,  Reach 16 node 9     Sub-area I, Reach I-I1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
7  ,                         PRINT
I1
5, 2, .246, .890,  -99  ,Reach 17        Reach I1-J1 - Route running h'graph downstream
4  ,                         Add running h'graph to last stored h'graph
3  ,                         Store running hydrograph
1, 1, .119,  -99  ,  Reach 18 node 10    Sub-area J, Reach J-J1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
7  ,                         PRINT
J1
5, 2, .284, .630,  -99  ,Reach 19        Reach J1-L1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .200,  -99  ,  Reach 20 node 11    Sub-area K, Reach K-L1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
3  ,                         Store running hydrograph
1, 1, 1.000,  -99  ,Reach 21 node 12     Sub-area L, Reach L-L1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
7  ,                         PRINT
K1
5, 2, .234, 1.150,  -99  ,  Reach 22     Reach L1-X1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .259,  -99  ,  Reach 23 node 13    Sub-area M, Reach M-M1 Rainfall excess h'graph and route d.s.
5, 1, .227,  -99  ,  Reach 24            Reach M1-N1 - Route running h'graph downstream
3  ,                         Store running hydrograph
1, 1, .194,  -99  ,  Reach 25 node 14    Sub-area N, Reach N-N1 Rainfall excess h'graph and route d.s.
4  ,                         Add running h'graph to last stored h'graph
5, 1, .251,  -99  ,  Reach 26            Reach N1-Q1 - Route running h'graph downstream
3  ,                         Store running hydrograph
```

```
1, 1, .170,  -99  ,  Reach 27 node 15    Sub-area O, Reach O-O1 Rainfall excess h'graph and route d.s.
5, 1, .195,  -99  ,  Reach 28            Reach O1-Q1 - Route running h'graph downstream
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .228,  -99  ,  Reach 29 node 16    Sub-area P, Reach P-Q1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .141,  -99  ,  Reach 30 node 17    Sub-area Q, Reach Q-Q1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
5, 2, .156, .640,  -99  ,Reach 31        Reach Q1-S1 - Route running h'graph downstream
3  ,                       Store running hydrograph
1, 1, .254,  -99  ,  Reach 32 node 18    Sub-area R, Reach R-S1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .135,  -99  ,  Reach 33 node 19    Sub-area S, Reach S-S1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
5, 2, .091, 1.260,  -99  ,  Reach 34     Reach S1-T1 - Route running h'graph downstream
3  ,                       Store running hydrograph
1, 1, .187,  -99  ,  Reach 35 node 20    Sub-area T, Reach T-T1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
5, 2, .197, 1.320,  -99  ,  Reach 36     Reach T1-U1 - Route running h'graph downstream
3  ,                       Store running hydrograph
1, 1, .106,  -99  ,  Reach 37 node 21    Sub-area U, Reach U-U1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
5, 2, .161, .680,  -99  ,Reach 38        Reach U1-X1 - Route running h'graph downstream
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .296,  -99  ,  Reach 39 node 22    Sub-area V, Reach V-V1 Rainfall excess h'graph and route d.s.
5, 1, .383,  -99  ,  Reach 40            Reach V1-X1 - Route running h'graph downstream
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .256,  -99  ,  Reach 41 node 23    Sub-area W, Reach W-X1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .126,  -99  ,  Reach 42 node 24    Sub-area X, Reach X-X1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
7  ,                       PRINT
X1
5, 2, .297, .970,  -99  ,Reach 43        Reach X1-Z1 - Route running h'graph downstream
3  ,                       Store running hydrograph
1, 1, .161,  -99  ,  Reach 44 node 25    Sub-area Y, Reach Y-Y1 Rainfall excess h'graph and route d.s.
5, 1, .209,  -99  ,  Reach 45            Reach Y1-Z1 - Route running h'graph downstream
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .120,  -99  ,  Reach 46 node 26    Sub-area Z, Reach Z-Z1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
7  ,                       PRINT
Z1
5, 3, .083, 1.360,  -99  ,  Reach 47     Reach Z1-AB1 - Route running h'graph downstream
3  ,                       Store running hydrograph
1, 1, .392,  -99  ,  Reach 48 node 27    Sub-area AA, Reach AA-AA1 Rainfall excess h'graph and route d.s.
5, 1, .458,  -99  ,  Reach 49            Reach AA1-AB1 - Route running h'graph downstream
4  ,                       Add running h'graph to last stored h'graph
3  ,                       Store running hydrograph
1, 1, .288,  -99  ,  Reach 50 node 28    Sub-area AB, Reach AB-AB1 Rainfall excess h'graph and route d.s.
4  ,                       Add running h'graph to last stored h'graph
7  ,                       PRINT
AB1
5, 2, .185, 1.300,  -99  ,  Reach 51     Reach AB1-out - Route running h'graph downstream
7  ,                       PRINT
out
0
C Sub Area Data
C Areas, km**2, of subareas A,B...
  0.317,   0.239,   0.334,   0.157,   0.155,   0.218,   0.675,   0.335,   0.193,   0.087,
  0.049,   0.057,   0.122,   0.101,   0.039,   0.113,   0.036,   0.066,   0.047,   0.068,
```

```
  0.074,    0.327,    0.228,    0.027,    0.086,    0.065,    0.189,    0.095,  -99
C Impervious Fraction Data
 1 ,
  0.200,    0.015,    0.017,    0.022,    0.032,    0.019,    0.010,    0.004,    0.022,    0.014,
  0.000,    0.024,    0.024,    0.020,    0.047,    0.077,    0.007,    0.129,    0.032,    0.280,
  0.080,    0.129,    0.110,    0.208,    0.000,    0.134,    0.036,    0.020,  -99
```

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