Floodplain Risk Management Study

APPENDIX A
COMMUNITY CONSULTATION BROCHURE AND QUESTIONNAIRE

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Floodplain Risk Management Options

The following list of Floodplain Risk Management options presents some preliminary strategies that could be considered to minimise the risk and reduce the impact of flooding throughout the Kangaroo Valley catchment. These options will be considered in further detail during the preparation of the Management Study and Plan.

Examples of Flood Management Options	
	Description
Flood Modification Options	• Construction of levees where properties are most at risk • Upgrading of drainage systems i.e. construction of detention/retarding basins • Stabilisation works along drainage channels
Property Modification and Planning Control Options	• Building and development controls • Voluntary house raising program (for selected properties) • Voluntary house rebuilding subsidy scheme (for selected properties) • Voluntary property purchase program (for selected properties).
Emergency Response Modification Options	• Revision of the Local Disaster Plan (DISPLAN) • Public awareness and education—locality based flooding information for residents • Public awareness and education—flooding information for schools • Flood depth markers at major (flood affected) road crossings • Continuation of existing public awareness and education campaigns • Data collection strategies for future floods

Consultation

During the Floodplain Risk Management Study and Plan process, consultation will be undertaken with the community in order to establish a comprehensive list of management options.

Interested members of the community are invited to forward any comments or suggestions for other floodplain management measures which may be worthy of consideration at this early stage of the process. Comments can be submitted in writing by no later than 26 October 2012 to:

General Manager, Shoalhaven City Council
PO Box 42 Nowra NSW 2541
or via email at: council@shoalhaven.nsw.gov.au

You will have further opportunities to comment on the direction of the project during the public exhibition periods of the Draft Risk Management Study and Plan. Any comments received during these periods will be taken into account before finalisation of the project.

For further information regarding this project please contact either Shoalhaven City Council or Cardno via the details below.

Contact Us

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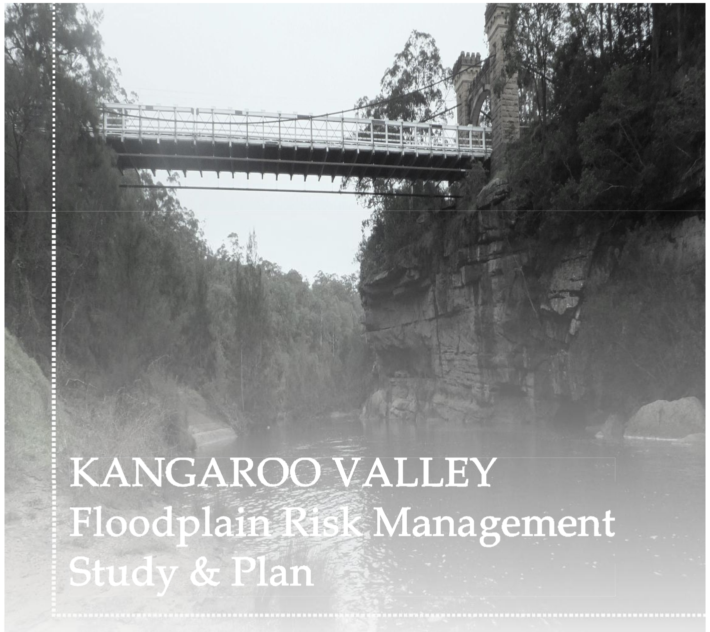


KANGAROO VALLEY Floodplain Risk Management Study & Plan

Information Brochure

Shoalhaven City Council has engaged Cardno to assist with the preparation of the Kangaroo Valley Floodplain Risk Management Study and Plan.

The Risk Management Study and Plan follows from the Flood Study, completed in 2009, which identified the existing flooding behaviour in the Kangaroo Valley catchment. The purpose of this Risk Management Study and Plan is to identify and recommend appropriate actions to manage flood risks in the Kangaroo Valley catchment.

This brochure provides an introduction to the Risk Management Study and Plan and informs you of its objectives.

prepared for Shoalhaven City Council

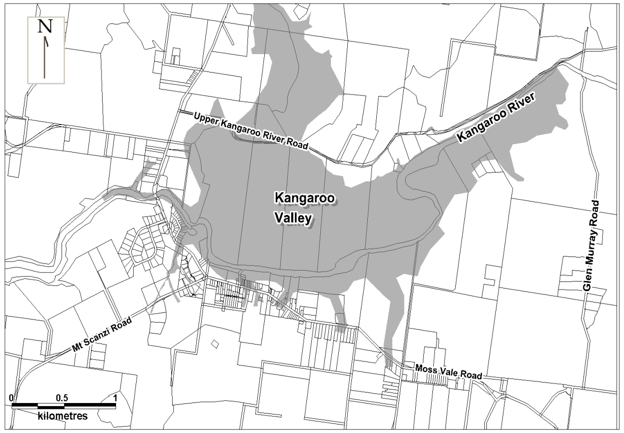
prepared by Cardno Shaping the Future

Formation of a Committee → Data Collection → Flood Study → Floodplain Risk Management Study → Floodplain Risk Management Plan → Implementation of Plan

Existing Flooding Issues

The township of Kangaroo Valley has experienced significant flooding in the past including 1975, 1978, 1990, 1991, 1999 and 2005.

The expected flood extents for the 1 in 100 year event is shown below.



100 year ARI

Flood durations have ranged from several hours to several days resulting in local roads being closed off by flood waters including Moss Vale Road, Glen Murray Road and Walkers Lane.

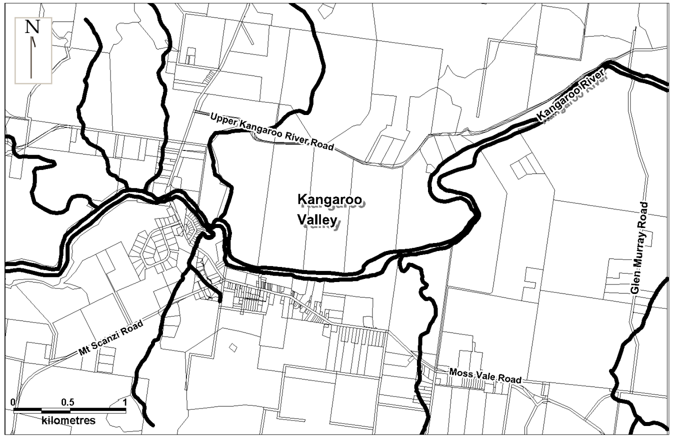
Numerous properties have been flood affected with some experiencing flooding above floor level.

Study Area

The study area comprises the Kangaroo River and its floodplain in and around the township of Kangaroo Valley including Barrengarry Creek, Nugents Creek, Sawyers Creek, Jaretts Lane Creek (Caravan Park Creek) and Myrtle Creek.

The catchment comprises rugged mountainous terrain with alluvial flats used for pasture and dairy farming.

The Kangaroo River rises within the Budderoo National Park, through the Budderoo Plateau and Kangaroo Valley into Morton National Park. The river ends by flowing into Lake Yarrunga formed by the Tallowa Dam.



Watercourses

Floodplain Management Process

Council's Floodplain Risk Management Committee (the Committee) oversees the Floodplain Management process. The Committee meets regularly and includes representatives from Council, Office of Environment and Heritage (OEH), State Emergency Service (SES), Catchment Management Authority (CMA), and representatives of the local community.

Floodplain Risk Management Study and Plan Objectives

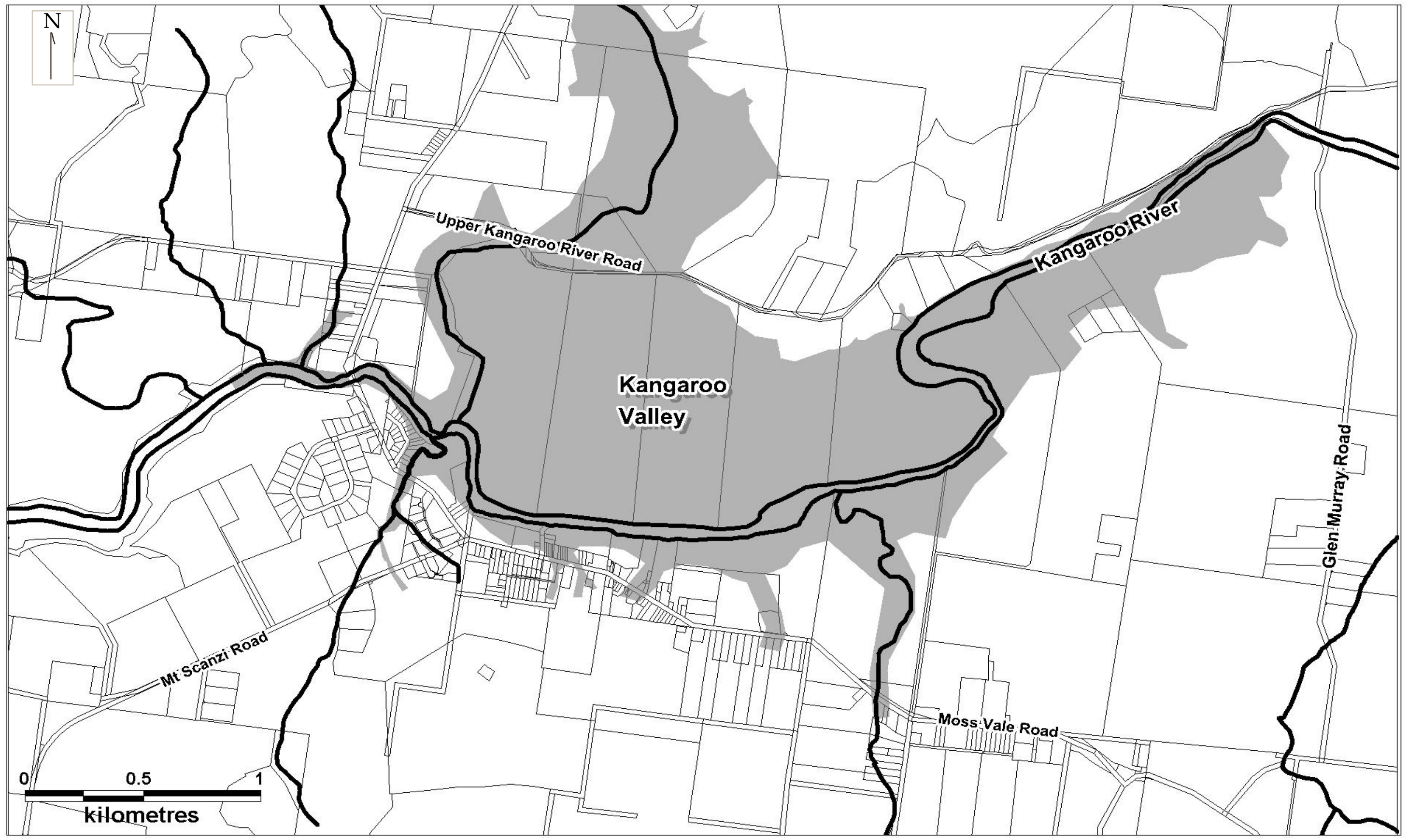
The objectives of the study and plan are:

Floodplain Risk Management Study

Find an appropriate mix of management measures and strategies to effectively manage the full range of flood risk in accordance with the NSW Government Floodplain Development Manual (2005) through an effective public participation and community consultation program. The information from this study will enable Council to formulate a Floodplain Risk Management Plan for the study area.

Floodplain Risk Management Plan:

Formulate a cost effective plan for the study area based on the findings of the Floodplain Risk Management Study and provide a priority program for implementation of the recommended works and measures in accordance with the Manual. The plan will detail how the existing and future flood risk within the study area will be managed.



100 year ARI — Watercourses

If you have any further comments that relate to the Kangaroo Valley Floodplain Risk Management Study and Plan, please express them in the space below. Please feel free to attach additional pages if necessary.

....

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Thank you for providing the above information. Please remember to return the completed survey in the reply paid envelope by 26th October 2012.
A representative from Cardno may contact you in the near future to discuss your response.

Glossary

Culvert – a drain or covered channel that passes under a road or railroad.

Levee Banks – An embankment usually constructed from earth or concrete built along the banks of a river to help prevent overflow of its waters.

Retarding/Detention Basin - A naturally occurring or constructed depression in the land surface that detains stormwater runoff by allowing it to slowly drain out of the basin into the adjoining natural drainage line or creek.

Stormwater Harvesting - the collection, storage, treatment and use of stormwater runoff from urban areas.

YOUR PERSONAL INFORMATION WILL REMAIN CONFIDENTIAL

If you have any queries, please contact:

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SEPTEMBER 2012

KANGAROO VALLEY
Floodplain Risk Management Study & Plan
Local Resident/Business/Land Owner Survey

*Note: information supplied will remain completely confidential.

Q1. Could you please provide us with the following details? We may wish to contact you to discuss some of the information you have provided us.

Name: ....
Address: ....
....
Daytime Ph: ....
Email: ....

Q2. Is your property (please tick)

- ☐ Owner occupied
- ☐ Occupied by a tenant
- ☐ Business
  Operating hours:
- ☐ Other

Q3. What type of structure is your property/business? (please tick)

- ☐ Freestanding house
- ☐ Apartment/ dual occupancy
- ☐ Caravan/mobile home
- ☐ Other (Please Specify) ....

Q4. How long have you lived, worked and/or owned your property?

.... Years

Q5. How long have you lived in the Kangaroo Valley Study Area?

.... Years

Q6. How many people live/work at your property?

....

Q 7. Number of permanent residents at this address aged:

- ☐ 0 - 4 years
- ☐ 5 - 24 years
- ☐ 25 - 64 years
- ☐ 65+ years

prepared for Shoalhaven City Council — prepared by Cardno Shaping the Future

Our team appreciates the diverse effects of flooding – from its dynamic shaping of the environment through to its potential negative social and economic impact. With this knowledge we analyse and develop comprehensive plans.

Q 8. Have you ever experienced flooding since living/working in the Kangaroo Valley catchment? (please tick relevant boxes)

- ☐ Yes, floodwaters entered my house/business
- ☐ Yes, floodwaters entered my yard
- ☐ Yes, the road was flooded and I couldn't drive my car
- ☐ Yes, the creek broke its banks
- ☐ Yes, other parts of my neighbourhood were flooded
- ☐ No, I haven't experienced a flood (go to Q.11)

Q 9. If you have experienced a flood, how did the flooding affect you and your family/business? (please tick relevant boxes)

- ☐ Parts of my house/business building were damaged
- ☐ The contents of my house/business were damaged
- ☐ My garden, yard, and/or surrounding property were damaged
- ☐ My car(s) were damaged
- ☐ Other property was damaged (specify) ....
- ☐ I couldn't leave the house/business
- ☐ Family members/work mates couldn't leave/return to the house/business
- ☐ The flood disrupted my daily routine
- ☐ The flood affected me in other ways (specify) ....
- ☐ The flood didn't affect me

Q 10. Do you have any materials or photos you can provide to evidence the flooding you experienced? If yes, when did the flooding occur?

☐ Yes ☐ No

The flooding occurred on ....

Q 11. Do you think your property would be flooded sometime in the future? (please tick relevant boxes)

- ☐ No
- ☐ Yes, but only a small part of my yard
- ☐ Yes, most of my yard/outdoor areas of business could be flooded
- ☐ Yes, my house/office/business could flood over the floor

Q12. Where have you looked for information about flooding on your property? (please tick relevant boxes)

- ☐ Council's customer service centre
- ☐ Other information from Council (specify)..........
- ☐ Viewed a Property Planning (Section 149) Certificate
- ☐ Information from a real estate agent
- ☐ Information from relatives, friends, neighbours, or the previous owner
- ☐ Other information (specify)..........
- ☐ No information has been sought
- ☐ I do not believe my property is affected by flooding

If you answered yes to having looked for information on Council's website:

- ☐ What information have you looked for? (Please specify) ....
- ☐ Where were you able to find information? (Please specify) ....

Q13. As a local resident who may have witnessed flooding/drainage problems, you may have your own ideas on how to reduce flood risks. Which of the following management options would you prefer for the Kangaroo Valley catchment (1=least preferred, 5=most preferred)? Please also provide comments as to the location where you think the option might be suitable.

Proposed Option	Preference (please circle)	Location/Other Comments?
Stormwater harvesting, such as rainwater tanks	1 2 3 4 5	
Retarding or detention basins; these temporarily hold water and reduce peak flood flows	1 2 3 4 5	
Improved flood flow paths	1 2 3 4 5	
Culvert/ bridge/pipe enlarging	1 2 3 4 5	
Levee banks (note Glossary on next page)	1 2 3 4 5	
Diversion of creeks and channels	1 2 3 4 5	
Environmental channel improvements, including removal of weeds & bank stabilisation	1 2 3 4 5	
Planning and flood-related development controls	1 2 3 4 5	
Education of community, providing greater awareness of potential hazards	1 2 3 4 5	
Flood forecasting, flood warning, evacuation planning and emergency response	1 2 3 4 5	
Other (please specify any options you believe are suitable). Please attach extra pages for other suggestions	1 2 3 4 5	

Q14. What do you think are the best ways to get input and feedback from the local community about this project? (please tick relevant boxes)

- ☐ Council's website
- ☐ Emails from Council
- ☐ Council's Floodplain Management Committee
- ☐ Formal Council meetings
- ☐ Council's information page in the local paper
- ☐ Other articles in the local paper
- ☐ Information days in the local area
- ☐ Community meetings
- ☐ Mail outs to all residents/business owners in the study area

Q15. What is the main language spoken at home?

- ☐ English
- ☐ Other (specify)..........

APPENDIX B
FLOOD STUDY MODELLING

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B Flood Study Modelling

The SOBEK 1D/2D hydraulic model was used to define the flood behaviour in the Kangaroo Valley study area. The hydrological model XP-RAFTS was used to generate inflow hydrographs for the hydraulic model.

The intention of the SOBEK model is to provide a better definition of the flood behaviour from the previous MIKE11 model that was adopted. The 2D component of the model allows for a better definition of the overbank and floodplain flows. This is particularly important in the areas near the township, where there are both complicated local flows along local creeks (Town Creek, Myrtle Creek) as well as cross catchment flows which occur along the Kangaroo River.

B.1 Hydrological Model

B.1.1 Sub-Catchments

These sub-catchments were generally based on those from the previous modelling, with minor changes made to further discretise some of the larger catchments, and to better allow the transfer of flows to the 2D hydraulic model.

The subcatchment layout is shown in **Figure B-1**.

Details of the RAFTS subcatchments are provided in **Table B-1**, including the PERN value, which is discussed below.

Table B-1 RAFTS Sub-catchment Details

Catchment	Area (ha)	PERN Value	Impervious %	Slope (%)
KV_BG1	2431.2	0.119	0	0.01
KV_BG2	2008.7	0.109	0	3.81
KV_BG3	2322.3	0.091	0	5.37
KV_BG4	918.0	0.076	0	3
KV_BY1	2990.7	0.079	1.2	4.8
KV_BY2	1786.2	0.109	0	4.1
KV_BY3	1000.1	0.079	0	2.34
KV_BY4	381.6	0.064	0	1.79
KV_CV1	46.0	0.064	2	7.21
KV_DB1	1282.3	0.090	0	8.5
KV_GG1	3041.5	0.114	0	4.5
KV_KR1	2907.4	0.103	0	5
KV_KR2	2058.4	0.098	0	10.5
KV_KR3	1537.3	0.104	0	6.5
KV_KR4	1524.9	0.104	0	5.33
KV_KR5	622.1	0.076	0	3.6
KV_KR6	147.4	0.054	0	2

Catchment	Area (ha)	PERN Value	Impervious %	Slope (%)
KV_KR7	23.3	0.043	4.2	1.39
KV_KR8	10.5	0.047	3.3	2.81
KV_KR9	8.0	0.061	2.5	2.2
KV_KR10	213.5	0.055	0.9	2.44
KV_KR11	0.001	0.047	10.3	8.5
KV_KR12	40.5	0.054	0	6.6
KV_MG1	81.1	0.073	0	9.78
KV_MG2	51.1	0.064	7.8	4.2
KV_MGTrib1	39.4	0.071	0	21.26
KV_MGTrib2	16.0	0.071	0	15.01
KV_ML1	1053.9	0.077	0	2.4
KV_ML2	1553.6	0.111	0	4.7
KV_NG1	263.8	0.118	0	17.2
KV_NG2	553.8	0.093	8.7	5.43
KV_NGTrib1	231.6	0.114	0	14.95
KV_SY1	2246.1	0.115	0	3.51
KV_TTrib1	36.0	0.075	4.1	15.09
KV_TTrib2	40.9	0.064	3.2	12.51

B.1.2 RAFTS 'PERN' Values

The PERN parameter within RAFTS is an unit-less empirical parameter used to describe the roughness value of individual catchment areas, and can be considered somewhat similar to the Manning's 'n' value. The RAFTS PERN values adopted are shown below in **Table B-2**.

Table B-2 PERN Values Adopted

PERN Value	Description
0.02	Impervious Area
0.035	Urban Pervious Area
0.05	Rural Pastures
0.12	Forested Catchments

The subcatchments were delineated based on the above regions, and a single PERN value generated based on the relative areas of each of the above within the sub-catchment.

B.1.3 Rainfall Losses

RAFTS has two methods for determining rainfall losses:

- Initial and continuing loss – this method removes an initial volume of rainfall from the start of the event, and then applies a smaller continuing loss for the remainder of the storm event; and
- Australian Representative Basin Model (ARBM) – this method considers soil parameters and infiltration rates to ground water in order to determine the rainfall run-off during a storm event.

The ARBM method was adopted for the calibration modelling. The ARBM method allows more realistic modelling of catchment response, particularity for long duration events, and events with multiple storm bursts. The calibration events were both of long durations and contained multiple bursts.

Adoption of this loss method also allowed all the calibration events to be run with the same loss parameters, which was not possible to achieve using initial and continuing losses. These parameters were then adopted for the design runs.

B.1.4 Routing Reaches for the Kangaroo River

RAFTS allows two overland connection types between catchments; a lag link and a routing link. The lagging link simply shifts the hydrograph by a specified time, with no attenuation of the peak flow, or changes to the hydrograph shape.

The routing link allows a typical section of the channel to be entered into the model, and provides a more accurate representation of the flow through the link. Flow through the link is dependent on the section and the flow hydrograph experiences both attenuation of the peak, and a delay of the peak.

Routing links were adopted for the Kangaroo River, and lag links were adopted for tributary catchments. Routing links were adopted for the Kangaroo River as it conveys the majority of flood waters through the catchment, and is a long reach, compared to the tributaries. Routing links ensure that flow along the river is appropriately timed. The tributaries convey significantly less flow, and are much shorter reaches. For these connections, lag links are suitable, as the flow behaviour is simpler than the Kangaroo River flows.

Channel sections were taken from survey where available, and from the DTM where detailed survey was not available.

B.2 Hydraulic Model Development

B.2.1 2D Terrain

The terrain was developed from aerial survey, taken in 2009.

A 5m grid was created to cover the study area. The size of the model area is approximately 8 km^2, represented by approximately 320,000 grid cells, and is shown in **Figure B-2**.

B.2.2 1D Elements

Culverts and pipes were modelled in SOBEK as distinct 1D elements connected to the 2D terrain grid via pits. The location and size of pipes and culverts were collected as part of the survey undertaken for the Flood Study.

Bridges were also modelled as 1D elements, with the bridge deck being represented in the 2D terrain. A 1D approach was adopted as the 1D solution schemes for flows through structures are generally more robust, and provide a more accurate calculation of head losses through the structure.

The 1D elements in the model are shown in **Figure B-3**.

B.2.3 Roughness

Each 2D model cell has a roughness value applied to model the influence on flow behaviour of a particular land use. The adopted roughness layout as based on aerial photography, site inspections, and photographs.

The roughness regions are shown in **Figure B-4**.

The roughness values adopted for each zone are listed in **Table B-3** below.

Table B-3 2D Roughness Values

Zone / Land use	Manning's 'n' roughness value
Open Space	0.055
Dense Vegetation	0.11
Water	0.03
Low Density Development	0.14
Medium Density Development	0.22
Roads	0.018

Each 1D element in the model was also given a roughness parameter. Roughness values were determined from photographs and site inspections. The roughness values adopted for the 1D elements are listed in **Table B-4** below. Note that the bridge roughness is only for the in-channel roughness. The roughness of the bridge deck is taken from the 2D domain.

Table B-4 1D Roughness Values

1D Element	Manning's 'n' Roughness Value
Concrete pipes and culverts	0.018
Hampden Bridge	0.06
Barrengarry Creek Bridge	0.06
Nugents Creek Bridge	0.06

B.2.4 Inflows

Inflows were applied to the model based on the flows generated from the hydrological model. Upstream flows were applied at the boundary of the 2D model. Flows resulting from rainfall within the 2D domain were applied as distributed flows along river and creek reaches.

B.2.5 Downstream Boundary

The downstream boundary on the Kangaroo River was modelled as a Q-H relationship. This relates a water level in the river to a discharge rate. The relationship was generated from HydroChan, an excel program that creates Q-H relationships for cross sections based on channel roughness and slope using the Manning's formula, and was verified against the modelled Q-H relationship in the MIKE-11 model. The cross section was taken from the DTM at the model boundary, and the slope was estimated from the DTM as 0.4%.

The generated relationship is shown below in **Figure B-5**.

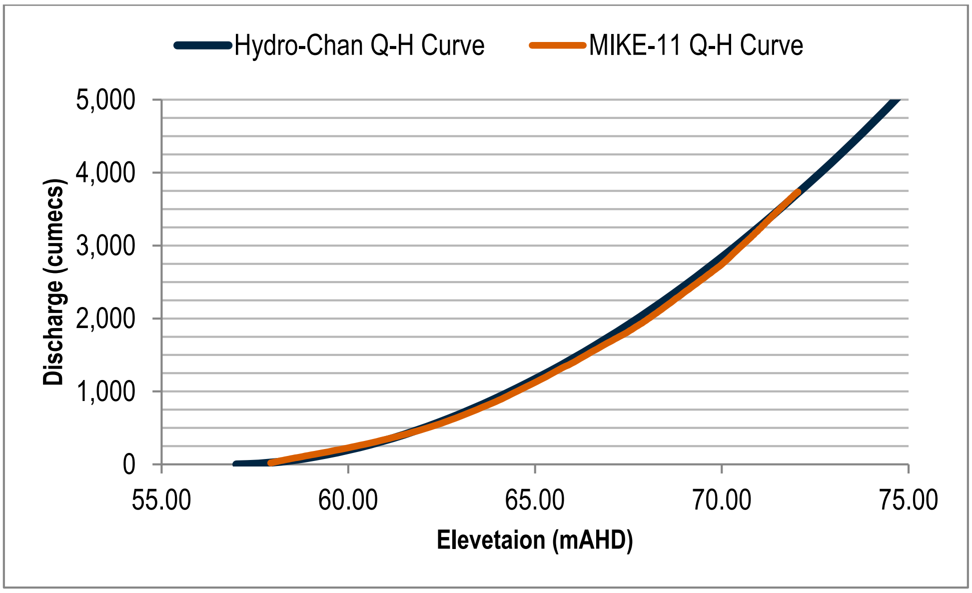

Figure B-5 Downstream Q-H Relationship

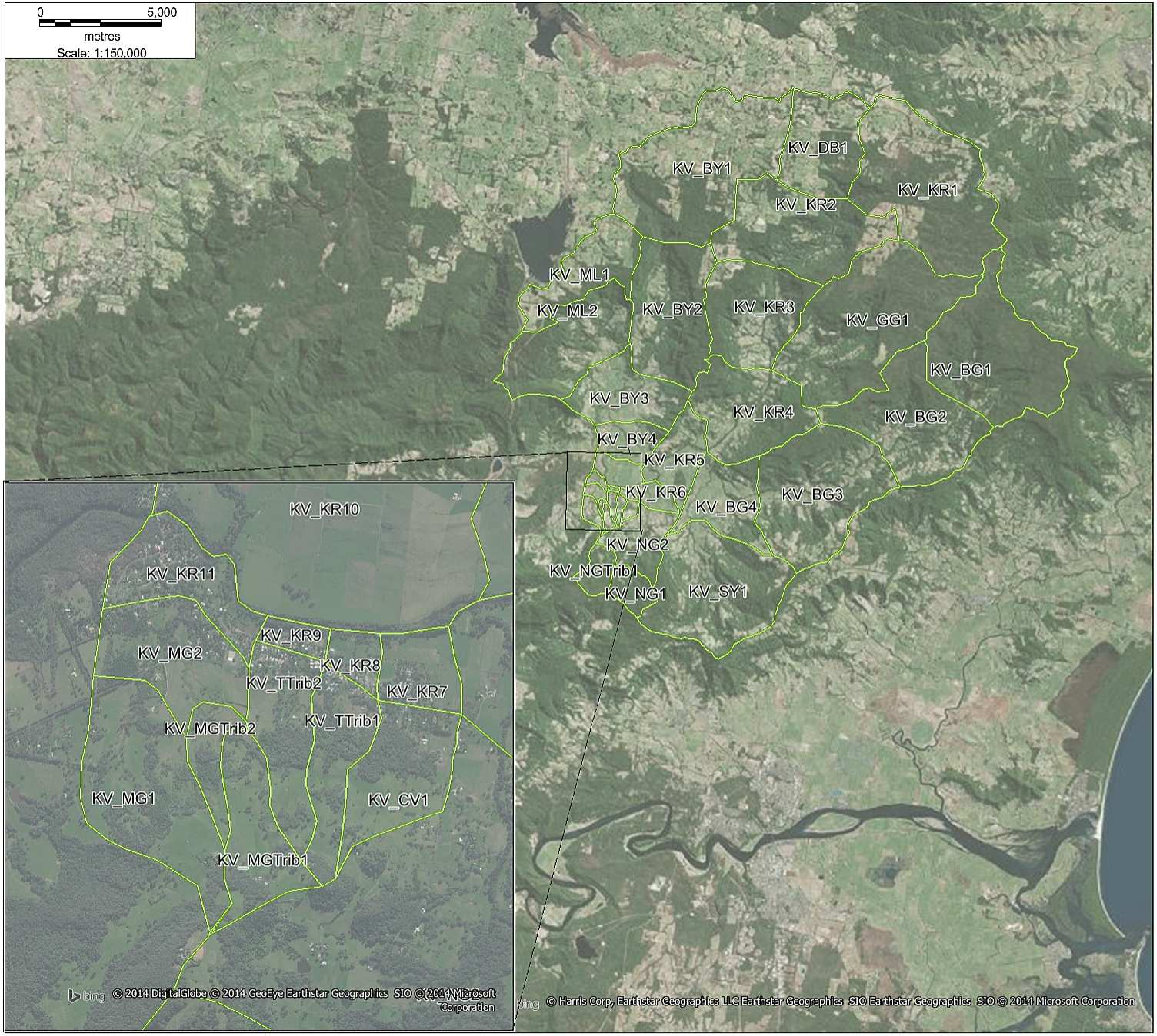

Figure B-1

RAFTS Subcatchments

Subcatchment Boundaries

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd
Date: July 2014
Coordinate System: MGA Zone 56

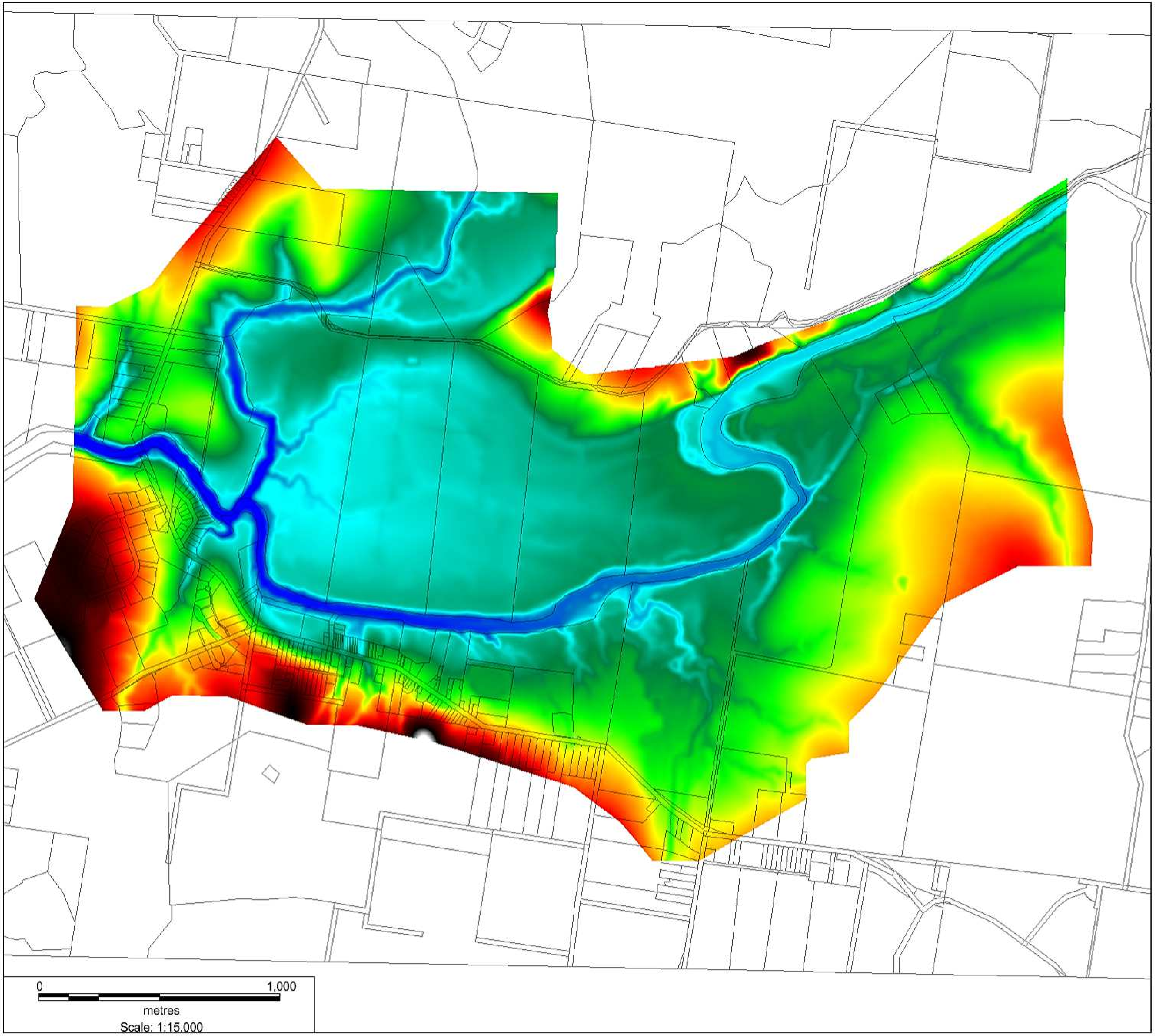

Figure B-2

Terrain Elevation

KANGAROO VALLEY
FRMSP

Elevation (mAHD)

- 60
- 65
- 70
- 75
- 80
- 85
- 90
- 95
- 100
- 105
- 110
- 115

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd
Date: July 2014
Coordinate System: MGA Zone 56

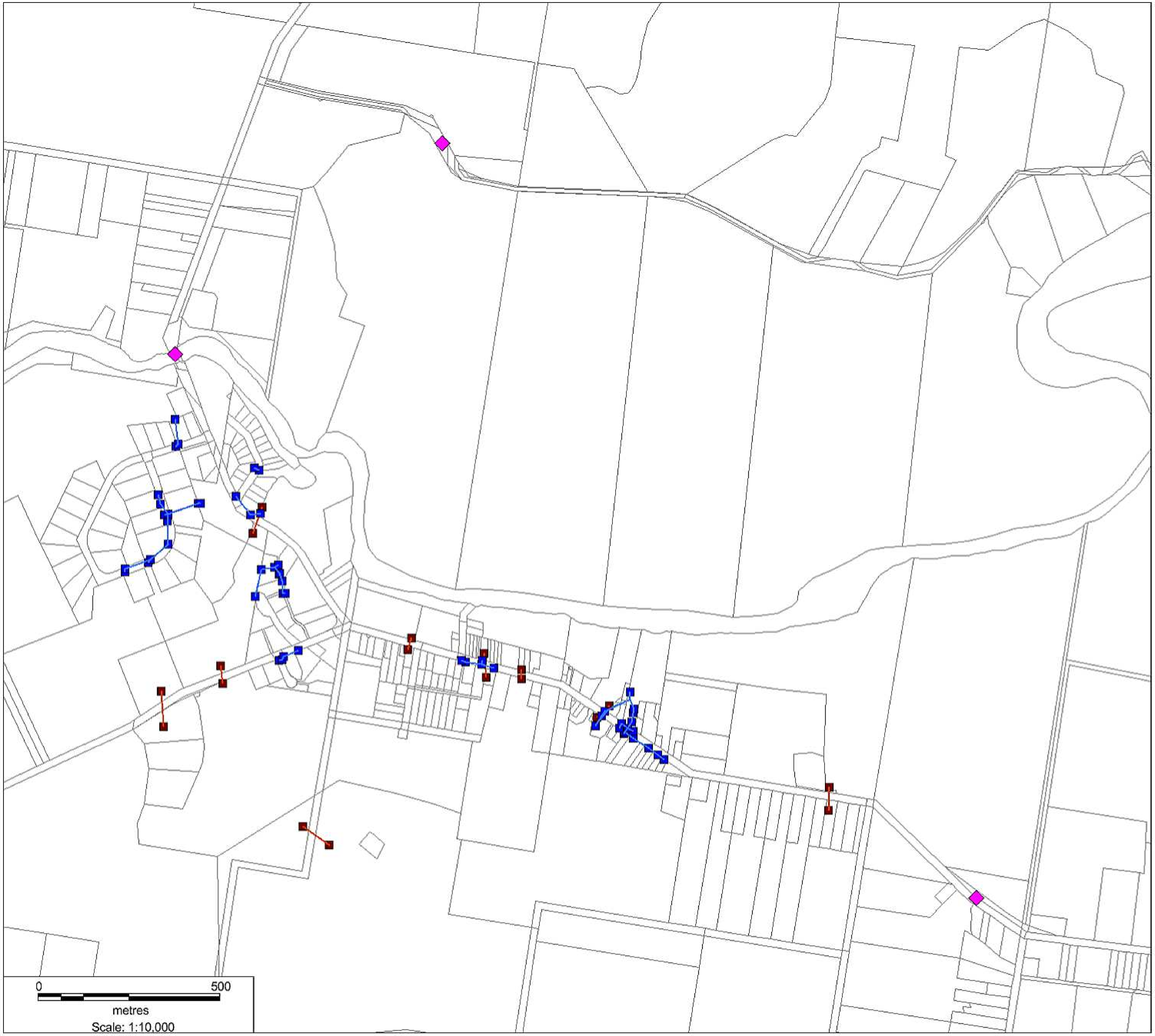

Figure B-3

1D Elements

KANGAROO VALLEY
FRMSP

	Cadastre
	Bridges
	Pipes
	Pipe Pits
	Culverts
	Culvert Pits

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Map Produced by Cardno NSW/ACT Pty Ltd
Date: July 2014
Coordinate System: MGA Zone 56

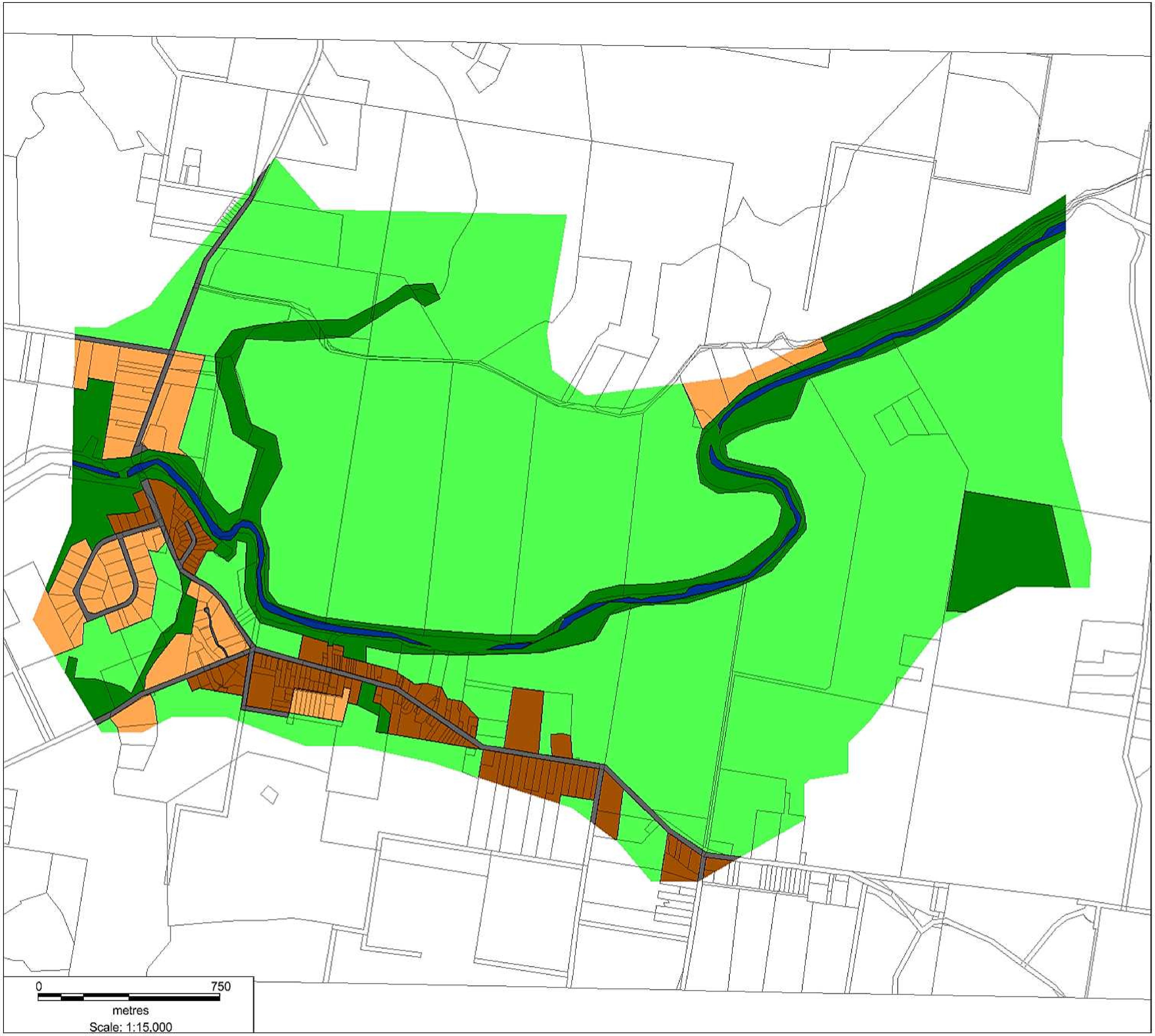

Figure B-4

Roughness Zones

KANGAROO VALLEY
FRMSP

- Cadastre
- Water
- Roads
- Low Density Development
- Medium Density Development
- Open Space
- Dense Vegetation

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd
Date: July 2014
Coordinate System: MGA Zone 56

Floodplain Risk Management Study

APPENDIX C
MODEL CALIBRATION AND VERIFICATION

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C Calibration and Verification

C.1 Hydrological Calibration

Calibration of the RAFTS model was undertaken for the four historical events used in the previous flood study, namely July 2005, August 1990, March 1978 and June 1975. A fifth large flood event occurred in October 1999, but there were errors with the flow gauging station on the Kangaroo River for this event, so it was not used in the calibration.

The calibration was undertaken to ensure that the model accurately represents the flooding behaviour of the catchment. The model was calibrated by comparing the recorded gauge flow at the Kangaroo River gauge upstream of Hampden Bridge with the predicted outflow from the hydrological model.

C.1.1 Hydrological Calibration Results

A summary of the observed peaks and run-off volumes are provided in **Table C-1** and **Table C-2** respectively**.** The results from the calibration model runs are shown below in **Figure C-1** to **Figure C-4** for the four events.

The results show strong matches for the 2005 and 1990 flood events, both in terms of peak flows and of flow timings.

The 1975 hydrograph shape and flow timings were similar to the gauged flows, although the peak was lower in the modelled flows by approximately 10%.

The 1978 results show a generally similar shape and overall timing, but the modelled peak flows are noticeably lower than the gauged flows. As can be seen from the isohyetal maps, the rainfall distribution within the Kangaroo River catchment is highly variable. The results of the 1978 calibration suggest that there were localised regions of high rainfall that was not captured on surrounding gauges. This spatial variation is also a likely cause of the smaller differences observed between peaks for the other events.

Overall, most peak flow rates and total discharge volumes are within 10% of the gauge results, which is reasonable given the accuracy of gauge data, and the distribution of pluvio-stations.

Table C-1 Calibration Results – Peak Flow Summary

Historical Event	Modelled Peak Flow (cumecs)	Observed Peak Flow (cumecs)	Difference (%)
July 2005	1,058	996	6%
August 1990	1,484	1,468	1%
March 1978	1,429	1,946	-27%
June 1975	1,827	2,037	-10%

Table C-2 Calibration Results – Discharge Volume Summary

Historical Event	Modelled Discharge (ML)	Observed Discharge (ML)	Difference (%)
July 2005	32,193,900	35,633,300	-11%
August 1990	134,234,200	130,041,300	3%
March 1978	164,528,700	182,703,900	-10%
June 1975	117,466,000	107,494,500	7%

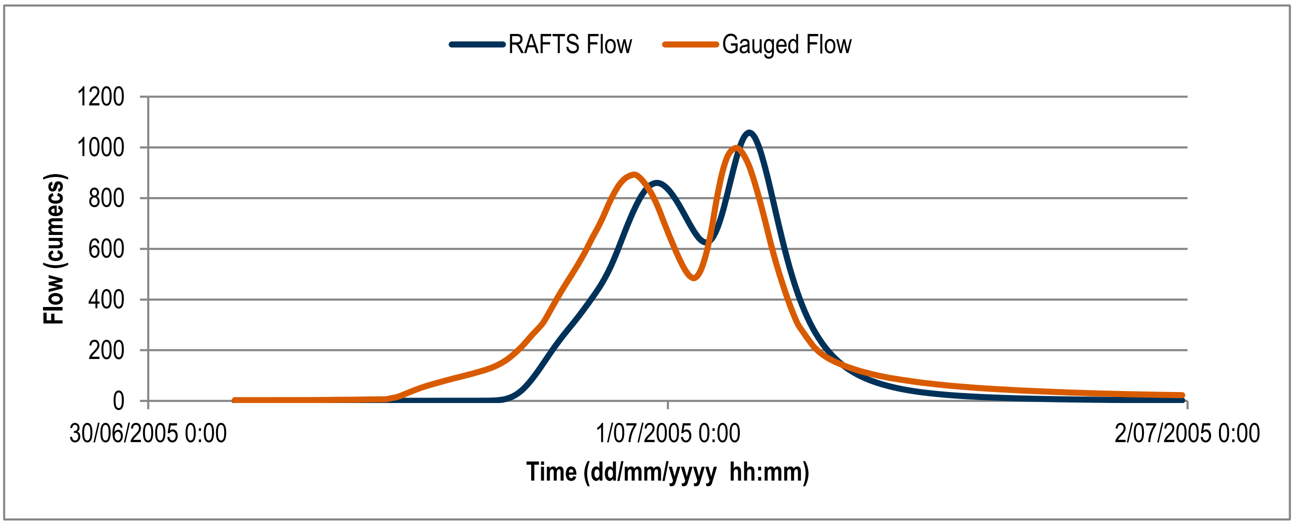

Figure C-1 July 2005 Calibration

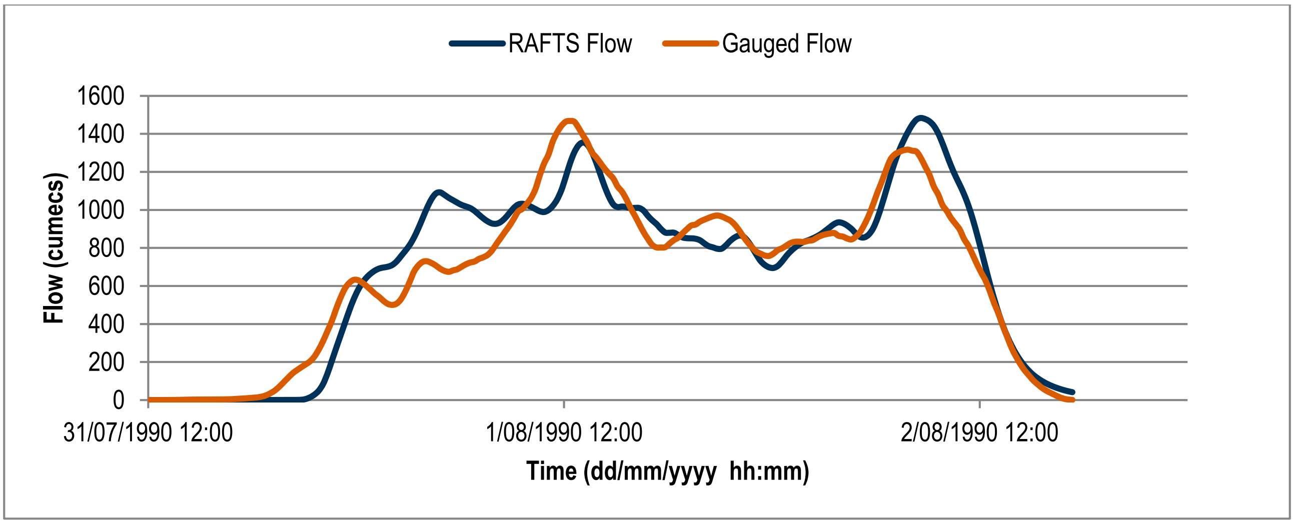

Figure C-2 August 1990 Calibration

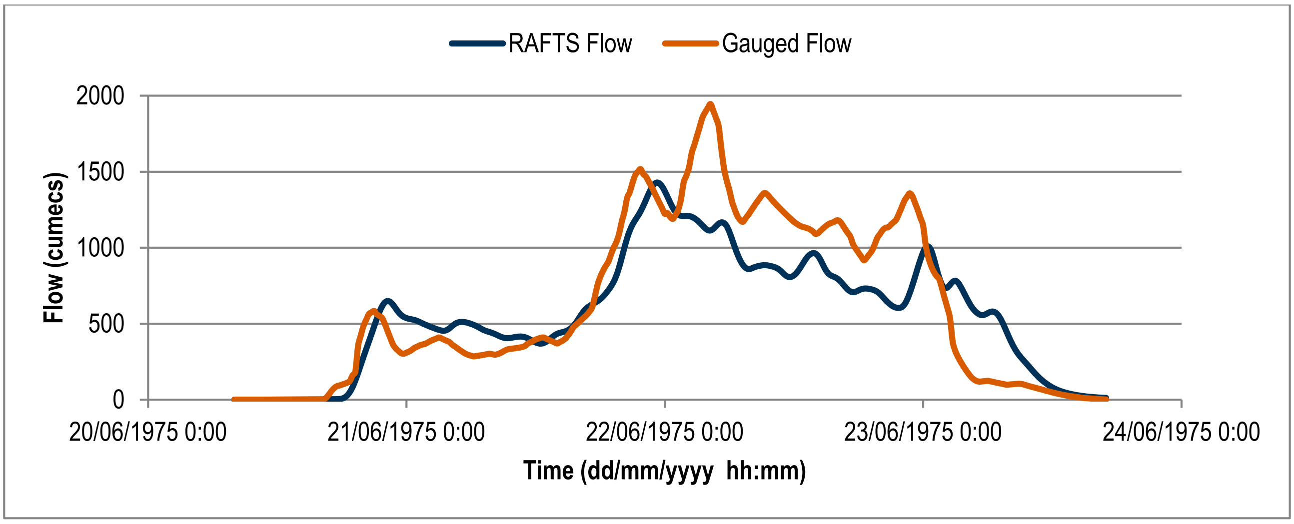

Figure C-3 **March 1978 Calibration**

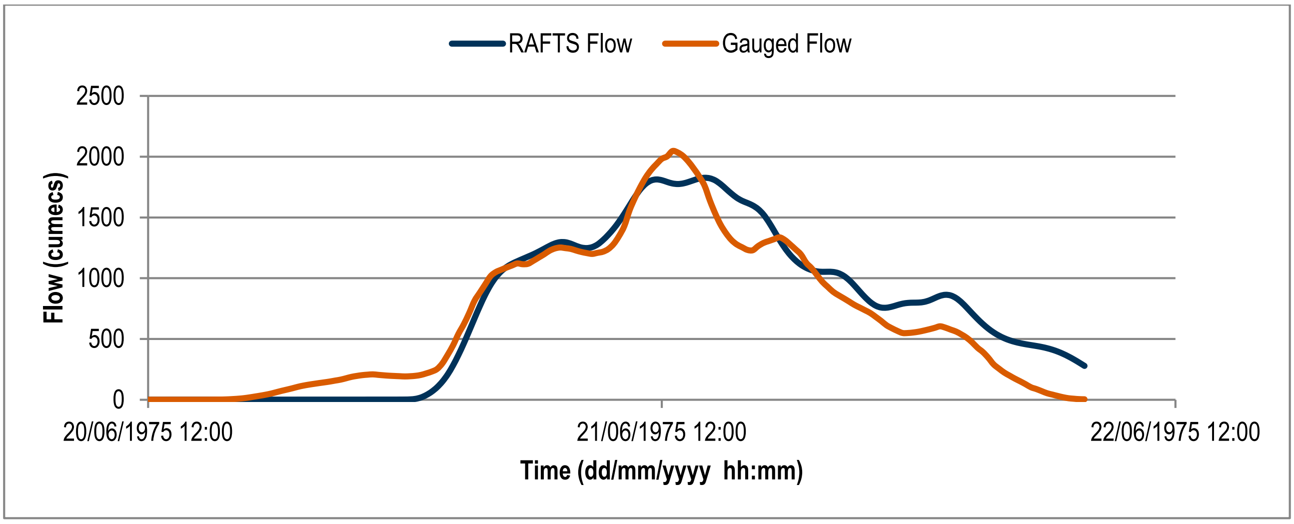

Figure C-4 **June 1975 Calibration**

C.1.5 Flood Frequency Analysis

A flood frequency analysis (FFA) was undertaken on the Kangaroo River gauge at Hampden Bridge. The FFA was undertaken to both assess the reliability of the gauge, and to provide some verification of the generated design flows. The process was undertaken following the methodology from AR&R.

The FFA was completed using gauge data from January 1970 through to May 2013, a period of 33 years, and is shown below in **Figure C-5**. Statistically, there is a 50% chance of the 1% AEP event occurring within a 70 year period. Given that the recorded period is less than half this, it is unlikely that the gauge data will cover a large range of flood events. The results of the FFA suggest that the largest event within the recorded period was in the order of a 5% AEP event.

The figure shows that all the historical flows are plotted within the 90% confidence limit (that is, between the plotted 5% and 95% confidence lines), suggesting that the gauge recordings are accurate.

The design flows from the hydrological model area also plotted in **Figure C-5** and a comparison between the RAFTS design flows, and the FFA estimated design flows is shown in **Table C-3**.

The figure and table show that the estimated RAFTS peak flows are a very close match to the flows estimated from the FFA.

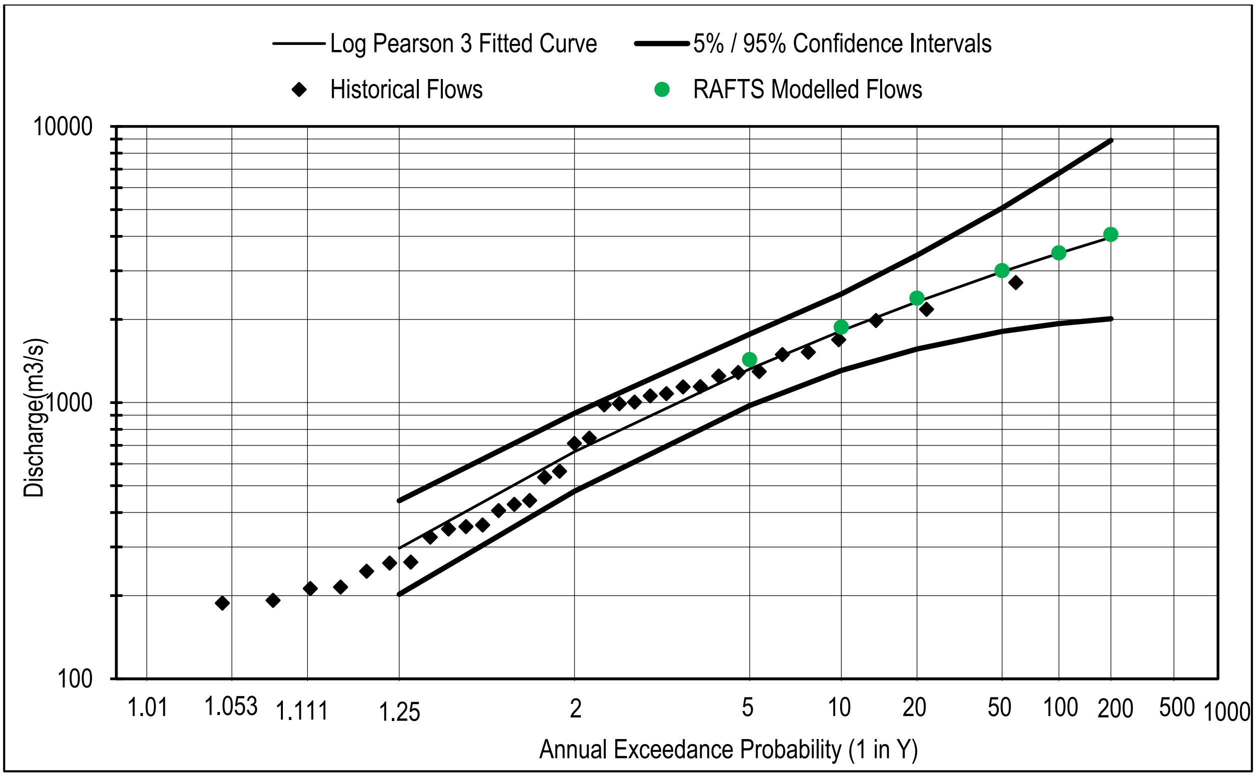

Figure C-5 **Flood Frequency Analysis**

Table C-3Peak Design Flows at Hampden Bridge Gauge

AEP Event	RAFTS Peak Flow (cumecs)	FFA Peak Flow (cumecs)	Difference
20%	1,429	1,324	7%
10%	1,875	1,820	3%
5%	2,387	2,318	3%
2%	3,002	2,976	1%
1%	3,482	3,472	0%
0.5%	4,058	3,964	2%

C.2 Hydraulic Calibration

The previous MIKE-11 model was calibrated primarily by matching the downstream hydrographs against the Hampden Bridge gauge. There was no comprehensive post flood survey available from recent historical events, but old flood marks were surveyed as part of the flood study. Although a number of flood marks were surveyed, only a small number could be tied accurately to a date. Accurate historical flood heights were collected for:

- The 1990 event at one location; and,
- The 1975 event at two locations.

All of these flood marks were within the township; none were available in the upper reaches of the river.

Given the above data, the SOBEK model was calibrated against the gauge flows at Hampden Bridge for the 2005 historical event, and against available flood levels for the 1990 and 1975 events. The model was then validated against the 1% AEP MIKE-11 model results.

C.2.1 Hydrological Input

The inputs for the 2005 event were taken from the RAFTS hydrological model. The inputs for the 1% AEP event were extracted directly from the MIKE-11 model. A summary of the peak inflows is provided in **Table C-4**.

Table C-4 Peak Inflows to the Hydraulic Model

Location	Peak 2005 Inflow from RAFTS (m^3/s)	Peak 1990 Inflow from RAFTS (m^3/s)	Peak 1975 Inflow from RAFTS (m^3/s)	Peak 1% Inflow from MIKE-11 (m^3/s)
Kangaroo River	1,019.7	986	1,319	3,596
Barrengarry Creek	71.1	421	634	1,400
Nugents Creek	34.7	87.8	63.5	195.8
Jarrets Creek	2.0	5.2	4.4	10.2
Town Creek 1	1.2	3.3	2.5	8.2
Town Creek 2	2.2	3.2	2.4	4.5
Town Creek 3	2.2	3.2	2.4	4.5
Myrtle Creek 1	2.4	7.3	6.4	17.6
Myrtle Creek 2	1.7	2.1	1.8	9.5
Myrtle Creek 3	1.7	2.1	1.8	3.2

C.2.2 Comparison of Hydraulic Model Results to the 2005 Gauge Data

The flow in the Kangaroo River at the Hampden Bridge gauge was extracted from the SOBEK model and compared against the recorded gauge flows. The comparison is shown in **Figure C-6**.

The figure shows a strong match between the hydraulic model flows and the recorded flows at the Hampden Bridge gauge, both in terms of flow peaks and flow timings.

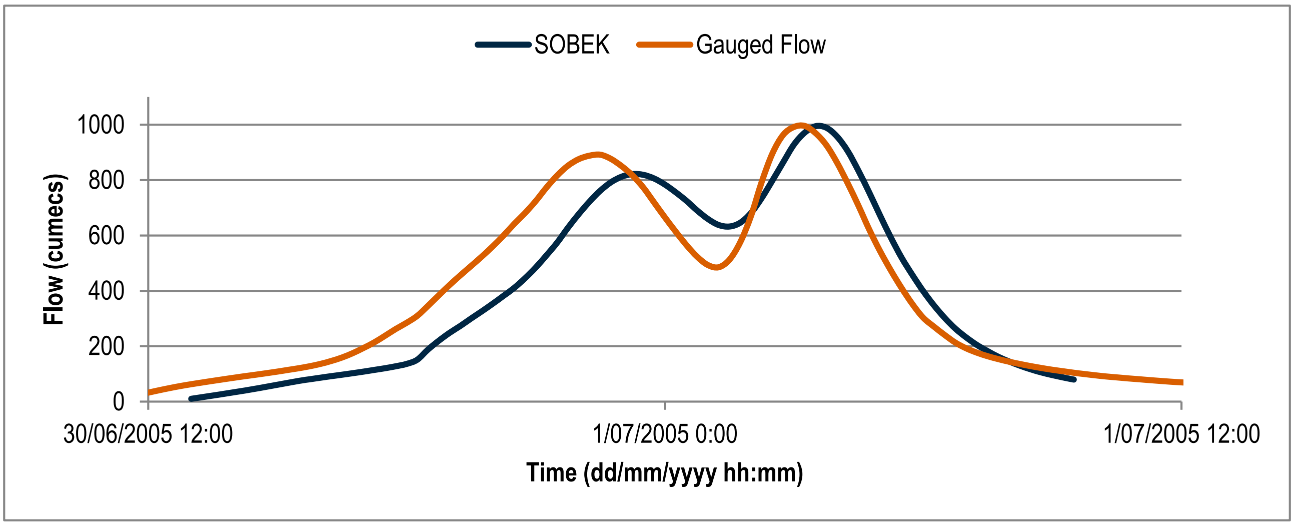

Figure C-6 Comparison of SOBEK and Gauge Flows for the 2005 Historical Event

C.2.3 Comparison of Hydraulic Model Results to Historical Flood Marks

A comparison of the surveyed flood marks, and the modelled levels at these locations are shown below in **Table C-5**.

The table shows that the modelled levels are within 0.15m of the historical levels. This level of precision is reasonable, given that there are a number of factors that can affect the calibration including;

- Accuracy of survey;
- Impacts of localised effects like waves and local debris;
- Uncertainty of the level of blockage of structures during the event; and,
- Accuracy of the model.

Table C-5 Comparison of historical flood heights

Event	Location	Surveyed Level (mAHD)	Modelled Level (mAHD)
1990	Hampden Bridge	69.7	69.75
1975	Hampden Bridge	69.94	69.82
1975	Tennis Courts	72.50	72.56

C.2.4 Comparison of Hydraulic Model Results to the 1% AEP MIKE-11 Results

A close match was observed between the previous MIKE11 model and the SOBEK model for the 1% AEP event.

Peak water levels from the SOBEK model along the Kangaroo River through the Township were within 0.2m of the MIKE11 levels, and were within 0.1m along Barrengarry Creek.

The models also predict a similar head loss through the bends and Hampden Bridge downstream of the township, as shown in **Figure C-7** below. The difference at chainage -100 is due to the MIKE11 model reporting at discrete locations, with levels smoothed between them, whilst the SOBEK results are reported at each grid cell.

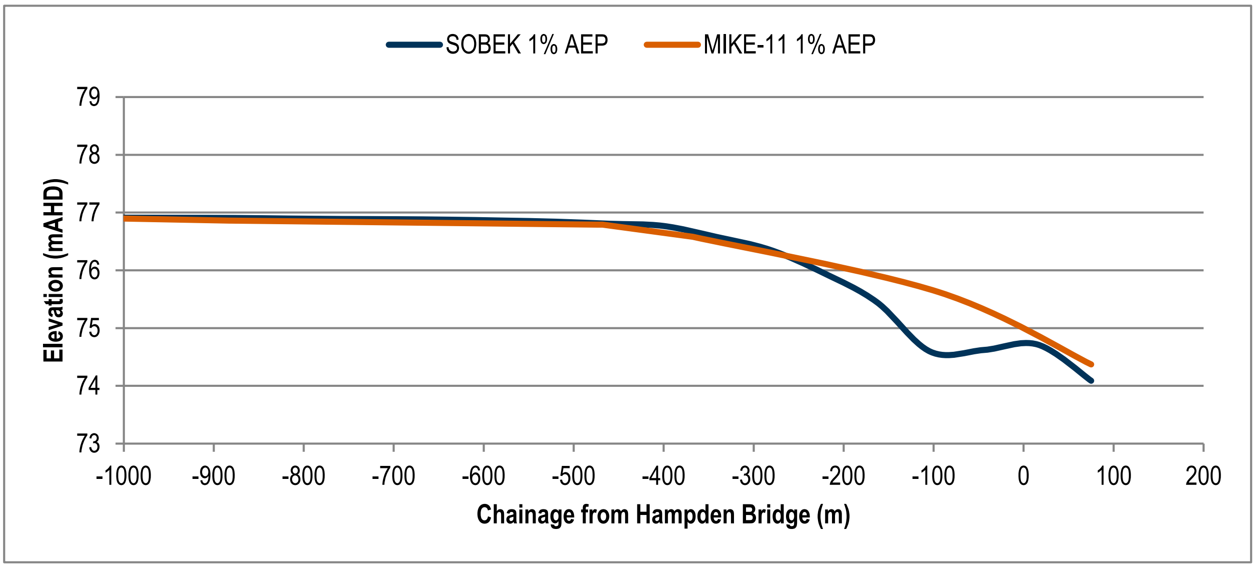

Figure C-7 Comparison of SOBEK and MIKE-11 1% AEP Levels at Hampden Bridge

Some divergence of the model results was observed in the upper reaches of the Kangaroo River, but given the lack of flood data for this region, it was not possible to calibrate this portion of the model. Roughness values in the MIKE11 model through this region were at the bounds of acceptable values, and it is likely that adopting more typical roughness parameters in the SOBEK model is the source of this divergence. As noted above, where calibration data is available, the models are in close alignment.

C.3 Outcomes of Hydrological and Hydraulic Model Calibration

The above calibration and validation assessments were undertaken in order to determine that the hydrological and hydraulic models are accurately representing flood behaviour within the Kangaroo Valley Township.

The results of the above assessment show that both the hydrological and hydraulic models have been successfully calibrated; the hydrological model to four historical events, and the hydraulic model to one historical event and the previous MIKE-11 model.

The hydrological model demonstrated an acceptable match to the 2005, 1990 and 1975 historical events in terms of flow timings, peak flows and flow volumes. The design flows outputted from the hydrological model plotted well against the flood frequency curve generated from the FFA undertaken on the Hampden Bridge gauge.

The hydraulic model showed a close match to the gauged hydrograph from the 2005 event, and to the flood marks from the 1990 and 1975 events. Peak 1% levels matched the MIKE-11 peak 1% levels through the Kangaroo Valley Township were historical flood survey was available. Levels along Barrengarry Creek were similar in both models.

As such, the models can be used with confidence in assessing design flood behaviour within the study area.

APPENDIX D
EXISTING SCENARIO RESULTS

D Existing Scenario Results

D.1 Extents and Flood Depths

Flood modelling of design storms was undertaken for the 20%, 10%, 2%, 1% and 0.5% AEP events and the PMF event.

Flood extents for the design storms are shown in **Figure D-1** to **Figure D-6**.

The peak flood depths for the design storms are shown in **Figure D-7** to **Figure D-12**.

D.2 Provisional Flood Hazard & Hydraulic Categories

D.2.1 Provisional Flood hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters and is based strictly on hydraulic considerations (Appendix L; NSW Government, 2005). The Floodplain Development Manual (NSW Government, 2005) defines two categories for provisional hazard – high and low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional hazard was prepared for 6 design events, namely PMF, 0.5%, 1%, 2%, 10%, and 20% AEP.

Hazard is calculated for each grid cell at each time step based on velocity, depth and velocity x depth, with the highest value giving the hazard rating for the cell.

D.3 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

- Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Floodways were determined for the 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 m^2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent, where the depth is greater than 0.1 m, are represented as Flood Fringe.

Combined hazard and hydraulic categories for the design events are shown in **Figure D-13** to **Figure D-18**.

D.4 Discussion of Existing Flooding

D.4.1 Kangaroo River

The Kangaroo River is the major flowpath in the study area. It runs east to west through the study area, and has one crossing within the study area; Hampden Bridge, located downstream of the Kangaroo Valley township.

It is a high hazard flow path, due to both depths and velocities, which reach 16m and 4.5m/s in the 1% AEP event.

In events as small as the 20% AEP event, the Kangaroo River breaks its northern banks and inundates the floodplain in the centre of the study area. The southern bank rises higher than the northern bank and prevents overtopping in events smaller than the 10% AEP. In events greater than the 10% AEP event, the river breaks its southern banks, which impacts properties between the river and Moss Vale Rd.

D.4.2 Barrengarry Creek

Barrengarry Creek enters the study area in the north, and joins with the Kangaroo River immediately downstream of the Kangaroo Valley Township

It is a high hazard flow path, due to both depths and velocities, which reach 16m and 2.5m/s in the 1% AEP event.

In events above the 20% AEP event, it breaks over the eastern bank, and contributes to flooding within the central floodplain. In larger events, flooding along the reach within the study area is largely governed by flooding in the Kangaroo

River; the central floodplain is fully inundated, and the levels along Barrengarry Creek are controlled by the large volume of flood water passing down the Kangaroo River.

D.4.3 Nugents Creek and Jarretts Creek

Nugents and Jarretts Creeks are two tributaries of the Kangaroo River that join it upstream of the Township.

The upper reaches of the creeks are typically well contained within the creek banks for events up to the 2% AEP. Flooding within the downstream extents of the creek however are controlled by the Kangaroo River, and backwater flows break creek banks in events as small as the 10% AEP event.

Creek flow is classified as high hazard as a result of velocities of up to 2.5m/s. The overbank flooding is typically low hazard, with depths of up to 0.4m in the 1% AEP event.

D.4.4 Town Creek and Myrtle Creek

Town and Myrtle Creeks are two tributaries of the Kangaroo River that join it within the Township. Similar to the Nugents and Jarretts Creeks, upstream reaches are typically contained within the creek banks, whilst downstream reaches are controlled by flood levels in the Kangaroo River.

Creek velocities and depths reached 1.8m and 0.6m/s respectively, resulting in regions of high hazard within the creek. The overbank flooding is low hazard, with depths of 0.3m.

D.4.5 Flow Timings

Each of the flowpaths responds at a different rate to storm events. Shown below in **Table D-1** are the times to peak flow in each flowpath from the start of the storm event for the 10% and 1% AEP events.

The table shows that the smaller creeks peak first, approximately 7 hours after the storm starts. The larger Barrengarry Creek peaks next, approximately 1 hour later. The Kangaroo River does not reach its peak until 11 hours after the storm commences.

It should be noted that the flow timings for the creeks only translate to peak flood level timings for the upper reaches of the creeks. Downstream, peak flood levels are governed by Kangaroo River flooding, and peak flood levels occur during the peak of the Kangaroo River flow. Within Barrengarry Creek for instance, the peak inflow occurs at 8 hours, but creek levels continue to rise after this time, as the flood levels are controlled by the downstream level in the Kangaroo River.

It should also be noted that the reported timings are for the critical 9 hour event. A more detailed assessment of timings for a range of durations will be undertaken as part of the Floodplain Risk Management Study and Plan.

Table D-1 Time to Peak Flow in the 100yr ARI (hours from start of storm event)

Flowpath	10% AEP	1% AEP
Kangaroo River - Hampden Bridge	11	11
Barrengarry Creek	8	8
Nugents Creek	7	7
Jarretts Creek	7	7
Town Creek	7	7
Myrtle Creek	7	7

D.4.6 Road Overtopping

There is one primary road, Mona Vale Road, which runs through the Kangaroo Valley Township. In events above the 10% AEP event, it is cut in multiple locations by overtopping depths greater than 0.2m. Summarised in **Table D-2** are the overtopping characteristics in the 2% and 1% AEP events at a number of locations along Mona Vale Road.

The table shows that overtopping occurs via two distinct mechanisms. The first, which applies at Nugents and Jarretts Creeks, is that upstream creek flow overtops the road due to insufficient culvert capacity. This overtopping is characterised by relatively shallow flow depths, and short overtopping durations, resulting from the quick flooding response of the upstream catchment.

Overtopping at the tennis courts and Myrtle Creek however are governed by backwater from the Kangaroo River. This overtopping is characterised by significantly greater overtopping depths and much longer durations.

The timings of the overtopping mechanisms also vary. Creek driven overtopping occurs 1 to 2 hours before the river driven overtopping occurs.

Table D-2 Road Overtopping Behaviour

Location	2% AEP Overtopping Depth (m)	2% AEP Overtopping Duration (hours) *	1% AEP Overtopping Depth (m)	1% AEP Overtopping Duration (hours) *
Moss Vale Rd at Nugents Creek crossing	0.26	1.5	0.36	2.0
Moss Vale Rd at Jarretts Creek crossing	0.07	-	0.08	-
Moss Vale Rd at tennis courts	2.97	> 5.0	3.89	> 5
Moss Vale Rd at Myrtle Creek crossing	1.20	4.5	2.17	> 5

* Duration times reported for when depth is greater than 0.2m

D.4.6 Impacts on Kangaroo Valley Sewer System

A survey was undertaken to locate sewer infrastructure within the Kangaroo Valley Township. Using this data, the flood affectation of the sewerage system was determined for a range of design events.

A summary of the flood affectation is provided in **Table D-3**.

The location of the affected infrastructure is shown in **Figure D-19**.

The infrastructure that was surveyed is flood free in events up to the 20% AEP event, with the first pieces of infrastructure becoming inundated in the 10% AEP event by depths of up to 0.4m.

There is a large jump in affectation to the 2% AEP event, with 20 pieces of infrastructure inundated by average depths of 0.9m, and a maximum of 3.1m. Affectation is similar in the 1% and 0.5% AEP with 30 and 33 pieces of infrastructure impacted respectively. Compared to the 2% AEP event, there was not a large increase in average depths in the 1% AEP but the maximum depth increased by 1m to 4.1m.

As shown in **Figure D-31**, all of the affected infrastructure lies in one region of the catchment, with the infrastructure most affected lying in depression surrounding the tennis courts and Broughton Street.

The assessment showed that the sewerage infrastructure in Kangaroo Valley is largely protected from frequent flood events, and is not inundated in events smaller than the 10% AEP event. Substantial inundation of sewer assets occurs in events of a 2% AEP magnitude or great.

Table D-3 Road Overtopping Behaviour

AEP Event	Infrastructure Elements Impacted	Average Flooding Depth (m)	Median Flooding Depth (m)	Maximum Flooding Depth (m)
20%	0	-	-	-
10%	3	0.2	0.1	0.4
2%	20	0.9	0.7	3.1
1%	30	1.2	0.8	4.1
0.50%	33	1.8	1.6	4.9
PMF	61	5.1	5.6	10.8