King Parrot Creek Design Flow Estimates

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1. INTRODUCTION

Water Technology has been engaged by the Goulburn Broken Catchment Management Authority (GBCMA) to provide design flood hydrograph estimates for the King Parrot Creek in central Victoria. The objectives of the study are:

- To assess relevant information on the streamflow regime in the local region; and
- To estimate design flood hydrographs for the 20, 50 and 100 year events for the King Parrot Creek to Flowerdale.

The study is being undertaken to provide design flow inputs to a hydraulic model of the King Parrot Creek adjacent to Flowerdale. The major components of this study are:

- Flood frequency analysis for the King Parrot Creek at the Flowerdale gauge to estimate peak design flows
- Construction and calibration of a RORB (runoff routing) model for the study area
- Estimation of design flood hydrographs for the 20, 50 and 100 year events at key inflow points to the hydraulic model
- Comparison of design flow estimates with neighbouring catchments and regional relationships
- Investigation of the impacts of the recent bushfires on the hydrologic regime and design flood estimation

1.1 Study Area

The King Parrot Creek catchment sits just north of the Great Divide near Whittlesea. The creek is a tributary of the Goulburn River, joining the Goulburn downstream of Lake Eildon. Settlements in the catchment include Kinglake West, Hazeldene and Flowerdale. The area of interest is the upper catchment upstream of Flowerdale, with a total area of 200.3 km^2.

The area of interest ranges in elevation from 250 m above sea level at the outlet to 780 m above sea level in the west of the catchment. West of the King Parrot Creek the topography rises steeply to the Mount Disappointment plateau. Much of this area is covered by the Kinglake National Park. The area of interest also contains significant areas of State Forest. The catchment has a low level of development, with agriculture and rural residential areas confined to the southern part of the catchment and a narrow corridor along King Parrot Creek. The catchment was extensively and severely burnt in the February 2009 “Black Saturday” bushfire.

Mean annual rainfall in the catchment lies within the range 1000-1200 mm/a, according to the Bureau of Meteorology’s climate maps. Mean annual rainfall recorded at Kinglake West (Wallaby Creek) (88062) in the south of the catchment is 1197.4 mm/a over the period 1884-2009. Rainfall tends to be highest at the southern end of the catchment, declining toward the north. At Strath Creek (88158), approximately 5 km north of the catchment, mean annual rainfall was 672.1 mm/a over the period 1983-2009.

Melbourne Water operates diversion weirs on the Silver and Wallaby Creeks, diverting water to the Yarra basin via a series of aqueducts. The catchments of these two creeks lie within Kinglake National Park and are protected from access. No other major storages or diversions are in operation in the catchment.

See Figure 1-1 for a map of the study area locality.

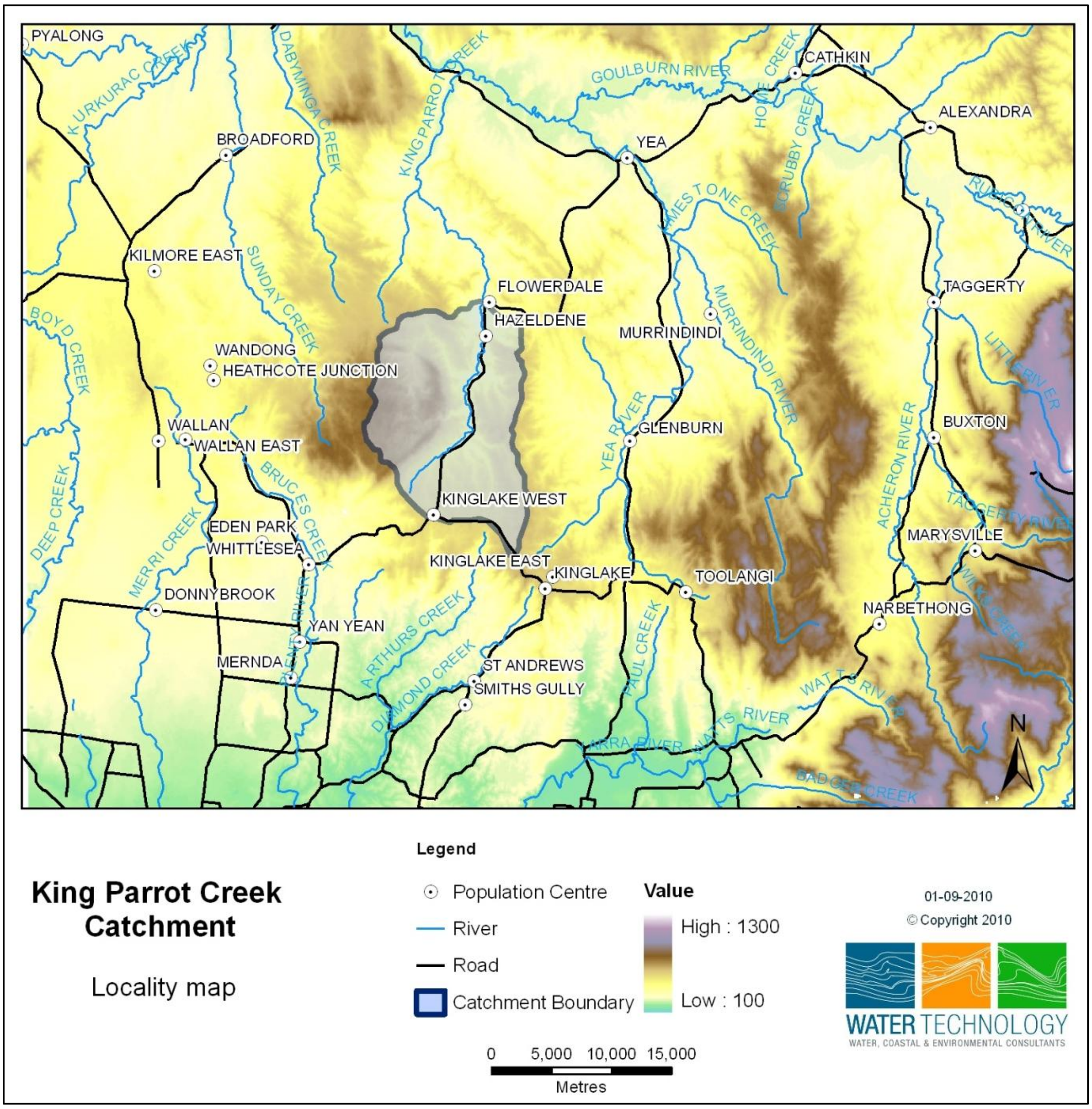

Figure 1-1 Study Area Location

2. FLOOD FREQUENCY ANALYSIS

A flood frequency analysis was undertaken for recorded streamflows at King Parrot Creek at Flowerdale (Gauging Station 405231). The analysis was undertaken using an annual series of instantaneous maximum flows from 1962 to 2009 (48 years). Instantaneous maxima were obtained from Victorian Surface Water Information to 1987 (RWC 1990) (1962-1974) and a full instantaneous flow series from Thiess (1975-2009). The full annual series is shown in Figure 2-1 below.

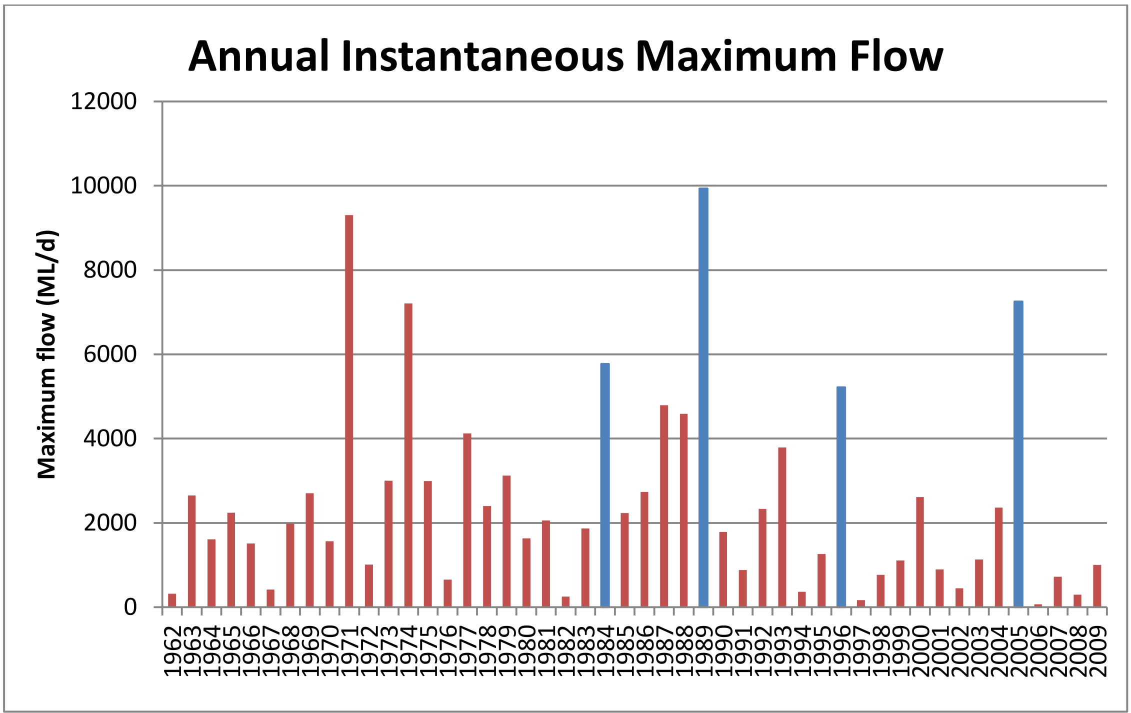

Figure 2-1 Annual series of instantaneous maximum flows. Flows highlighted in blue were selected for calibration of the RORB model for this study.

A range of probability distributions were fitted to the data (Generalised Pareto, Log Pearson III, Log-normal, Gumbel and Generalised Extreme Value) and the Log Pearson III distribution was found to yield the best fit. The probability plot for observed and fitted flows is shown in Figure 2-2 below.

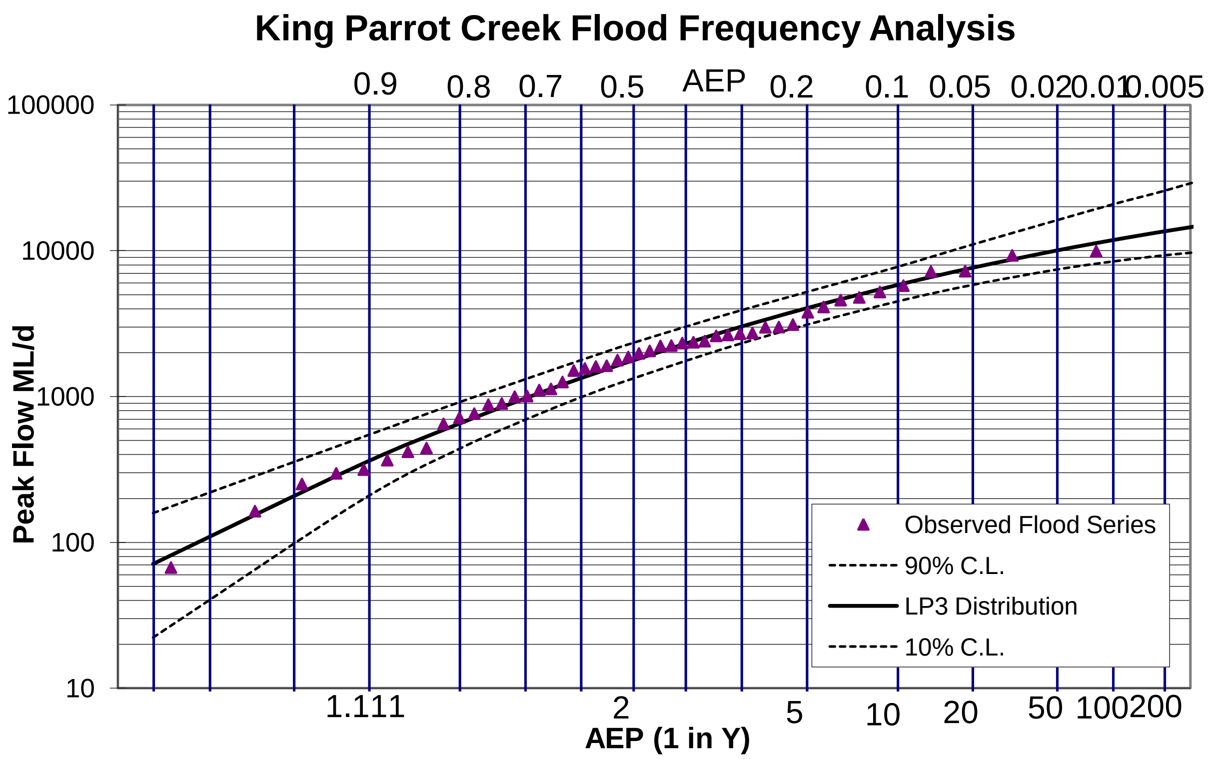

Figure 2-2 **Log-normal probability plot for observed peak flows and fitted LP3 distribution - dotted lines show 90% probability limits**

The estimated design flows for standard Average Recurrence Intervals (ARIs) are presented in Table 2-1 below.

A similar flood frequency analysis was undertaken by Water Technology in 2009 for the Goulburn River Environmental Flows Hydraulics Study. The frequency analyses considered the annual maximums for each year from the instantaneous flow record. Generalised Extreme Value (GEV) distributions were fitted using L- moments. The results of the 2009 study are provided in Table 2-1 below for comparison.

Table 2-1 **Design flows for King Parrot Creek at Flowerdale (Gauging Station 405231)**

Recurrence interval (yrs)	Expected peak flow (ML/d)	Monte Carlo 90% quantile probability limits		Water Technology (2009) expected peak flow
10	5833	4500	7762	5911
20	7650	5835	11035	8511
50	10053	7434	16189	13200
100	11845	8443	20835	18060

The frequency analysis for this study is fairly consistent with the 2009 analysis, especially for the 10 and 20 year ARI flows. Differences in the higher flow estimates are likely to be due to the use of the Log Pearson III distribution instead of the GEV. In this analysis, the Log Pearson III distribution was chosen because it resulted in a better fit to the observed flows than the GEV.

3. RORB MODELLING

3.1 Overview

The catchment hydrologic model, RORB, was employed to estimate flood hydrographs.

RORB (*Laurenson et al 2005*) is a non linear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be subdivided into subareas, connected by conceptual flow reaches. Section 3.2 details the RORB model structure.

The RORB model parameters were determined through calibration against observed flood hydrograph at the Flowerdale gauge. This model calibration required concurrent pluviographic and daily rainfall data, and streamflow. Section 3.3 details the RORB model calibration.

3.2 RORB Model Structure

The RORB model structure was created using the MiRORB MapInfo tool. The catchment boundary was delineated from a Digital Elevation Model (DEM) of the area. Sub-area boundaries were then delineated and nodes placed at all areas of interest and at the junction of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type. All reach types were set to natural (Type 1) reaches, and the fraction impervious was set to 0% to reflect the undeveloped nature of the catchment. The breakdown of the catchment and channel network and the positioning of nodes is shown in Figure 3-1. The detail is sufficient that the contribution from major tributaries can be assessed, and flow hydrographs can be calculated at a number of points along the King Parrot Creek main stem for input into the hydraulic model.

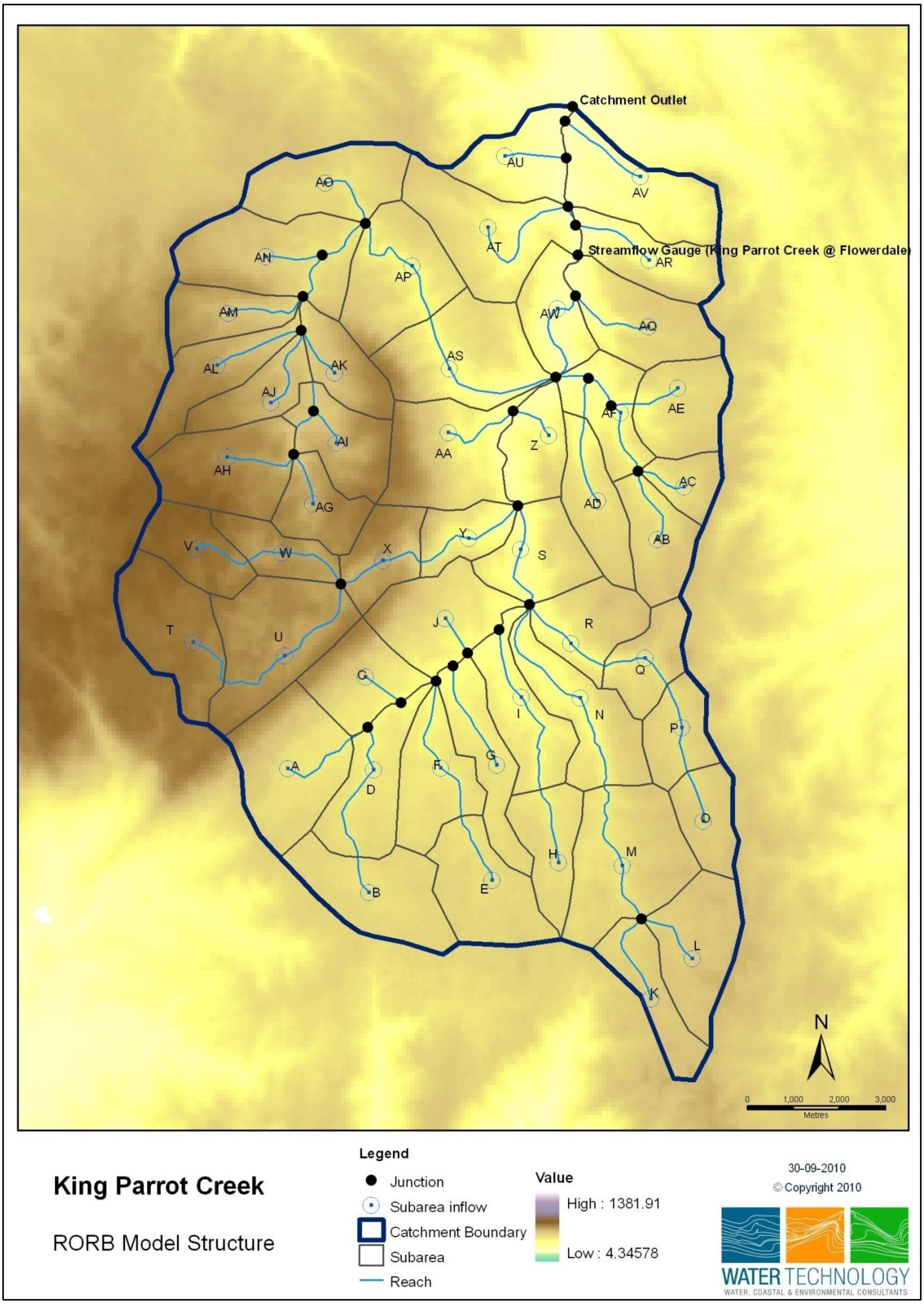

Figure 3-1 RORB Model Structure

3.3 RORB Model Calibration

3.3.1 Available Data for Calibration

The streamflow gauge at King Parrot Creek at Flowerdale (Gauge number 405231) was used for calibration. It is located within the study catchment, close to the catchment outlet (see Figure 3-1).

A full time series of instantaneous flows for this gauge were available from 30/12/1974 to 10/2/2010 and were provided by Thiess. The four highest observed flows from the annual series of peak flows at the gauge within this period were selected as calibration events, as listed in Table 3-1.

Pluviograph data was available at Toolangi (86142) for the 1984, 1989 and 1996 events and at Strath Creek (88158) for the 2005 event. The location of these pluviographs can be seen in Figure 3-2. The 6 minute pluviograph data was accumulated to a 30 minute time step and the instantaneous flow data (at a non-constant time step) was interpolated to the same time step.

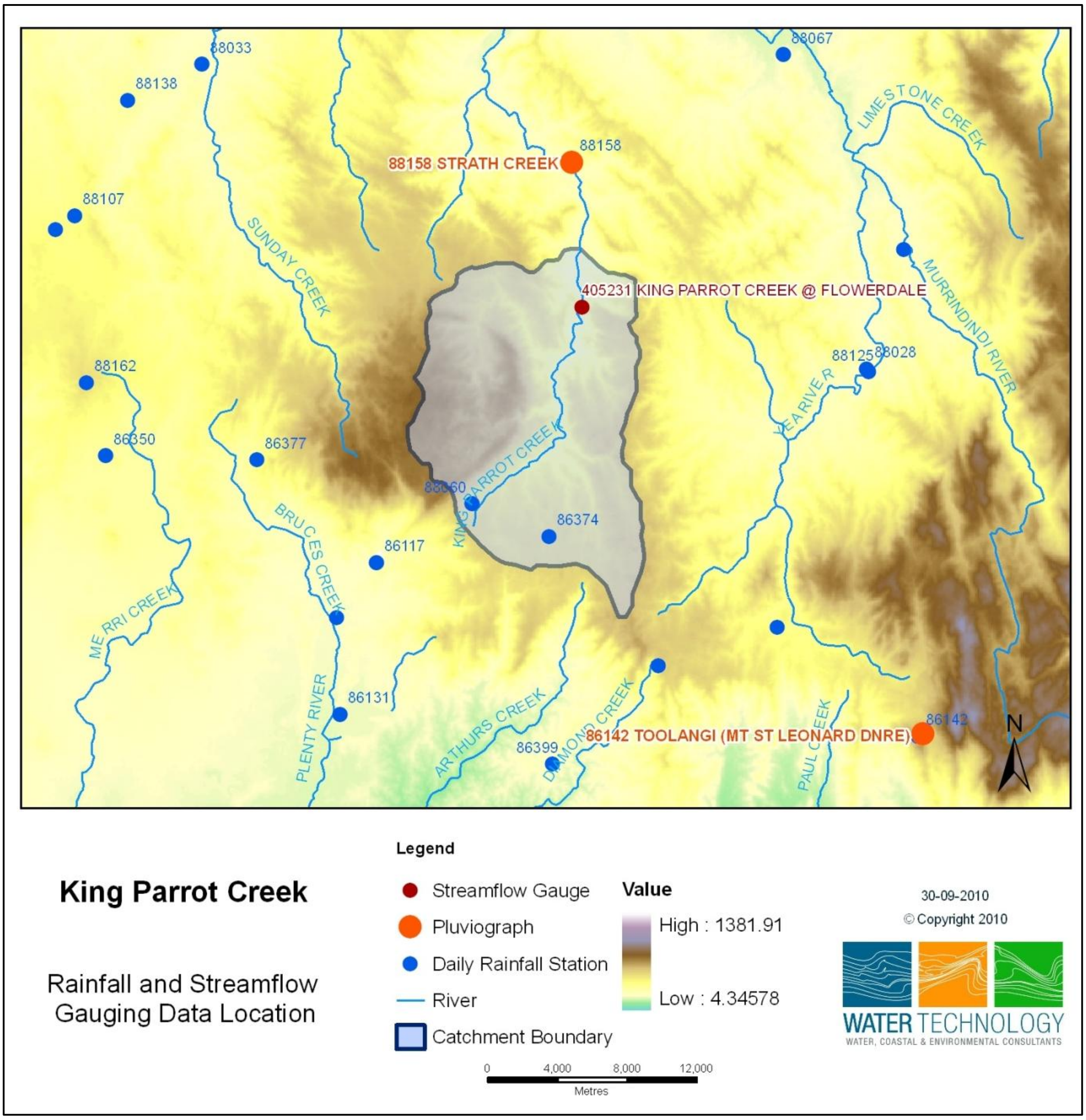

Figure 3-2 Rainfall and streamflow gauging data location

Table 3-1 Calibration events at King Parrot Creek @ Flowerdale (405231)

Year	Peak flow (ML/d)	Event dates	Pluviograph location
1984	5770	17-19 September 1984	86142 Toolangi
1989	9930	10-11 June 1989	86142 Toolangi
1996	5220	23-24 June 1996	86142 Toolangi
2005	7250	2-3 February 2005	88158 Strath Creek

Daily rainfall totals were available for each event at a range of stations within and surrounding the catchment (Figure 3-2). Rainfall totals derived from these stations for each calibration event (for the event dates defined in Table 3-1) were interpolated to give a continuous surface of total event rainfall across the catchment. Rainfall totals at each RORB subarea were then extracted from the interpolated surface. The spatial pattern of the total rainfall for the four calibration events are shown in Figure 3-4.

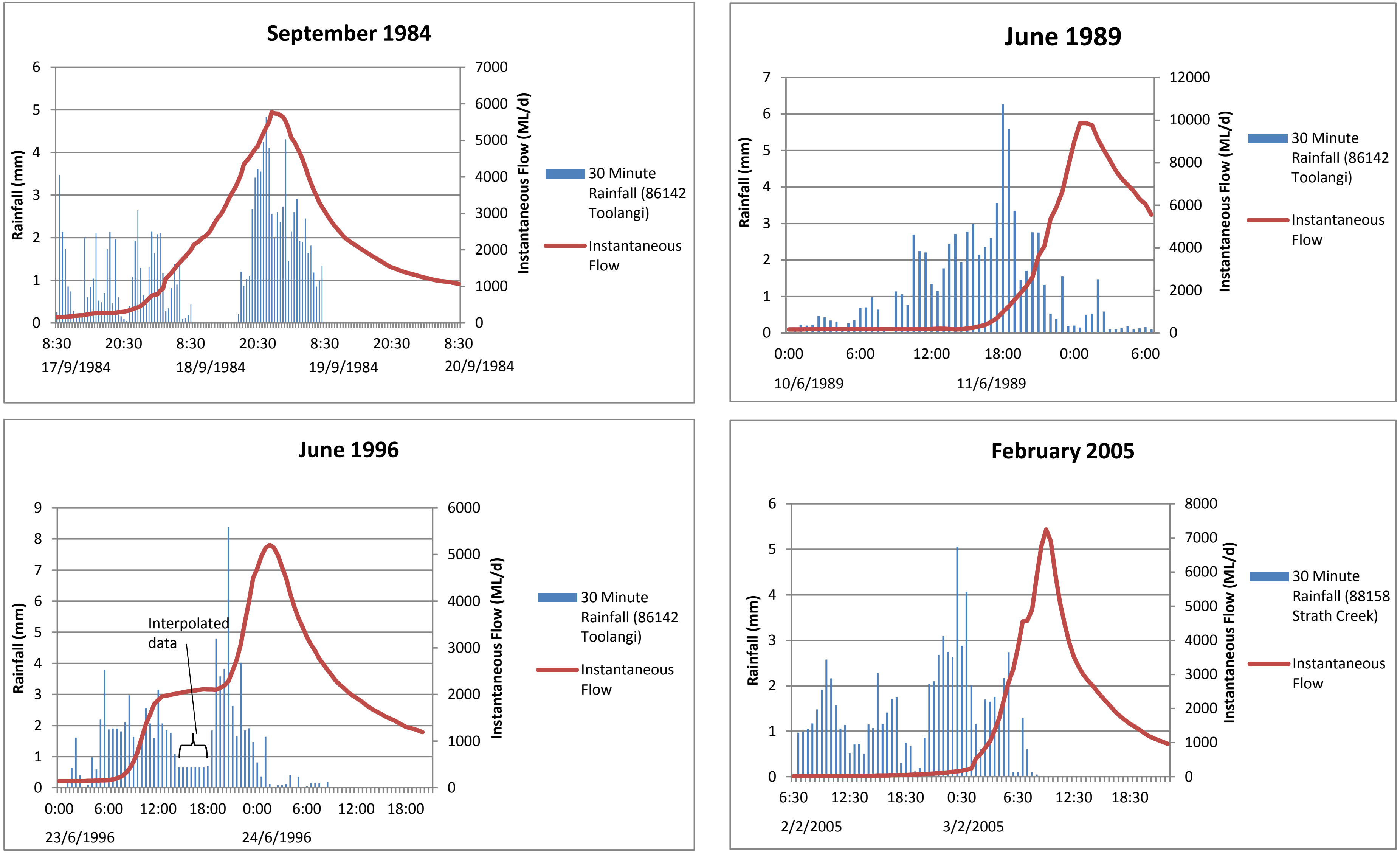

Figure 3-3 **Calibration event hyetographs and instantaneous flow hydrographs**

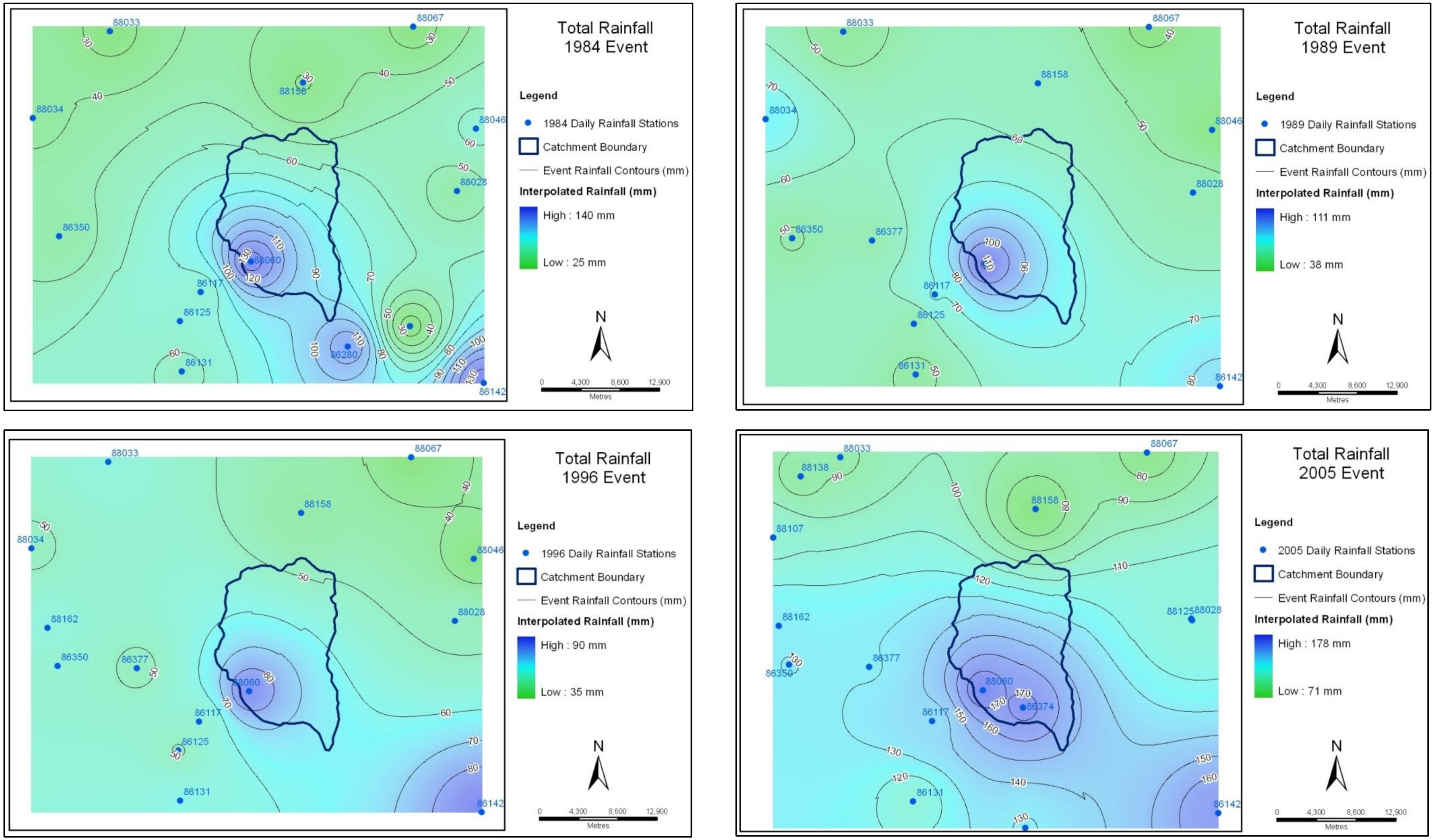

Figure 3-4 Total rainfall across catchment for calibration events

3.3.2 Calibration Results

The RORB model was run using the initial loss/continuing loss model. The RORB storage and loss parameters – k_c, m, initial loss (IL) and continuing loss (CL) – were fitted for each calibration event to give the best fit to the observed hydrographs. Priority was given to fitting the hydrograph peak, with the hydrograph shape, volume and timing fitted as a lower priority. The exponent m was set to 0.8. The following suggested values of k_c (from RORBWin 6.15) were used to guide the selection of this parameter:

- Default (Eqn 2.4 RORB Manual) k_c = 31.14
- VIC (MAR > 800 mm) – Eqn 3.21, ARR(BkV) k_c = 27.91
- Victoria Data (Pearse et al. 2002) k_c = 18.76

The calibration was first undertaken as a FIT run, where the hydrograph volume is automatically preserved by changing the continuing loss, while kc, m and the initial loss can be adjusted by the user. The best fits were achieved by the parameter sets in Table 3-2 below. The calibration was repeated as a DESIGN run, whereby all four parameters were manipulated to get the best fit without necessarily preserving volume. The parameter sets were similar to those obtained for the FIT runs (Table 3-3).

Table 3-2 Calibrated parameter sets for FIT runs (hydrograph volume is preserved)

Calibration event	k_c	m	IL (mm)	CL (mm/hr)
Sep 1984 Toolangi	30	0.8	0	2.01
Jun 1989 Toolangi	21	0.8	15	3.02
Jun 1996 Toolangi	23	0.8	0	2.4
Feb 2005 Strath Creek	15	0.8	30	9.25

Table 3-3 Calibrated parameter sets for DESIGN runs (hydrograph volume not necessarily preserved)

Calibration event	k_c	m	IL (mm)	CL (mm/hr)	% error in volume
Sep 1984 Toolangi	30	0.8	0	2	-18.6%
Jun 1989 Toolangi	21	0.8	15	3	-5.4%
Jun 1996 Toolangi	19	0.8	0	2.8	-21.9%
Feb 2005 Strath Creek	15	0.8	30	9.2	-1.2%

The k_c values obtained by calibration are consistent with the range of suggested values. The best fit was obtained for the June 1989 event. The loss parameters for this event were consistent with values suggested in ARR87. The calibration for the 1996 and 2005 events had a reasonable fit, however a reasonable fit could not be achieved for the 1984 event. The temporal pattern of rainfall obtained from the Toolangi gauge appears to be unrepresentative of the temporal pattern across the catchment. Initial and continuing losses for the February 2005 event were considerably higher than the other events. However, it is expected that losses are likely to be somewhat higher in summer due to dry preceding catchment conditions. These losses were within the range of losses observed by Hill et al. (1998) for Victorian catchments.

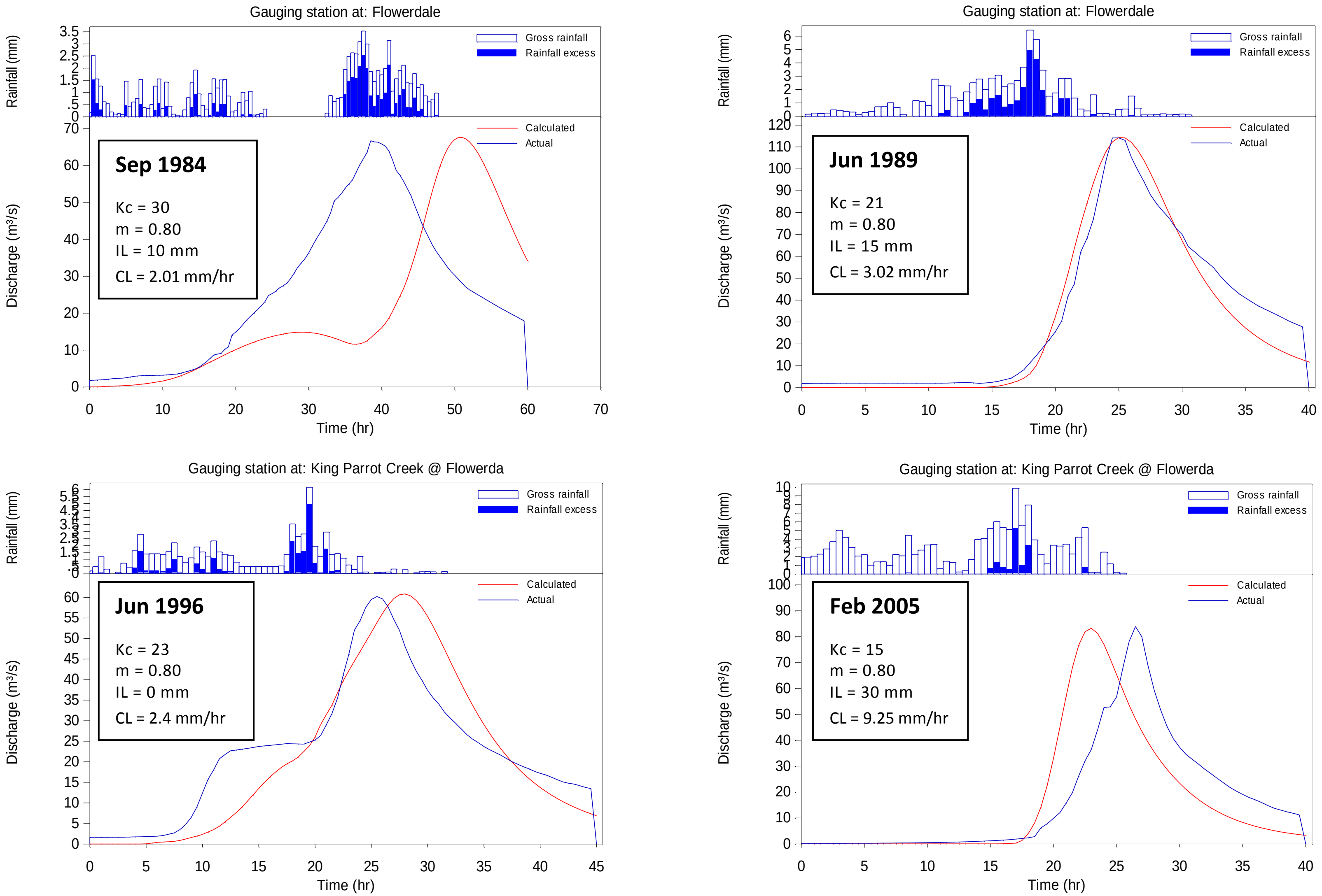

Figure 3-5 Calibration results for FIT runs (hydrograph volume is preserved)

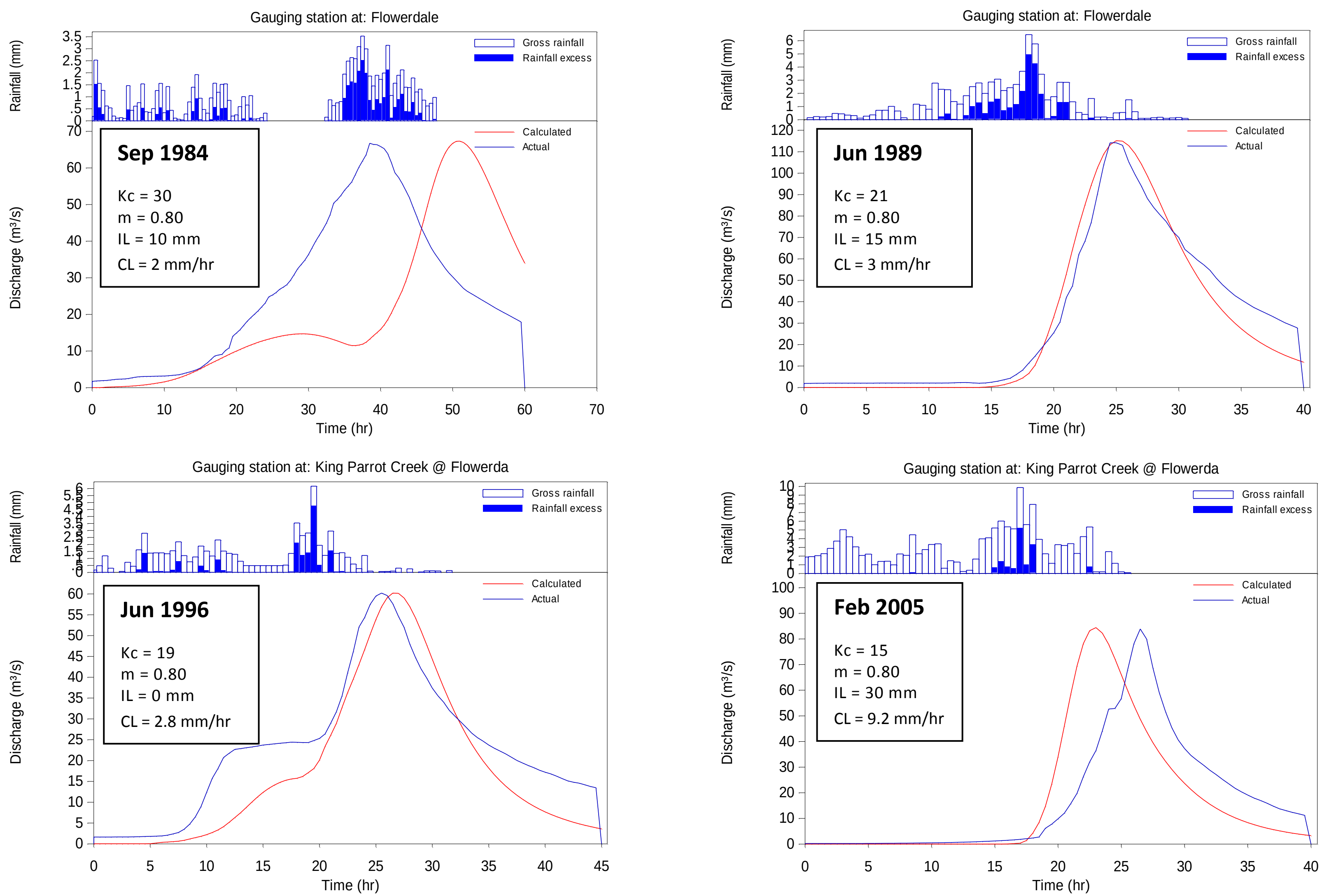

Figure 3-6 Calibration figures for DESIGN runs (hydrograph volume not necessarily preserved)

3.4 Model Verification for Design Flood Estimation

3.4.1 Approach

The model parameters need to be verified for their suitability for design flood estimation. In particular, the rainfall loss parameters are influenced by the initial catchment soil moisture content and hence the loss parameters from the calibration events cannot be applied directly to estimate design flows.

Design rainfall loss parameters have been developed for Victoria by the Cooperative Research Centre for Catchment Hydrology (Hill et al 1998). These design losses have been shown to provide estimates of peak design flows that are more consistent with flood frequency analysis than the current ARR87 losses. A consistency of design flow estimates between runoff routing models and flood frequency analysis indicates that the runoff routing parameters are resulting in design peak flow estimated with the same ARI as the causative rainfall.

The following procedure was followed to verify the RORB model for use in design flow estimation:

- Determine design rainfall losses according to the predictive equations of Hill et al. (1998)
- Determine design peak flows for King Parrot Creek at the Flowerdale gauge using the RORB model with the calibrated routing parameters k_c and m and the design rainfall losses from Hill et al (1998)
- Compare the design peak flows from the RORB model with the results of the flood frequency analysis from section 2. Adjust the loss parameters until a reasonable match is obtained between the two.

3.4.2 Design Routing Parameters

A k_c of 21 and m of 0.8 were adopted for design flood estimation. These values resulted in the best fit for the June 1989 calibration event, which was the largest calibration event. A good fit was achieved for the June 1996 flood with a similar k_c value of 19. The k_c values required for the calibration of the September 1984 and February 2005 floods were 30 and 15 respectively. However the fit for these events was poorer than the other two. The adopted value of k_c = 21 is consistent with the regional prediction formula of Pearse et al (2002).

3.4.3 Design Rainfalls

Design rainfalls were calculated for the 20, 50 and 100 year ARI events using the Intensity-Frequency-Duration (IFD) analysis from ARR87. The IFD parameters were obtained from the Bureau of Meteorology's IFD program website (www.bom.gov.au/ifd) for the catchment centroid (see Table 3-4 and Table 3-5).

Table 3-4 IFD parameters

2yr 1hr rainfall intensity (mm/hr)	20.15
2yr 12hr rainfall intensity (mm/hr)	4.86
2yr 72hr rainfall intensity (mm/hr)	1.43
50yr 1hr rainfall intensity (mm/hr)	40.03
50yr 12hr rainfall intensity (mm/hr)	8.51
50yr 72hr rainfall intensity (mm/hr)	2.58
Skew	0.30
F2	4.3
F50	15.02

Table 3-5 IFD table showing rainfall intensity in mm/hr for various durations and Average Recurrence Intervals

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins	50.7	67.1	90.9	107	128	158	182
6Mins	47.5	62.8	85	99.9	120	147	170
10Mins	38.7	51	68.6	80.4	95.8	118	136
20Mins	27.8	36.5	48.7	56.6	67.3	82.2	94.4
30Mins	22.4	29.4	38.9	45.2	53.5	65.2	74.7
1Hr	15.2	19.9	26.1	30	35.4	42.9	48.9
2Hrs	10.3	13.4	17.3	19.7	23.1	27.7	31.5
3Hrs	8.19	10.6	13.6	15.4	18	21.5	24.3
6Hrs	5.56	7.14	8.99	10.1	11.7	13.9	15.6
12Hrs	3.72	4.76	5.93	6.64	7.64	8.99	10.1
24Hrs	2.4	3.08	3.83	4.29	4.93	5.81	6.49
48Hrs	1.48	1.9	2.39	2.69	3.1	3.67	4.11
72Hrs	1.09	1.41	1.77	1.99	2.3	2.72	3.06

Filtered temporal patterns from ARR87 for Zone 2 were applied for the design events. Rainfall depths were applied uniformly across the catchment.

Areal reduction factors from Siriwardena and Weinmann (1996) were applied to the point design rainfall estimates. These areal reduction factors are recommended for use in Victoria instead of the original ARR87 values (Hill et al. 1998)

3.4.4 Design Losses

Design losses were estimated by the design loss prediction equations developed by Hill et al (1998). The losses currently recommended in ARR87 consistently overestimate peak flows. The new losses, in combination with the new areal reduction factors from Siriwardena and Weinmann (1996), produced peaks that were more consistent with the results of flood frequency analysis.

The initial loss is calculated by first calculating the storm initial loss using Equation 1, then the burst initial loss (Equation 2). The burst initial loss varies with storm duration and accounts for the embedded nature of ARR87 design rainfalls (Hill et al 1998). The continuing loss is estimated using Equation 3.

Storm Initial Loss:

$$IL_s = -25.8BFI + 33.8 \qquad (1)$$

Burst Initial Loss:

$$IL_b = IL_s \left\{ 1 - \frac{1}{1+142\frac{\sqrt{duration}}{MAR}} \right\} \qquad (2)$$

Continuing Loss:

$$CL = 7.97BFI + 0.00659PET - 6.00 \qquad (3)$$

In these equations:

- BFI is the baseflow index, the volume of baseflow divided by the total streamflow volume. It is a fixed value for a given catchment, determined as an average ratio over a long period of time. The BFI was calculated using the eWater toolkit River Analysis Package (RAP). RAP uses the Lyne and Hollick digital filter to separate a flow series into quick and slow response components. The filter was applied to daily instantaneous data from 1974 to 2010 to calculate the BFI.
- MAR is the mean annual rainfall in mm. The MAR was derived from Bureau of Meteorology climate maps.
- PET is the potential evapotranspiration. The PET was derived from maps of areal PET in Grayson et al (1996).

The design rainfall loss estimates derived from the above equations for King Parrot Creek are presented in Table 3-6.

Table 3-6 Hill et al (1998) design losses

Location		King Parrot Creek catchment
BFI		0.437
PET (mm)		1025
MAR (mm)		1100
IL_s (mm)		22.53
CL (mm/hr)		4.24
IL_b (mm)	duration 2 hr	3.48
	duration 3 hr	4.12
	duration 4.5 hr	4.84
	duration 6 hr	5.41
	duration 9 hr	6.29
	duration 12 hr	6.96
	duration 18 hr	7.97
	duration 24 hr	8.73

3.4.5 Verification of Design Losses

The design losses were verified by comparison of design flow estimates using the Hill et al (1998) losses and the flood frequency analysis (FFA). The estimates calculated using the Hill et al (1998) losses tended to be higher than the respective flows calculated by the FFA especially for the less frequent flows. The design flows were reconciled to the FFA by varying the initial loss to achieve consistency between the 10 and 20 year ARI design flows and the respective flows from the FFA. The FFA was calculated on a period of 48 years, so there is reasonable confidence around the estimates of the 10 and 20 year ARI floods, however the estimates for less frequent flows are less certain.

To reconcile the 10 year design flow to the FFA, an initial loss of 11.1 mm was required. For the 20 year design flow, an initial loss of 14.3 mm was required. The average of the two, 12.7 mm, was adopted as the design initial loss. The continuing loss from the Hill et al (1998) predictive equations (4.24 mm/hr) was adopted without alteration.

The design flows achieved with the adopted losses (with the initial loss reconciled to the FFA) were more consistent with the FFA over the range of ARIs. The critical duration was 4.5 hours for the 10 year ARI event and 6 hours for 20, 50 and 100 year ARIs. The design flows and losses are summarised in Table 3-7 below. The design flows (with Hill et al (1998) losses and reconciled losses) are plotted alongside the flood frequency analysis in Figure 3-7 for comparison.

Table 3-7 Design flows from verified design losses

ARI	RORB Design flow (Hill et al (1998) losses) (ML/d)	FFA Design flow (ML/d)	RORB Design flow (losses reconciled to FFA) (ML/d)	Adopted CL (mm/hr)	Adopted IL (reconciled to FFA) (mm)	Critical duration (hr)
10yr	8298	5833	5139	4.24	12.7	4.5
20yr	11769	7650	8355	4.24	12.7	6
50yr	16921	10053	13240	4.24	12.7	6
100yr	21076	11845	17423	4.24	12.7	6

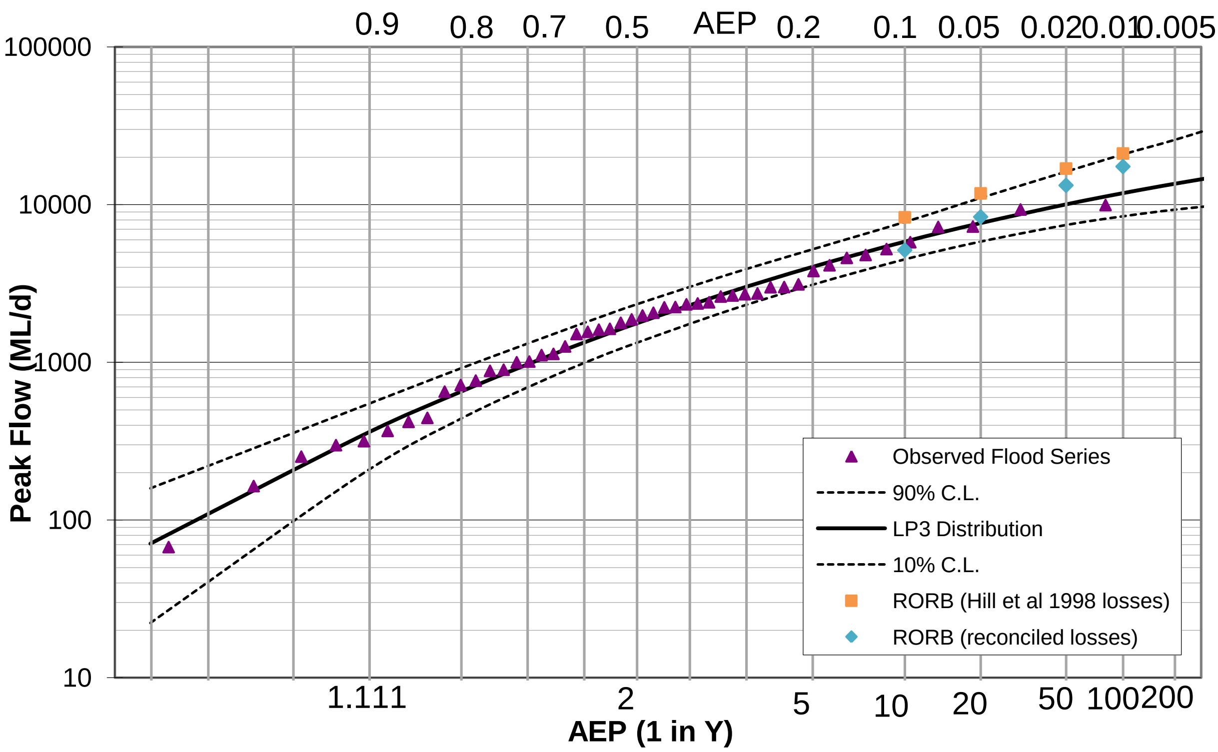

Figure 3-7 Verification of design flows against flood frequency analysis

The consistency between the design flows and the Flood Frequency Analysis indicates that the adopted design losses are appropriate for calculating design flows that have a similar ARI to the causative rainfall.

3.5 Design Flood Estimation using RORB Model

The parameters verified in Section 3.4 were used for estimation of design flows at the catchment outlet as described below.

3.5.1 Design Parameters

The design routing parameters and losses in Table 3-8 below were adopted for design. The routing parameters k_c and m were adopted as a result of calibration against the observed flows for the June 1989 flood in Section 3.3.2. The continuing loss (CL) was adopted from the prediction formula of Hill et al (1998) and the initial loss (IL) was reconciled to the flood frequency analysis. These parameters were verified for use in design flood estimation in Section 3.4.

Table 3-8 Design parameters

Parameter	Design value
kc	21
m	0.8
IL	12.7 mm
CL	4.24 mm/hr

3.5.2 Design Rainfalls

Design rainfalls were calculated for the 20, 50 and 100 year ARI events for the catchment centroid as described in Section 3.4.3.

3.5.3 Design Peak Flow Estimates

The RORB model was used with the above inputs to calculate design flows for 20, 50 and 100 year ARIs at the downstream model extent. The peak design flows are shown in Table 3-9 below.

Table 3-9 Design flows

ARI	Duration	Design flow at gauge (ML/d)	Design flow at downstream model extent (ML/d)
20yr	6 hr	8355	8351
50yr	6 hr	13240	13271
100yr	6 hr	17423	17518

4. DISCUSSION

4.1 Comparison with Previous Studies

To assess the reliability of the design flood estimates, they were compared to estimates obtained by other methods. The following regional prediction equation (Grayson et al 1996) is based on regression of 1% flood flows for catchments on either side of the Great Dividing Range in Victoria:

$$Q_{100}(m\text{^}3/s) = 4.67A^{0.763}$$

This equations was used to provide an estimate of the 100 year ARI peak flow for comparison with the design flood estimates. The equation gives an estimate of 23,015 ML/d for the 100 year peak flow (approximately 31% higher than the design flow estimate 17,518 ML/d).

To compare the design flow estimates with flood behaviour in neighbouring catchments they were plotted against data from the Yea Flood Study (Water Technology 2005) for the following sites:

- Yea River at Yea (URBS modelled flows)
- Yea River at Devlin's Bridge (Flood Frequency Analysis and URBS modelled flows)
- Boundary Creek at Yea (URBS modelled flows)

The peak flow estimates for these catchments are shown in Table 4-1.

The 20, 50 and 100 year ARI peak flows for these sites was plotted against their respective catchment area, as were the design flows for King Parrot Creek. Peak flows are expected to vary with catchment area in a power relationship, i.e. a straight line on a log-log graph of peak flow versus catchment area. Figure 4-1 shows that the peak flow estimates for King Parrot Creek fit such a relationship with the neighbouring catchments well.

The peak flows estimated from the regional prediction equation (Grayson et al 1996) are also shown on Figure 4-1. The regional prediction equation is consistently higher than 100 year ARI peak flow estimates for the four catchments. This indicates that the regional prediction equation is likely to overestimate the 100 year ARI flow in this region.

Table 4-1 Peak flow estimates comparison with neighbouring catchments

Catchment	Catchment area	ARI	Peak flow estimate (ML/d)			
			RORB model	URBS Model	Flood Frequency	Regional prediction equation $Q_{100} = 4.67A^{0.763}$
King Parrot Creek at downstream model extent	200.3	100yr	17518		11845	23015
		50yr	13271		10053	
		20yr	8651		7650	
Boundary Creek at Yea	45	100yr		6221		7366
		50yr		5530		
		20yr		4925		
Yea River at Devlins Bridge	358.2	100yr		23933	24970	35862
		50yr			21427	
		20yr			16762	
Yea River at Yea	908.2	100yr		36979		72933
		50yr		31795		
		20yr		27821		

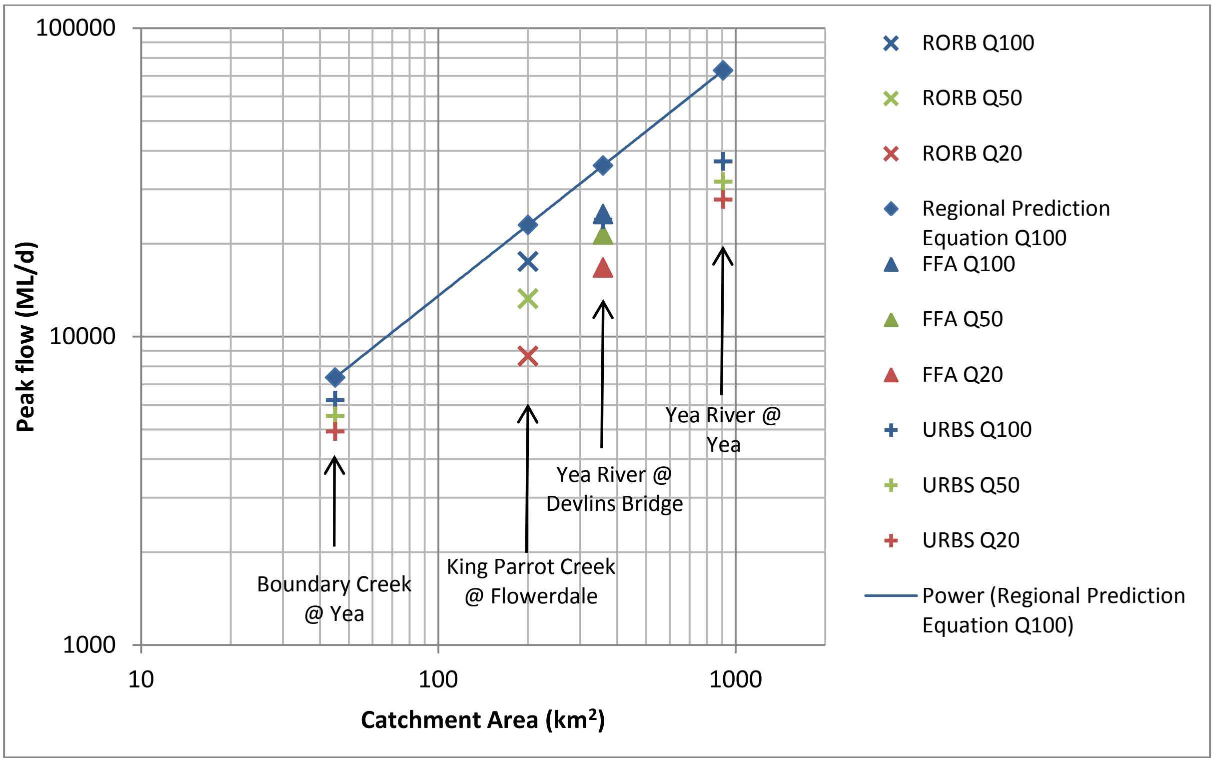

Figure 4-1 Peak flow estimates versus catchment area for King Parrot Creek and neighbouring catchments

The variation of the flows with ARI is shown in Figure 4-2. The peak flows have been divided by catchment area for easy comparison between the four catchments. The King Parrot Creek design flow estimates fit within the envelope of the neighbouring catchments and follow a similar pattern with increasing ARI.

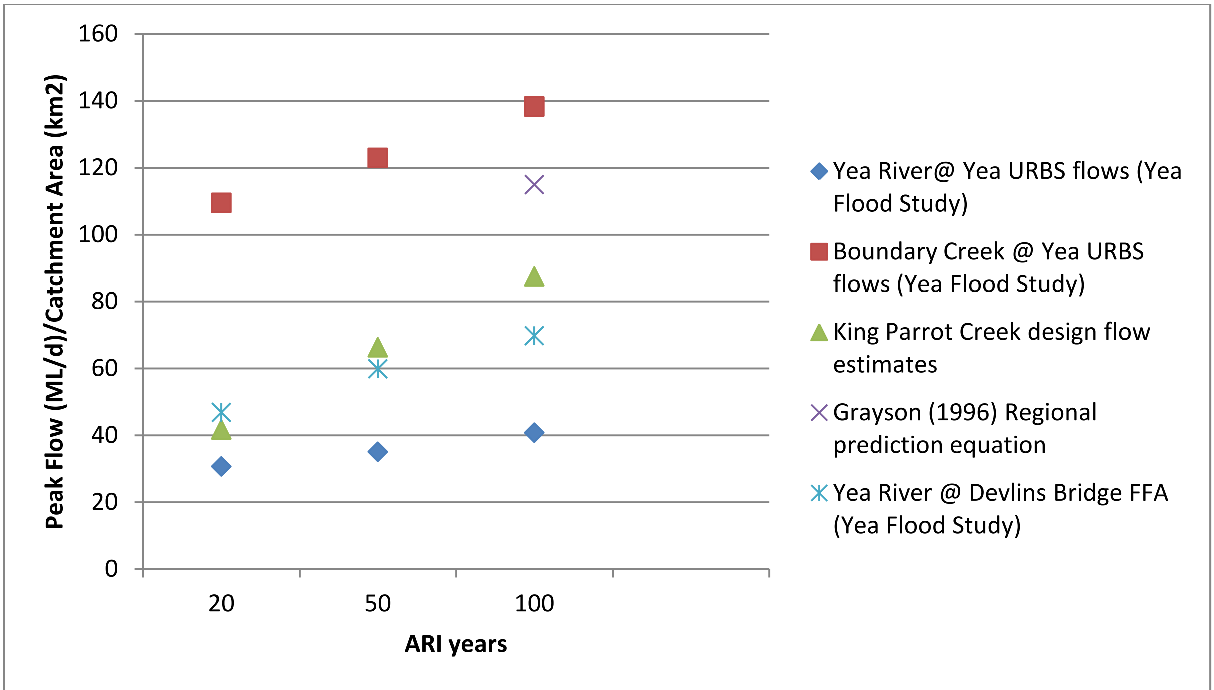

Figure 4-2 Peak flow estimates divided by catchment area for King Parrot Creek and neighbouring catchments – variation with ARI

4.2 Bushfire Impact on Hydrologic Regime and Flood Estimation

The King Parrot Creek catchment was almost entirely burnt in the February 2009 bushfires. Hence it is important to understand the effect bushfire might have on peak flood flows.

The relationship between catchment disturbance and water yield has been studied extensively in Australia, and particularly in Melbourne Water catchments. Kuzcera (1987) developed a water yield versus forest age relation for mountain ash catchments that were burnt in the bushfires of 1939. The Kuzcera curve (Figure 4-3) predicts a decline in water yield for 20-30 years after a bushfire, followed by a gradual recovery back to pre-fire conditions at about 100 years. The Kuzcera curve did not include an initial yield increase immediately after fire. In practice, following bushfires of sufficient intensity to kill trees, evapotranspiration (ET) is dramatically reduced, resulting in increased runoff (typically for 5-10 years after fire) (Feikema et al 2008). Watson et al (1999) included this effect in a revised relationship similar to the Kuzcera curve (see Figure 4-3).

Bushfires and subsequent loss of tree cover can not only affect the total amount of water lost through ET, but also the partitioning of water between surface runoff and groundwater recharge (Marcar et al 2006). The amount of water that enters the groundwater system depends on the rate at which water can infiltrate and percolate through the soil. The loss of the canopy and litter layer due to fire is likely to decrease the proportion of excess flow infiltrating into the soil and following sub-surface flow paths or contributing to groundwater recharge. Infiltration in naturally water-repellent soils is particularly affected by bushfire, as the fire can change the soil structure and remove preferential flow paths through the hydrophobic layer. Moody and Martin (2001) found in their literature review that infiltration rates have been shown to decrease by a factor of two to seven following fire.

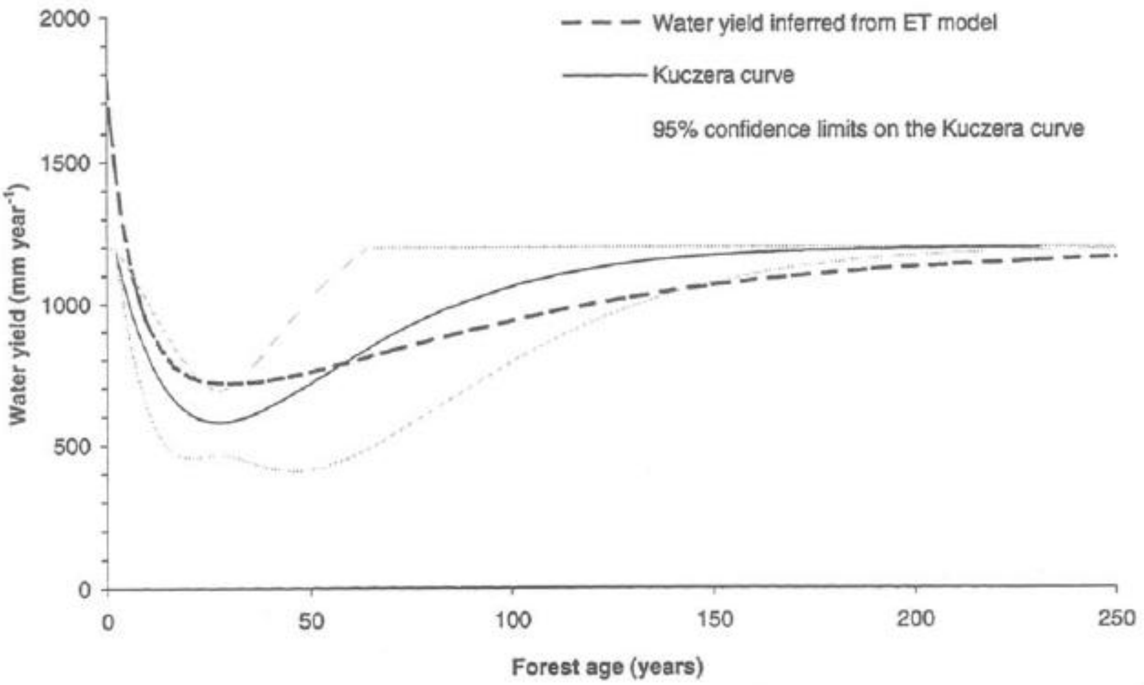

Figure 4-3 Average annual water yield relation with forest age – Kuzcera curve (1987) and inferred from ET (Watson et al 1999). In Feikema et al (2008)

A large volume of work in Australia focuses on long-term catchment yields following fire, however there has been less work done on peak flood flows. In the USA, Martin and Moody (2001) investigated changes to peak flow in three mountainous watersheds by comparing the unit-area peak discharge before and after fire. They found that immediately after fire, changes in peak discharges are larger than changes in annual runoff. However the increase in peak discharge is greater for more frequent, lower-intensity rainfall events than for rarer, higher-intensity events. For rainfall events with ARIs from 5 to 100 years, Rowe (1954, in Martin and Moody 2001) found that the unit area peak discharge shows a two to threefold increase in the first year after bushfire.

Without making quantitative predictions, indicative guidance is offered on the likely response of the flood regime in King Parrot Creek to the February 2009 bushfire. Over the first 5-10 years peak flows are likely to increase dramatically due to reduced ET and infiltration. The less extreme events are likely to experience a greater percentage increase than the more extreme events. The initial increase is expected to be followed by a decline to a minimum, around 20-30 years after the fire, then a gradual increase to pre-fire conditions 100-150 years after the fire. The implication for the design flow estimates is that the true likelihood of occurrence of each flow will vary and will not always be equal to the stated ARI as the catchment recovers.

4.3 Climate Change Impacts

The effect of potential climate change was explored using simple scenarios of increased rainfall intensity.

Although mean annual rainfall is likely to decline due to climate change, extreme precipitation is likely to increase in intensity. There is still a great deal of uncertainty around the likely change to extreme rainfall intensity. For the purposes of this study, a simple sensitivity analysis was adopted, rather than following any particular projection.

For each design event, the RORB design rainfall total was increased by 10% and 20% to simulate the effect of climate change. The design losses, design parameters and temporal rainfall patterns were held constant. The analysis showed that an increase in rainfall intensity of 10% resulted in an increase of 23-31% in the design flow estimates (see Table 4-2 below). An increase in rainfall intensity of 20% resulted in design flow increases of 47-65%. More common flows are more affected by the increase in rainfall intensity, although in reality it is likely that rarer events will experience a greater increase in rainfall intensity rather than a constant increase across the range of ARIs. The critical storm duration was increased from 6 hours to 9 hours under the increased rainfall intensity scenarios.

Table 4-2 Climate change impacts on design flows

	Historic conditions		+10% rainfall intensity			+20% rainfall intensity		
ARI	Duration	Design flow (ML/d)	Duration	Design flow (ML/d)	% increase	Duration	Design flow (ML/d)	% increase
20yr	6 hr	8,351	9hr	10,956	31%	9hr	13,746	65%
50yr	6 hr	13,271	9hr	16,718	26%	9hr	20,287	53%
100yr	6 hr	17,518	9hr	21,546	23%	9hr	25,828	47%

The results of the sensitivity analysis show that any increase in extreme rainfall intensity due to climate change is likely to be amplified two to three times in the magnitude of extreme flows.

4.4 Melbourne Water Diversions from Wallaby and Silver Creeks

Melbourne Water currently operates diversion weirs and aqueducts on the Wallaby and Silver Creeks, the effects of which have not been explicitly accounted for in this analysis. The diversions have been in operation since 1884, hence the effect of the diversions has been included in the streamflow data used for flood frequency analysis and calibration of the RORB model.

The average diversions are small in comparison to the design flow estimates (see Table 4-3 below). Since the 2003-04 water year the annual diversion has not exceeded 9300 ML/a (average daily diversion 25 ML/d). Hence the effect of average diversions on design flows is expected to be insignificant. The bulk entitlement held by Melbourne Water is 22,000 ML/a (average 60 ML/d) (Melbourne Water Sustainability Report 2008-09) and the aqueduct capacity is 150 ML/d (Melbourne Water 2004). Melbourne Water has not approached their bulk entitlement in recent years and even if they operated the diversion at full capacity the effect would be small.

Table 4-3 Usage (from State Water Reports 2003-04, 2004-05 and 2005-06, Victorian Water Accounts 2006-07 and 2007-08 and Melbourne Water Sustainability report 2008-09)

Year	Silver and Wallaby Creeks diversion to Yarra basin (ML/a)	Average daily volume (ML/d)
2008-09	1070	3
2007-08	1100	3
2006-07	1200	3
2005-06	5300	15
2004-05	9300	25
2003-04	3000	8

5. DESIGN FLOWS FOR HYDRAULIC MODELLING

5.1 1D Modelling Inputs

Design flows were required for input to the hydraulic model at three locations:

- Upstream of confluence with Silver Creek,
- Upstream of confluence with Gum Creek (including flow from Silver Creek), and
- Total flow to catchment outlet

The design flows are given in Table 5-1 below, for 20, 50 and 100 year ARI events and the 100 year ARI climate change (increased rainfall intensity) scenarios.

Table 5-1 Design flows for input to hydraulic model

ARI	Duration	Total flow u/s of Silver Creek (ML/d)*	Total flow from Silver to Gum Creek (ML/d)#	Total flow at d/s model extent (ML/d)^
20yr	6 hr	5,968	8,124	8,351
50yr	6 hr	9,375	12,794	13,271
100yr	6 hr	12,290	16,786	17,518
100yr (+10% intensity)	9 hr	13,909	19,460	21,546
100yr (+20% intensity)	9 hr	16,453	23,066	25,828

* sub-catchments A-Z and AA (see Figure 3-1)
# add sub-catchments AG-AP and AS
^ all sub-catchments

5.2 2D Modelling Inputs

Design flow hydrographs were required for a 2D unsteady hydraulic model of the King Parrot Creek study reach from upstream of Silver Creek to the downstream model extent. Hydrographs were provided at the upstream and downstream extents and at tributary inflow locations (total 12 locations) for the five design events (20, 50 and 100 year ARI events and the 100 year ARI climate change (increased rainfall intensity) scenarios) and the 1989 calibration event. The flow hydrographs are shown in Figure 5-1 to Figure 5-6 below. The names of the hydrographs refer to the subcatchments contributing to that hydrograph. Refer to Figure 3-1 for the location of hydrographs.

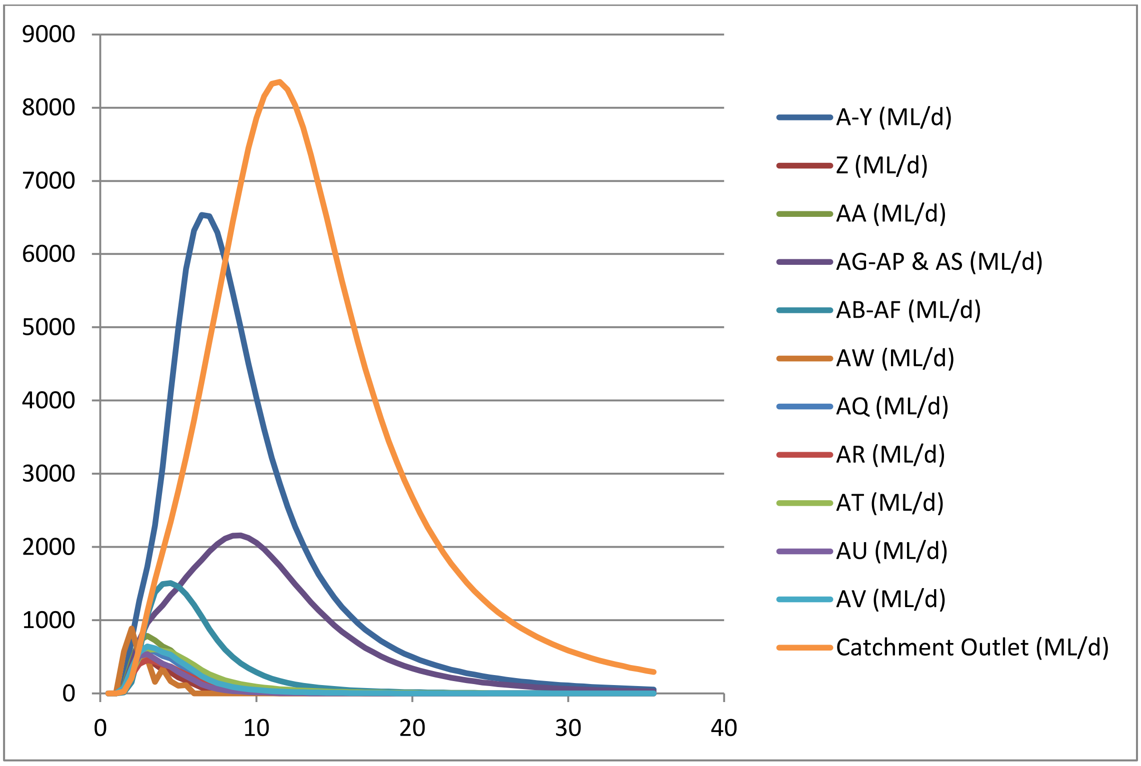

Figure 5-1 **Hydraulic model inflow hydrographs for King Parrot Creek and tributaries for 20 yr 6 hr design event**

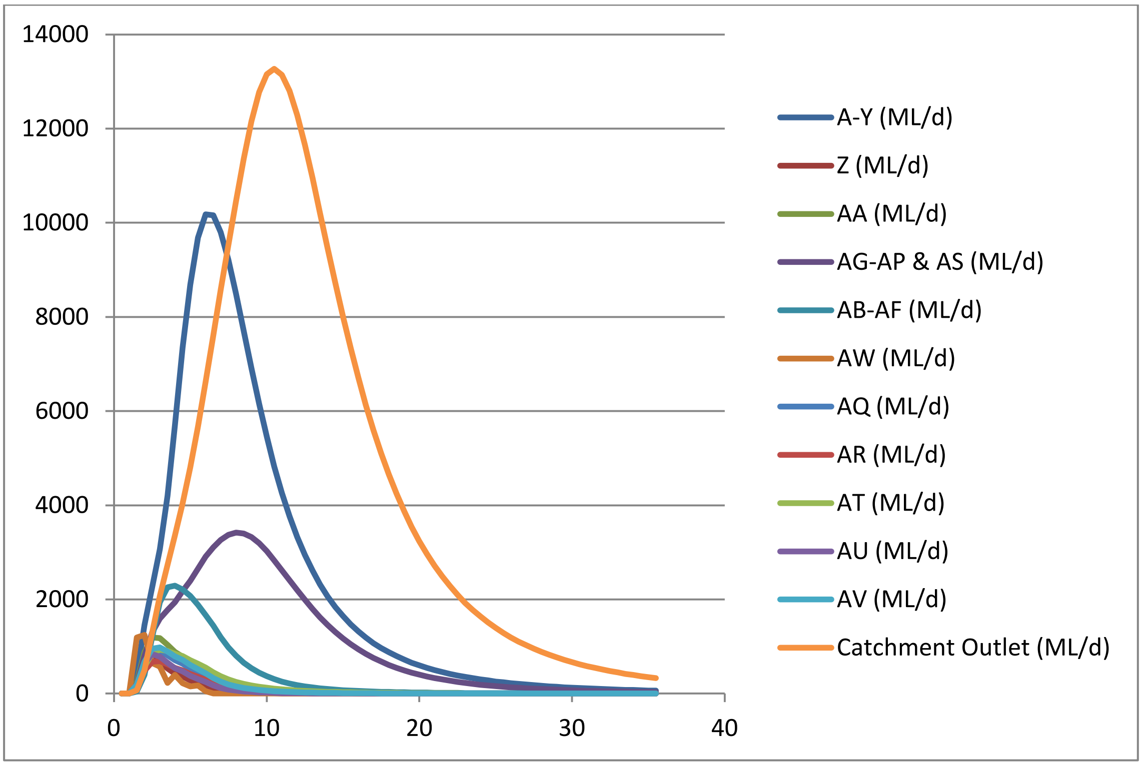

Figure 5-2 **Hydraulic model inflow hydrographs for King Parrot Creek and tributaries for 50 yr 6 hr design event**

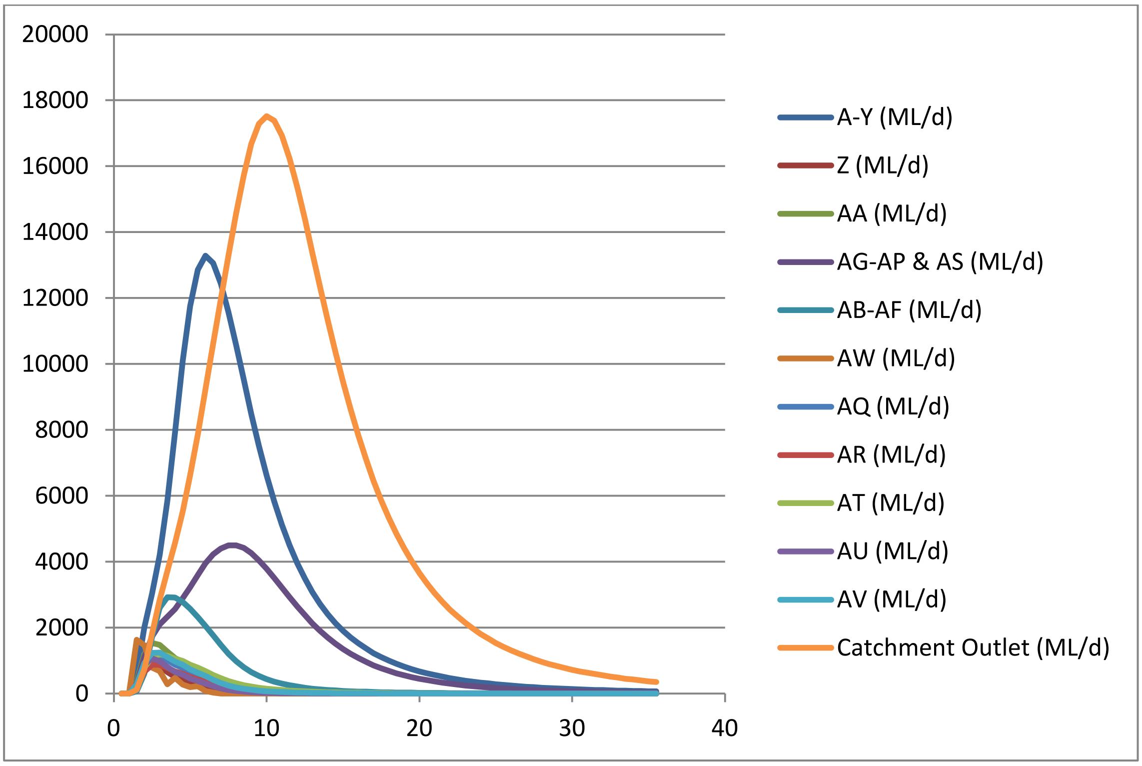

Figure 5-3 Hydraulic model inflow hydrographs for King Parrot Creek and tributaries for 100 yr 6 hr design event

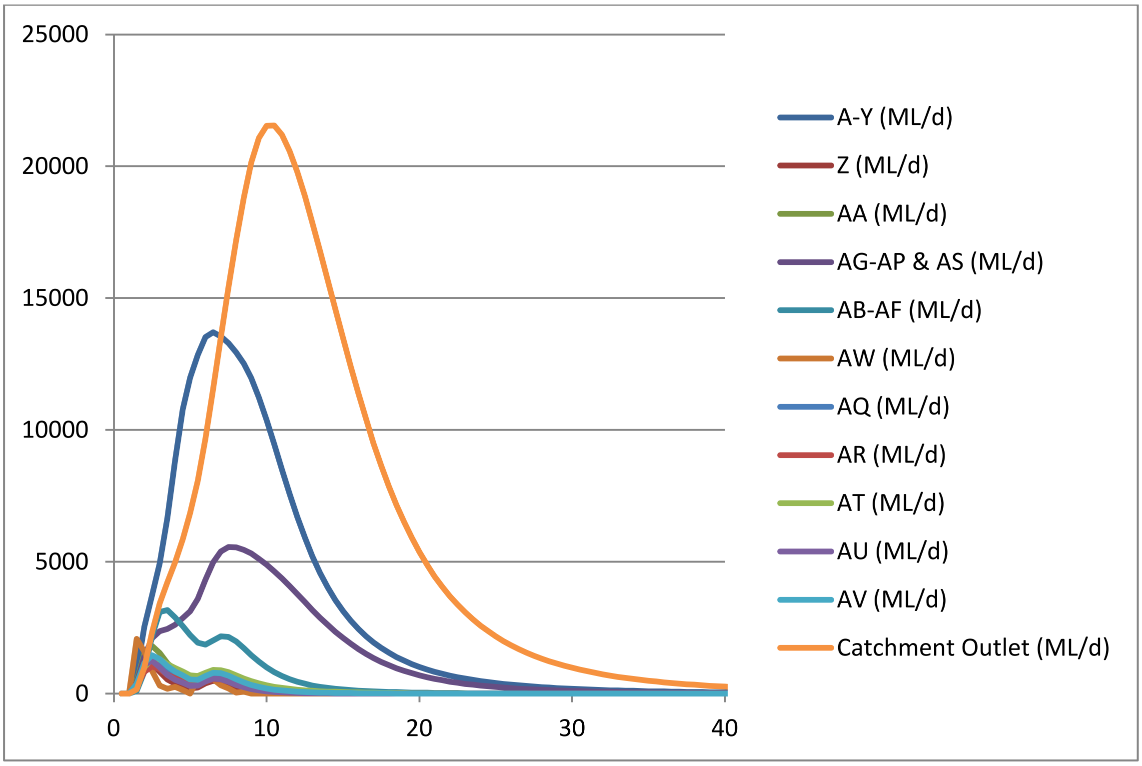

Figure 5-4 Hydraulic model inflow hydrographs for King Parrot Creek and tributaries for 100 yr 9 hr (+10% rainfall intensity) climate change scenario design event

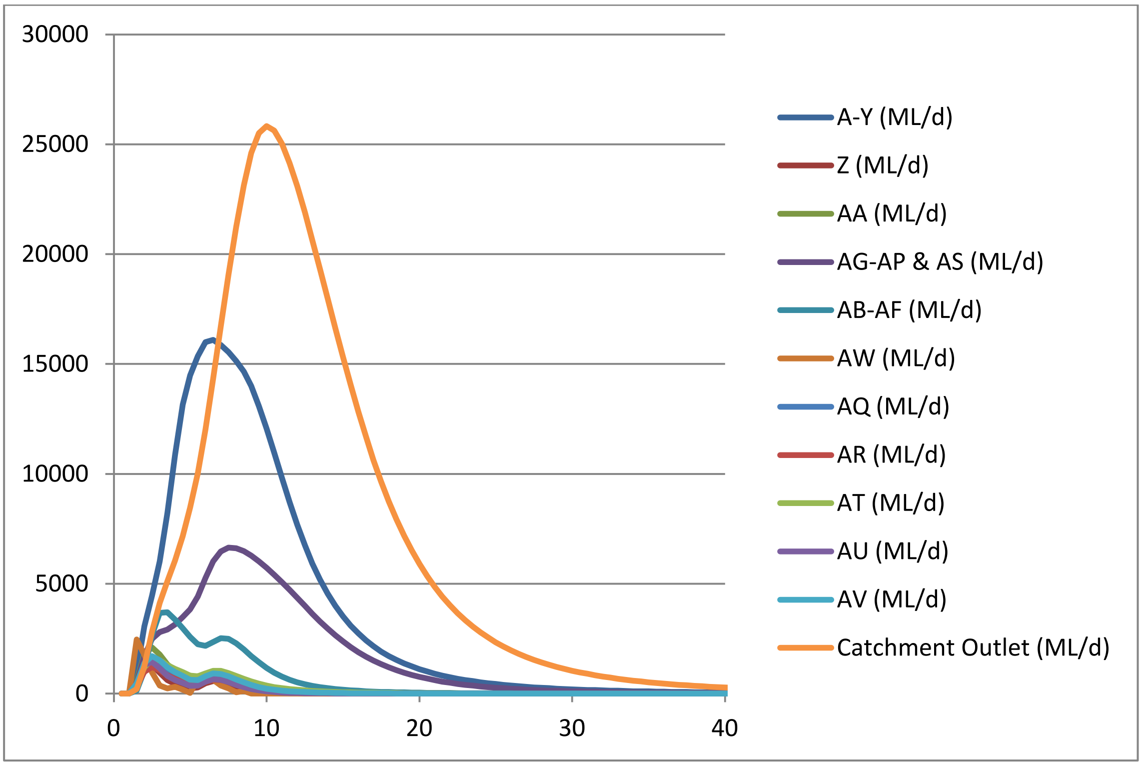

Figure 5-5 **Hydraulic model inflow hydrographs for King Parrot Creek and tributaries for 100 yr 9 hr (+20% rainfall intensity) climate change scenario design event**

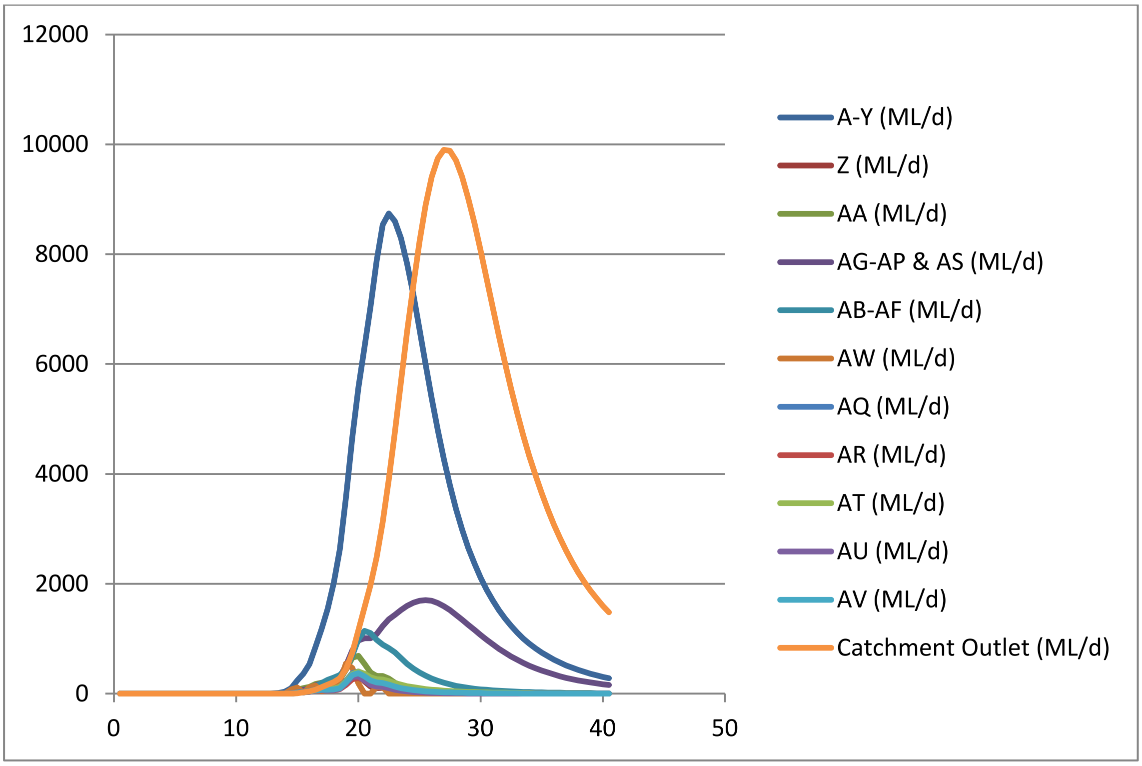

Figure 5-6 **Hydraulic model inflow hydrographs for King Parrot Creek and tributaries for 1989 calibration event**

6. REFERENCES

Feikema, P., Lane, P. And Sherwin, C. (2008) *Hydrological studies into the impact of timber harvesting on water yield in state forests supplying water to Melbourne – Part 2 of Hydrological studies (Climate Change and Bushfire)*. School of Forest and Ecosystem Science, The University of Melbourne.

Grayson, R.B., Argent, R.M., Nathan, R.J., McMahon, T.A and Mein, R.G (1996) *Hydrological Recipes: Estimation Techniques in Australian Hydrology*. Cooperative Research Centre for Catchment Hydrology, Clayton, Victoria.

Hill, P., Mein, R. And Siriwardena, L. (1998) How Much Rainfall Becomes Runoff? Loss modelling for flood estimation. Report 98/5. Cooperative Research Centre for Catchment Hydrology, Clayton, Victoria.

Kuzcera, G. (1987) Prediction of water yield reductions following a bushfire in ash-mixed species eucalypt forest. *Journal of Hydrology* 94, 215-236.

Laurenson, E.M., Mein, R.G., and Nathan, R.J. (2007) *RORB Version 6 User Manual,* Monash University Department of Civil Engineering and Sinclair Knight Merz Pty. Ltd.

Marcar, M.E., Benyon, R.G., Polglase, P.J., Paul, K.I, Theiveyanathan, S. and Zhang, L. (2006) *Predicting the hydrological impacts of bushfire and climate change in forested catchments of the River Murray Uplands: A review.* CSIRO: Water for a Healthy Country National Research Flagship.

Melbourne Water (2004) Watertight Goal, *The Source: A magazine by Melbourne Water*, Issue 31, August 2004.

Melbourne Water Sustainability report 2008-09. Melbourne Water, East Melbourne.

Moody, J.A. and Martin, D.A. (2001) Post-fire, rainfall intensity–peak discharge relations for three mountainous watersheds in the western USA. *Hydrological Processes* 15, 2981-2993.

Pearse M., Jordan, P. and Collins, Y. (2002) A simple method for estimating RORB model parameters for ungauged rural catchments. *27th Hydrology and Water Resources Symposium*, Melbourne. Institution of Engineers, Australia. 2002

Pilgrim, D.H. (1987) *Australian rainfall and runoff: a guide to flood estimation (AR&R).* Institute of Engineers Australia.

Rowe, P.B., Countryman C.M. and Storey, H.C. (1954) *Hydrologic analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds.* US Department of Agriculture, Water Resources Centre Archives, University of California, Berkely; 48.

RWC (1990) *Victorian Surface Water Information to 1987*, Volume 3, River Basins 1-5, Rural Water Commission of Victoria, Armadale, Victoria.Grayson, R.B., Argent, R.M., Nathan, R.J., McMahon, T.A and Mein, R.G (1996) *Hydrological Recipes: Estimation Techniques in Australian Hydrology*. Cooperative Research Centre for Catchment Hydrology, Clayton, Victoria.

Siriwardena, L. and Weinmann, P.E. (1996). *Derivation of areal reduction factors for design rainfalls in Victoria for rainfall durations 18-120 hours*. Report 96/4, Cooperative Research Centre for Catchment Hydrology, Clayton, Victoria.

State Water Report 2003-2004, Victorian Government Department of Sustainability and Environment, Melbourne.

State Water Report 2004-2005, Victorian Government Department of Sustainability and Environment, Melbourne.

State Water Report 2005-2006, Victorian Government Department of Sustainability and Environment, Melbourne.

Victorian Water Accounts 2006-2007, Victorian Government Department of Sustainability and Environment, Melbourne.

Victorian Water Accounts 2007-2008, Victorian Government Department of Sustainability and Environment, Melbourne.

Water Technology (2005) *Yea Flood Study*. Report Number J054/R04.

Water Technology (2009) *Goulburn River Environmental Flows Hydraulics Study: Hydrologic analysis Streamflow data assessment and Tributary inflow analysis*. Report Number J804_R02.

Watson, F.G.R., Vertessy, R.A. and Grayson, R.B. (1999) Large-scale modelling of forest hydrological processes and their long-term effect on water yield. *Hydrological Processes* 13, 689-700.