MURRAY-DARLING BASIN COMMISSION

Risks to Shared Water Resources

Impact of the 2003 Alpine Bushfires on Streamflow
Seasonal streamflow response

December 2007

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Published by Murray-Darling Basin Commission
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This report may be cited as: Impact of the 2003 Alpine Bushfires on Streamflow - Seasonal streamflow response

MDBC Publication No. 25/08

ISBN 978 1 921257 65 0

This project was funded by the Department of Sustainability and Environment, the Murray-Darling Basin Commission, the Gippsland Lakes Taskforce, the North East Catchment Management Authority and the East Gippsland Catchment Management Authority.

Contents

Executive Summary

A project was established under the Department of Sustainability and Environment's Bushfire Recovery Program to predict the magnitude and duration of changes to the quality and quantity of water available to downstream users following the 2003 alpine bushfires. Task 1 of the project made a broadscale assessment of water yield impacts over the entire burnt area in Victoria and selected parts of New South Wales. The broadscale assessment considered annual changes in streamflow resulting from the fires. Tasks 2 and 3 of the program involved the development and application of the Macaque model to investigate the changes in annual streamflow for the Mitta Mitta catchment.

While there is a significant body of research reported on the impact of changes in forest age (resulting from both logging and bushfires) on mean annual streamflow, there is far less information on the within-year or seasonal impacts. Task 4, which is the focus of this report, is aimed at examining these seasonal impacts on streamflow.

The Macaque model was calibrated and applied to two sub-catchments of the Mitta Mitta River located upstream of Dartmouth Dam: Livingstone Creek and Big River. Macaque is a daily catchment model, which has detailed parameterisation based on physical properties, with key spatial parameters including topography, precipitation, vegetation leaf area index and soils. Macaque was calibrated to streamflow gauging data for the two sub-catchments. Simulation experiments were conducted with Macaque to assess the seasonality of changes in water yield based on the consideration of spatial and temporal changes in topography, forest species and rainfall.

These simulations provided an opportunity for various changes to be made to the catchment characteristics, which allowed the within-year streamflow impacts to be investigated under a range of conditions. Simulations included:

- A Base Case, which provided baseline conditions for comparison.
- Changes in forest type. The entire catchment area was covered with Mountain Ash, Mixed Species or Snowgum forest.
- Changes to the catchment elevation. The entire catchment elevation was lowered.
- For the Livingstone Creek catchment, additional changes included: stretching the catchment elevation to conditions similar to Big River, modifying the rainfall series used, and changing the forest cover.

The average of the thirteen Macaque model simulations (five for Big River and eight for Livingstone Creek) revealed that approximately 21% of the mean annual reduction in flow would be experienced in summer, 11% in autumn, 27% in winter and 41% in spring. In all of the model simulations, the seasonality of the change in mean annual runoff was consistent between the second and ninth decades after the bushfire.

There was very little variation in the proportional contribution in each season to the reduction in annual streamflow between the Macaque model experiments. The largest variations in the seasonal proportions were about 5% from the average values. This indicates that the seasonality of the streamflow impacts is remarkably consistent between the Big River and Livingstone Creek catchments, even though they have very different catchment characteristics.

The average proportional contributions to reductions in mean annual flow, as estimated from the thirteen model simulations, were therefore adopted for transposition across the study area. The distributions of catchment characteristics for Livingstone Creek and Big River generally span that from all of the catchments in the bushfire affected region. This supports the approach of applying the seasonal impact proportions for the Big River and Livingstone Creek simulations across the bushfire affected region without explicitly taking account of variations in physiographic characteristics.

Seasonal estimates of reduction in flow were estimated by multiplying the annual estimates of flow reduction from the Task 1 report by the seasonal proportional effects. These were then subtracted from the estimates of pre-fire runoff for each season for each catchment to estimate the changes in mean seasonal streamflow that would be expected for the maximum impact period, approximately 20 to 30 years after the fire. The predicted percentage impacts on mean summer flows were greater in all of the bushfire affected catchments than the predicted percentage impacts on mean annual flows. Conversely, the predicted percentage impacts on mean winter flows were less in all of the bushfire affected catchments than the predicted percentage impacts on mean annual flows.

The estimates of changes in seasonal streamflows have been estimated across the entire bushfire affected region by transposing Macaque model simulations from two sub-catchments of the Mitta Mitta River upstream of Dartmouth. They are regional estimates of streamflow impacts that are appropriate for a broadscale assessment. To derive more robust estimates of actual seasonal impacts in a particular catchment, it would be advisable to carry out a detailed study that would involve calibration and application of the Macaque model to that catchment.

1. Introduction

As a part of the Department of Sustainability and Environment's (DSE) Bushfire Recovery Program includes a project which aims to predict the magnitude and duration of changes to the quality and quantity of water available to downstream users following the 2003 alpine bushfires. This will provide information to water resource managers on the implications for water availability following this and future bushfire events.

Task 1 of the program made a broadscale assessment of water yield impacts over the entire burnt area of Victoria and selected parts of New South Wales. The broadscale assessment considered annual changes in streamflow resulting from the fires. Task 3 of the program, undertaken by the Forest Science Centre and Melbourne University, involved the application of the Macaque model to investigate the fire impact in a series of representative catchments.

Extending on Tasks 1 and 3, this report presents the work associated with Task 4 of the Bushfire Recovery Program. Task 4 investigated within year impacts resulting from bushfires using a modelling approach. This utilised the calibrated model developed in Task 3 for the Mitta Mitta catchment. The broadscale assessment of Task 1 provided a basis for the extrapolation of the modelling results throughout the entire bushfire area.

The Macaque model was used to undertake this task. Macaque is a daily catchment model, which has detailed parameterisation based on physical properties, with key spatial parameters including topography, precipitation, vegetation leaf area index and soils. The model was used to investigate the seasonal impacts to streamflow resulting from a bushfire for sample sub-subcatchments (Big River and Livingstone Creek), and the results were then transposed to the wider bushfire affected area.

This report is structured in eight sections. Section 2 contains a review of previous studies that are relevant to this investigation. A brief description of the Macaque model is contained in Section 3. The calibration of the Macaque model for use in this task is described in Section 4, including information on the calibration method and results of the model calibration for the Big River and Livingstone Creek catchments. The application of the model involved running numerous simulations to estimate seasonal changes in streamflow, as described in Section 5. Numerous simulations were undertaken to ensure the range of catchment characteristics within the bushfire affected area were considered. The transposition of these experiments to the wider bushfire affected area is outlined in Section 6. Finally, Section 7 reaches conclusions about seasonal streamflow impacts based on the study results.

2. Previous relevant studies

2.1 Introduction

There is a significant body of research reported on the impact of changes in forest age (resulting from both logging and bushfires) on streamflow. The research is summarised in reports such as Zhang *et al.* (2003) and Sinclair Knight Merz (1998) and are not discussed further in this report. The basis of the majority of these studies has been the analysis and interpretation of recorded streamflow and hence the inferences relate to changes in mean annual streamflow. There is far less information on the within-year impacts on streamflow resulting from changes in forest age, which is the focus of Task 4. This chapter briefly outlines some recent research on this topic.

2.2 Review of Literature

Farley *et al.* (2005) performed a synthesis on the effects of afforestation on water yield, using data from a wide selection of other published studies. They concentrated on the effects on streamflow of new forest plantations, mostly for catchments that were previously grassland or shrubland. There are likely to be differences between the effects in these catchments and the effects in catchments recovering from bushfire, where we are concerned with regrowth of previously forested areas.

Farley *et al.* (2005) identified that afforestation caused a consistent and substantial decrease in runoff across their entire data set. For catchments that were afforested with Eucalypts, the mean change in annual runoff was 50%. Farley *et al.* (2005) also identified that “proportional losses in low flow with afforestation were closely correlated with, but even larger than, proportional losses in annual flow”. Because Farley *et al.* (2005) synthesise data from several other studies, the definition of low flow is not consistently applied. However, Farley *et al.* (2005) surmise that “dry season losses are predicted to be even more severe than total annual losses, possibly leading to shifts from perennial to intermittent flow regimes in dry region streams”. Farley *et al.* (2005) found that both annual flows and low flows recover as forests age but that the recovery of low flows is more complete for Eucalypts than for pine forests.

Lane *et al.* (2003) provided a comparative analysis of the effects of different forest species and climatic regimes on flow duration curves. Their study used data from four catchments in south eastern Australia, with three of these catchments planted with pine species, predominantly *Pinus radiata*, and the fourth catchment (Traralgon Creek, Victoria) covered mostly with *Eucalyptus regnans* (Mountain Ash). Lane *et al.* (2003) found that afforestation in the three South East Australian catchments with pine species caused proportionally larger reductions in low flows than in high flows in the three south east Australian catchments. A consequence of the larger proportional impact on low flows than on high flows was that the south east Australian catchments each showed large increases in the number of days of zero flow each year.

By contrast with the three pine species catchments, Lane *et al*. (2003) found that the flow duration curve for Traralgon Creek showed about the same proportional reduction in high and low flows and no increase in the number of days of zero flow (Traralgon Creek was perennial both before and after afforestation). These differences could be related to forest type, but analysing the cause of the difference in response is confounded by Traralgon Creek having a much larger catchment area, higher mean annual rainfall, more uniform seasonal rainfall pattern and deeper soils than any of the south east Australian pine forested catchments studied.

Lane *et al.* (2003) also found flow duration curves for pine forested catchments in New Zealand and South Africa displayed fairly constant proportional reductions for high and low flows, which was a contrast with the south east Australian pine forested catchments. The New Zealand and South African catchments generally had deeper soils and much higher base flow indices than any of the Australian pine forested catchments.

The catchments considered in the current study are probably more similar to Traralgon Creek than to the pine forested catchments considered by Lane *et al.* (2003). The bushfire catchments that we consider in this study are all larger than Traralgon Creek (which is 87km² in area) and are mainly forested with native eucalypt species. As stated previously, Traralgon Creek was perennial both before and after afforestation and showed a relatively consistent proportional change in high and low flows. Although Lane *et al.* (2003) do not explicitly address changes in seasonality of flows due to afforestation, based on the similar proportional reduction in high and low flows, it would be reasonable to assume that the percentage changes in flows were relatively consistent between seasons for Traralgon Creek.

Silberstein *et al*. (2004) found that the number of days of no flow disappeared following clearing of native vegetation from catchments in the south west of Western Australia. They found that a stream would change from ephemeral to perennial within two to three years of native vegetation clearing.

The limited information on within year impacts on streamflow indicates that little work has been done on this subject. The most similar studies considered afforestation of cleared grassland or shrubland catchments rather than regrowth of existing forest. Further, most studies considered pine plantations rather than native eucalypt forest. The purpose of this study is to consider the seasonal changes in streamflow that would result from recovery and regrowth of catchments that are predominantly forested with mixed eucalypt and *Eucalyptus regnans* (Mountain Ash) species.

3. The Macaque Model

3.1 Model theory

The Macaque model was developed by Dr. Fred Watson at the Cooperative Research Centre for Catchment Hydrology. The following summary provides a simple description of the model processes, providing suitable background for the current application. A more detailed description of the model and its use are provided in Watson (1999).

Macaque is a daily catchment model, which has detailed parameterisation based on physical properties, with key spatial parameters including topography, precipitation, vegetation leaf area index and soils. It allows water yield changes to be predicted based on the consideration of spatial and temporal changes in the catchment, including climatic conditions, land cover and topography.

The model divides a catchment into smaller spatial units referred to as hillslopes. Hillslopes are further subdivided into Elementary Spatial Units (ESUs). Each ESU is modelled separately and ESUs are linked by subsurface water flow pathways. These combine to form hillslopes, which are linked by a stream network. The total catchment flow is calculated by summing the flow from all hillslopes.

In the model, streamflow is derived from the interaction of climate, plant water use, water contained within the soil and the rate at which this soil water moves into the streams. Changes in water yield are consequently the net result of changes to these conditions. The structure of Macaque and the theory behind modelling each of these variables is described below:

- A climatic module is incorporated in Macaque which converts the input climate data (temperature and rainfall) into other variables such as humidity and radiation.
- Within each ESU, vegetation is represented at two levels: canopy and understorey. Precipitation and radiation are applied to the ESU and can be intercepted (or absorbed) by the layers, or transferred between them. This establishes the basis for evapotranspiration to be calculated for each of the layers within the ESU, and also from the soil.
- Leaf Area Index (LAI) and leaf conductance are used to represent changes in forest type and age. A series of curves are incorporated into the model, which represent the known changes in LAI or conductance for each forest type as the species ages.
- Two soil layers are represented for each ESU, the boundary between these acting as the water table surface. The depth of the water table moves up and down within the soil profile, reacting to the inflows and outflows from the ESU, both above and below ground. Various processes predicting vertical and lateral movement of water are incorporated to account for this soil water movement.

A suite of parameters is incorporated into Macaque to provide further physical representation of the processes captured by the model. Many of these have been previously defined (Watson, 1999) based on direct measurements of physical properties or reasonable values taken from the literature and do not require modification for model application. However, calibration of a few parameters is necessary to accurately model water yield in a catchment. These parameters tend to relate to soil properties and are considered unlikely to change with forest disturbance.

3.2 Model inputs

Macaque requires several spatial and temporal data sets as inputs to the model. These provide the model with details of topography, vegetation, precipitation, and temperature.

Topographic information is required in the form of a digital elevation model (DEM). The DEM is used by the model to define hillslopes and ESUs throughout the catchment, as well as other catchment characteristics (such as aspect, slope, elevation). These are used in the calculation of various climatic variables, such as solar radiation.

Spatial vegetation data is input in the form of forest species and forest disturbance maps. A single map for forest species is required, showing the spatial distribution of the various tree species throughout the catchment. In order to provide detailed information on forest disturbance, several maps can be input into the model reflecting the dates of different forest disturbances.

Precipitation at each ESU for each day of the model simulation is required by Macaque. In order to provide this level of detail, daily precipitation timeseries are supplied in conjunction with precipitation coefficient maps. These maps provide the spatial information to transpose the daily timeseries of gauge rainfall at the selected rainfall stations to the entire catchment area. This is normally in the form of a ratio relative to the site at which the timeseries data has been sourced. Hence, the precipitation at any ESU is calculated by scaling the known timeseries data.

Temperature is supplied in the form of a daily timeseries record. Both minimum and maximum temperatures are required, along with the elevation of the base station. Timeseries of minimum and maximum temperatures at each point in the catchment are estimated by subtracting the product of the difference in elevation between the point and the base station and the assumed lapse rate for temperature with elevation.

3.3 Model application

The Macaque model has been applied in a limited number of studies. Task 2 of the project involved the recoding and documentation of the model to provide a more sophisticated interface and make it more compatible with the other programs in the CRC toolkit. All technical components of the model were retained. Utilising this updated model software, Task 3 of the Bushfire Recovery Program applied the model to the Mitta Mitta upstream of Hinnomunjie.

Model input files from the Mitta Mitta catchment were provided by the Forest Science Centre at Melbourne University. These were used as inputs into the Macaque model established to study the seasonal streamflow effects as a result of bushfire. The following sections describe the application and outcomes of this modelling task.

4. Model Calibration

4.1 Initial Model Results for Mitta Mitta at Hinnomunjie

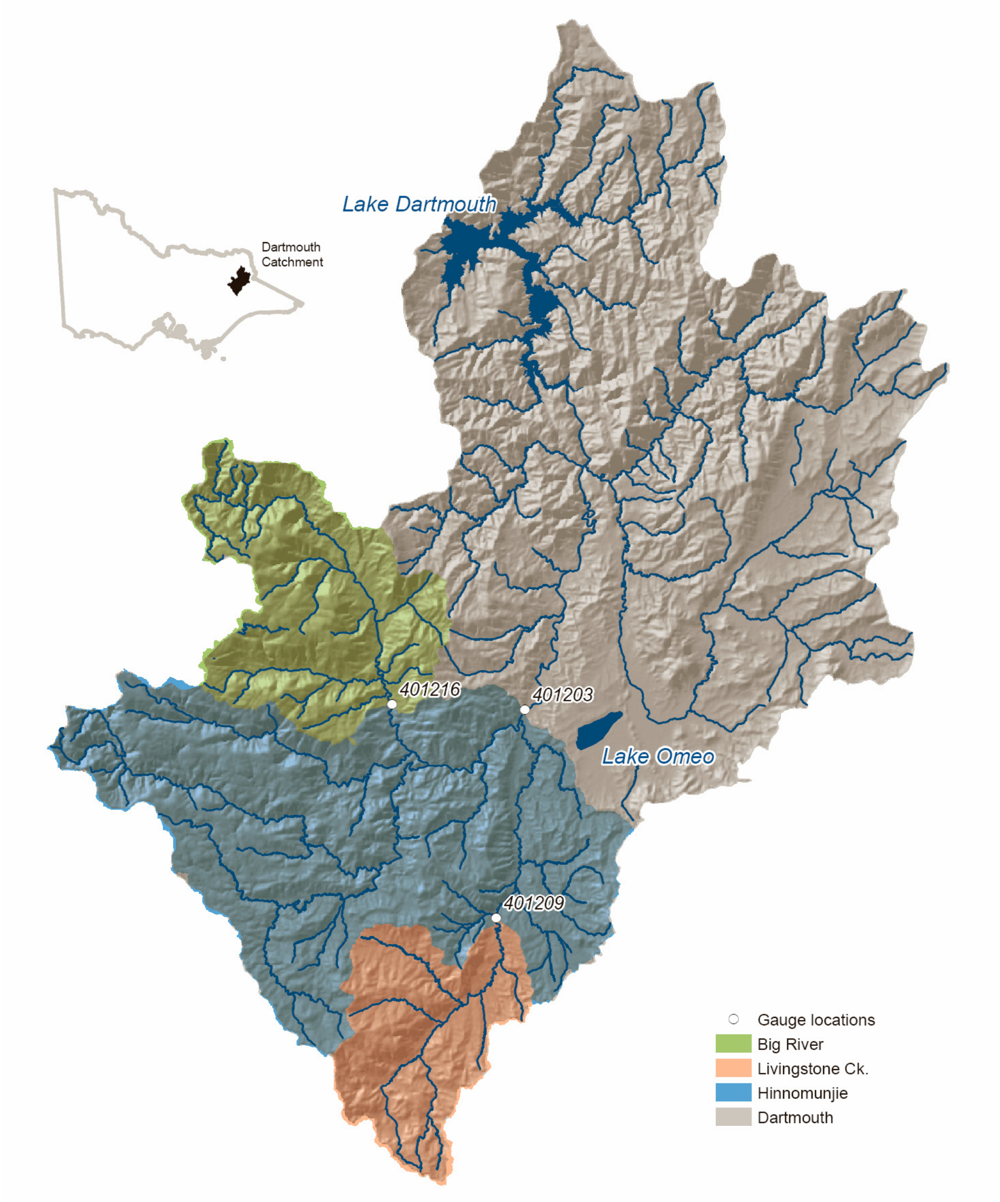
At the outset, Macaque was to be configured, calibrated and run for the catchment captured by a gauge on the Mitta Mitta River at Hinnomunjie (gauging station 401203). This catchment was modelled by the Forest Science Centre (FSC) as a part of Task 3 of the Bushfire Recovery Program, and calibrated data was provided for use in this project. However, due to the size of the catchment (greater than 1,500km^2) and the spatial resolution, the model could not be configured without running out of computer memory. Furthermore, while the predicted and gauged data were comparable at the Hinnomunjie station, there was little internal consistency at other streamflow gauges located within the Hinnomunjie catchment (specifically Big River at Joker Creek, 401216, and Livingstone Creek at Omeo, 401209). Additional problems were encountered when considering the seasonal results. While the annual results at Hinnomunjie from the calibrated model were reasonable, the seasonal outputs poorly matched the recorded data. This was of particular concern, as the basis behind this modelling task was to estimate the within year impacts to streamflow as a result of the bushfire.

4.2 Selection of sub-catchments

In order to easily run Macaque, and to ensure the model results were consistent with recorded data particularly on a seasonal basis, a possible solution was to split the Hinnomunjie catchment into the smaller sub-catchments. From consideration of the available streamflow data and the catchment characteristics, the Big River and Livingstone Creek sub-catchments were selected for modelling. These two sub-catchments were found to be small enough to eliminate computer memory issues. Additionally, streamflow data was available at these two locations for an adequate period of time. The combination of these two factors meant that it was feasible to separately model the Big River and Livingstone Creek catchments.

The location of the Big River and Livingstone Creek sub-catchments is presented in Figure 4-1 below. The Big River catchment has an area of 356 km^2, while the area of the Livingstone Creek catchment is 243 km^2.

A check was made of the characteristics of these two sub-catchments, to ensure they were representative of the range of bushfire affected catchments. This catchment comparison is discussed in Section 6.



- **Figure 4-1 Location of Big River and Livingstone Creek sub-catchments in eastern Victoria**

4.3 Model inputs

As described in Section 3.2, the Macaque model requires a variety of spatial and temporal inputs., The specific model inputs are described below for the Big River and Livingstone Creek catchments. For the Big River catchment, the model was run from 1 January 1957 to 31 October 2004. Due to a shorter streamflow record for the Livingstone Creek catchment, this model was run from 29 February 1968 to 1 July 1994.

4.3.1 Physical catchment characteristics

Information on the catchment topography and vegetation is provided to the model in the form of several spatial maps.

DEM data for the calibrated Hinnomunjie catchment was supplied by the FSC based on the outcomes of Task 3 of the Bushfire Recovery Program. Based on the known catchment boundaries of the Big River and Livingstone Creek sub-catchments within the Hinnomunjie, the relevant areas of the DEM were extracted for use. The DEM data is based on a 40 m grid size, providing a relatively high level of detail to the model. Figure 4-2 and Figure 4-3 show the digital elevation models for the Big River and Livingstone Creek catchments.

As for the DEM, maps of vegetation species and disturbance were provided by the FSC for the Hinnomunjie catchment. Information for the Big River and Livingstone Creek catchment areas were extracted from these maps to provide the details for the model. Forest species maps for the Big River and Livingstone Creek catchments are provided in Figure 4-4 and Figure 4-5.

4.3.2 Climatic characteristics

Temperature and precipitation timeseries provide the inputs of climatic conditions into the model. Additional spatial information is provided to the model to allow the localised precipitation data to be scaled across the entire catchment.

Precipitation scalar maps were supplied by the FSC along with all other inputs to the model. These maps were based on linear regression spline relationships for three rainfall gauges surrounding the Hinnomunjie catchment. Three maps were put into the model; one for each gauge, which provided spatial information on how the rainfall data from that gauge needed to be scaled at any given location. The sum of these scaled rainfalls provided a complete picture of the rainfall conditions throughout the catchment area. Initial calibration results for both Big River and Livingstone Creek provided a relatively good fit between the recorded and predicted streamflows when considering annual flows. However, the seasonal response of the catchment was quite poor. In particular, summer flows tended to be over predicted while winter flows were under predicted.

As an attempt to improve these inconsistencies, several changes to the input precipitation coefficient maps were made. Firstly, new rainfall coefficient maps were generated by dividing the BOM gridded mean annual rainfall dataset (converted from 2 km grid cells to 40 m grid cells, to be consistent with the input DEM) by the mean annual rainfall at the daily rain gauge site used. Thus, the resulting rainfall coefficient maps depended on only a single rainfall gauging station. Ideally, this would result in a scalar of approximately 1 at the gauge locations. However, in reality, due to the smoothing associated with processing the grid based data, there is a difference between the grid value at the gauge location and the actual mean annual value of the gauge data. Despite this, the need to alter the rainfall scalar parameter value (one of the parameters modified during calibration) within Macaque was greatly reduced by using these new rainfall coefficient maps.

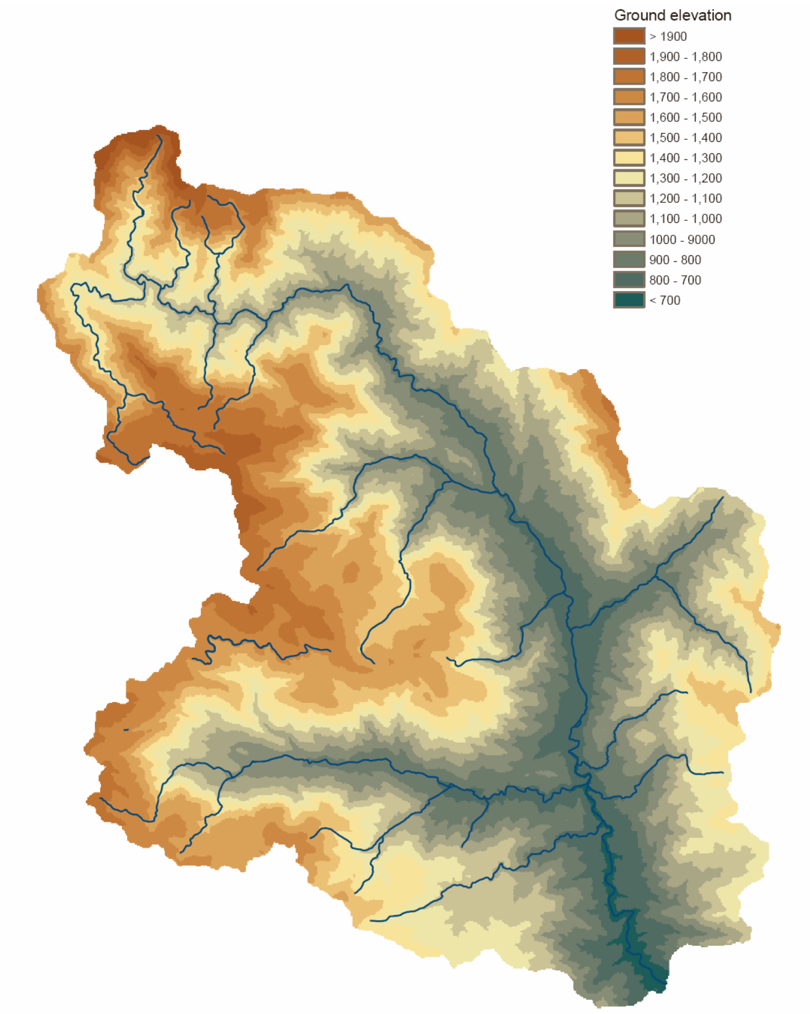
Secondly, after discussions with the wider project team, the use of annual climate records to generate the input rainfall coefficient maps was identified as a possible source of discrepancy between the recorded and modelled seasonal results, as the orographic enhancement of rainfall varies between seasons. Summer rainfall, which is often generated by thunderstorms is often more uniform than precipitation during winter, which is generated by large scale systems that have high rainfall gradients related to topography. Hence, the input rainfall coefficient maps were re-generated using BOM gridded monthly average rainfall records (refer to Appendix A for the maps).

Twelve input coefficient maps were prepared for each catchment, one for each month. Twelve rainfall series were prepared (one for each month) in association with these maps,. Due to the requirements of Macaque, these rainfall records contained date entries for the entire simulation, with values of 0 for all dates except those of the corresponding month. For example, for the January rainfall timeseries, all daily entries for January contained actual rainfall records while all other days for other months contained entries of 0.

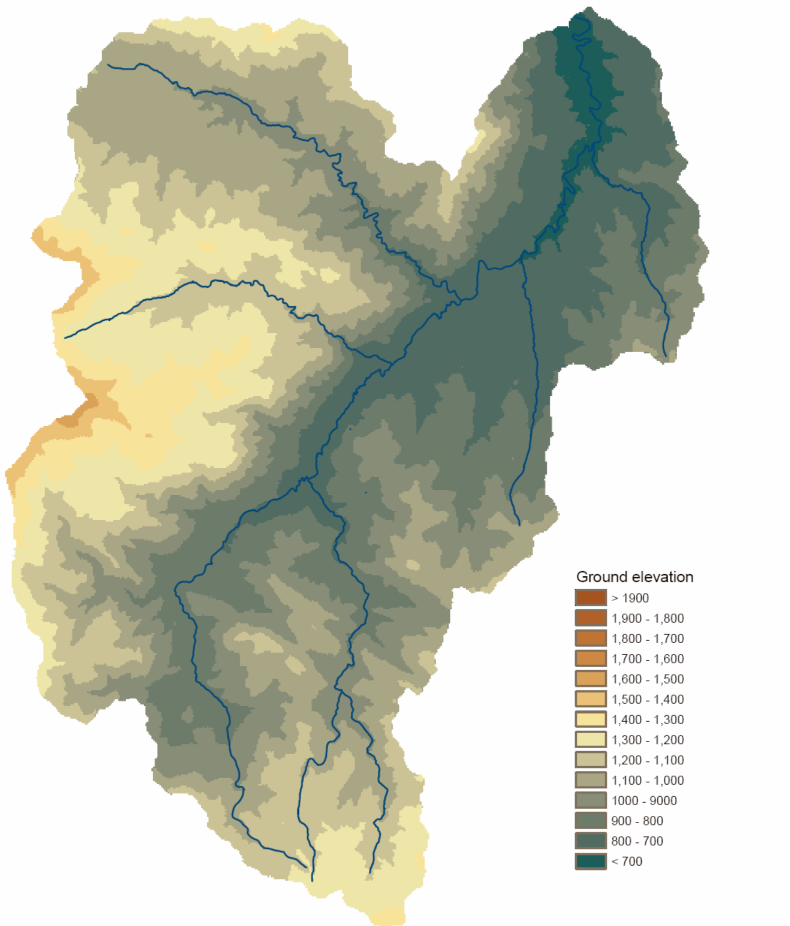
A summary of model inputs is provided in Table 4-1.

- **Table 4-1 Macaque Input Data**

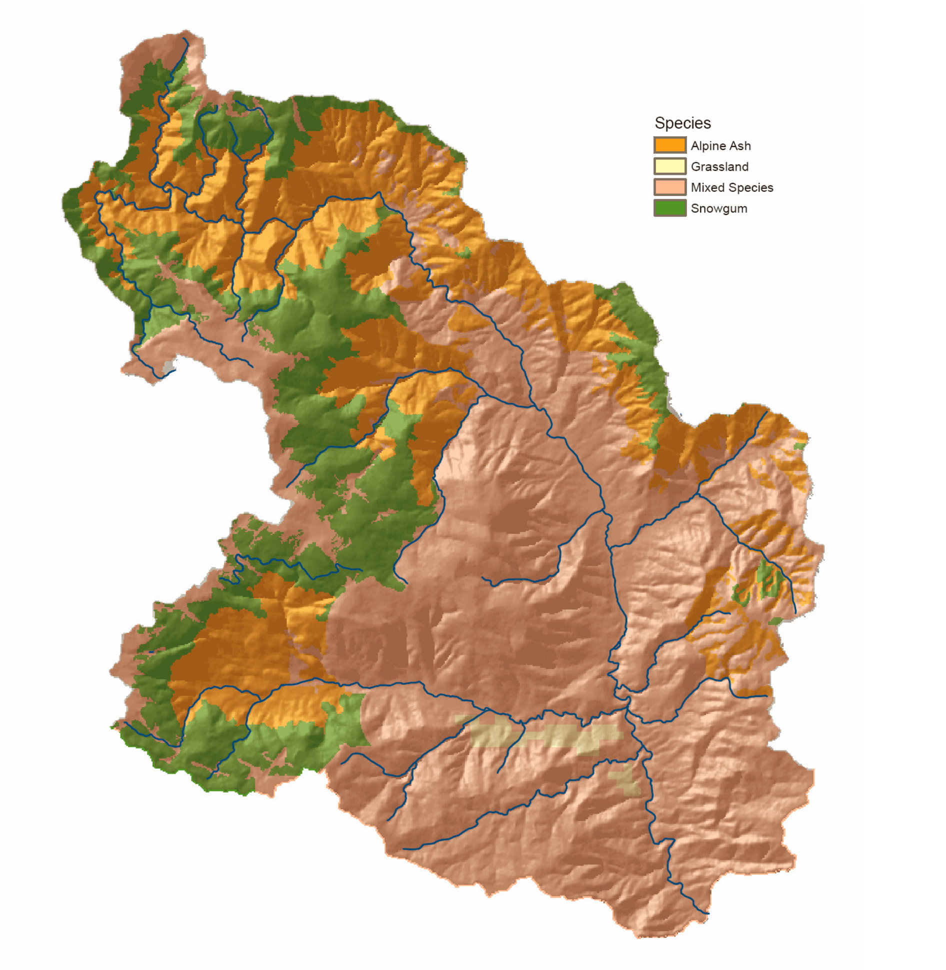
Input Data	Source
Catchment digital elevation model	40 m grid size DEM for Hinnomunjie catchment used to extract DEM for Big River and Livingstone Creek catchments.
Forest species map	Map of actual forest type and cover
Forest disturbance maps	Maps of areas of burnt forest
Daily rainfall timeseries	Daily recorded data at the closest gauged location. Big River: Shannon Vale (083035) Livingstone Creek: Omeo Comparison (083025)
Precipitation coefficient maps	Preliminary maps were generated using: ▪ Linear regression spline relationships for three rainfall stations surrounding the Hinnomunjie catchment. ▪ BOM gridded mean annual rainfall data and rainfall data from a single gauge. Final maps for use in Macaque modelling: ▪ BOM gridded monthly rainfall data and rainfall data from a single gauge. 12 maps were used as input, with the associated rainfall timeseries records for each of the 12 months.
Daily temperature timeseries	Daily recorded minimum and maximum data from Omeo
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

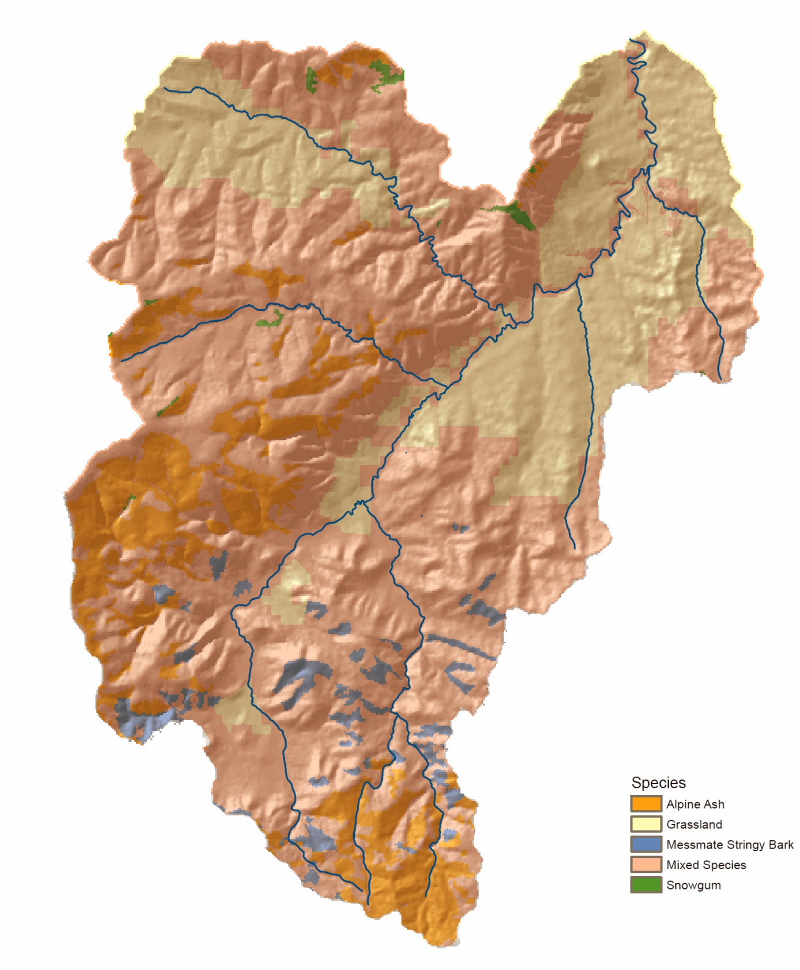


- **Figure 4-2 Big River catchment digital elevation model**



- **Figure 4-3 Livingstone Creek catchment digital elevation model**





- **Figure 4-4 Big River forest species map**
- **Figure 4-5 Livingstone Creek forest species map**

4.4 Calibration aims

Set up of the Macaque model requires a stepwise process for data input. This allows information on the local conditions to be saved for configuration and includes the following inputs, as described in Section 3.2:

- Catchment digital elevation model (DEM).
- Forest species map.
- Maps of years of forest disturbance (clearing or bushfire).
- Daily rainfall timeseries.
- Precipitation coefficient maps.
- Minimum and maximum daily temperature timeseries.
- Base station elevation, and
- Catchment outlet location.

Model configuration uses this input data to establish the spatial extent of the model. This can require significant computer memory depending on the catchment size and resolution of the input data.

For this project, the calibration process primarily considered the total flow and the total snow pack melt outputs, and aimed to produce a reliable estimate of change in seasonal streamflow response. The intention was to match the modelled monthly streamflow to the recorded gauge data as closely as possible, with the following objectives to be met:

- Mass balance – mean annual flow within a few per cent of the gauged data.
- High coefficient of efficiency for monthly flows.
- Minimise the difference in standard deviation between the monthly modelled and gauged flows.
- Scatter plot of gauged versus predicted data with trendline through the origin – gradient of trendline close to 1, and high coefficient of determination (R^2) for monthly flows, and
- Snowmelt occurring at appropriate times – with melt water runoff primarily during spring and no melt water in mid or late summer.

4.5 Calibration results

Calibration of Macaque required the manipulation of the following parameters within the model:

- Rainfall scalar (I_p_precipitation_scalar).
- Hydraulic gradient ratio(I_p_ratio_hydraulic_to_surface_gradient),
- Lapse rate (for both max and min temperature) (I_p_min/max_temperature_elevation_lapse_rate).

The soil properties of the catchments were also considered by testing the sensitivity of the results to changes in K_{sat}. Despite altering the Macaque K_{sat} parameters by an order of magnitude, results were not significantly impacted. The Plant Available Water Holding Capacity values were also extracted from McKenzie's Atlas of Australian Soils for the catchment areas and compared to the soil moisture variables contained within Macaque. Macaque assumes a larger active soil moisture store than the typical estimates inferred for soils in the McKenzie database. However, Ladson *et al*. (2004) found that the estimates of Plant Available Water Holding Capacity from McKenzie are normally too low, particularly in forested areas. Furthermore, in his thesis Watson (1999) states that Macaque sensitivity to variations in root depth parameters is low. As the Macaque default root depths for canopy trees and understorey appear to be physically plausible (and given the model's low sensitivity to these parameters), subsequent calibration used the default values. Hence, calibration modified only the three Macaque parameters identified in the bullet points above.

These parameters were modified as required in order to produce a good fit between the recorded data and the model output. The following sections provide a summary of all the calibration runs undertaken for both the Big River and Livingstone Creek catchments.

4.5.1 Big River catchment

Numerous runs were undertaken to achieve calibration of the Big River catchment. A summary of the final calibration results are tabulated in Table 4-2. The parameters used to obtain this calibration are presented in Table 4-3.

- **Table 4-2 Calibration results for the Big River catchment**

Data source	Mean Annual Flow (ML)	Monthly Standard Deviation (ML)	Monthly Coefficient of Variation	Monthly Coefficient of Efficiency
Recorded	224222	16362	0.073	
Modelled	222216	14903	0.067	0.665

- **Table 4-3 Calibration parameters for the Big River catchment**

Parameter	Value
Rainfall Scalar	0.88
Hydraulic Gradient	0.985
Maximum/Minimum temperature lapse rate	0.005

A good calibration was achieved with the above parameter values. This calibration run gives a mass balance less than 0.9% difference from the gauge data, a standard deviation within 9% and an acceptable coefficient of efficiency. Further details of the calibrated model are presented in Figure 4-6 and Figure 4-7. The scatter plot (Figure 4-6) indicates the relationship between the predicted and the gauged data. The model tends to under predict flows, as shown by the gradient of the trendline through the origin (shown by the black line). However, due to the size of the flows that are under predicted, and the fact that some flows are actually over predicted, the model results in a mass balance. The timeseries of the monthly flows (Figure 4-7) shows a good replication of the recorded flows over time.

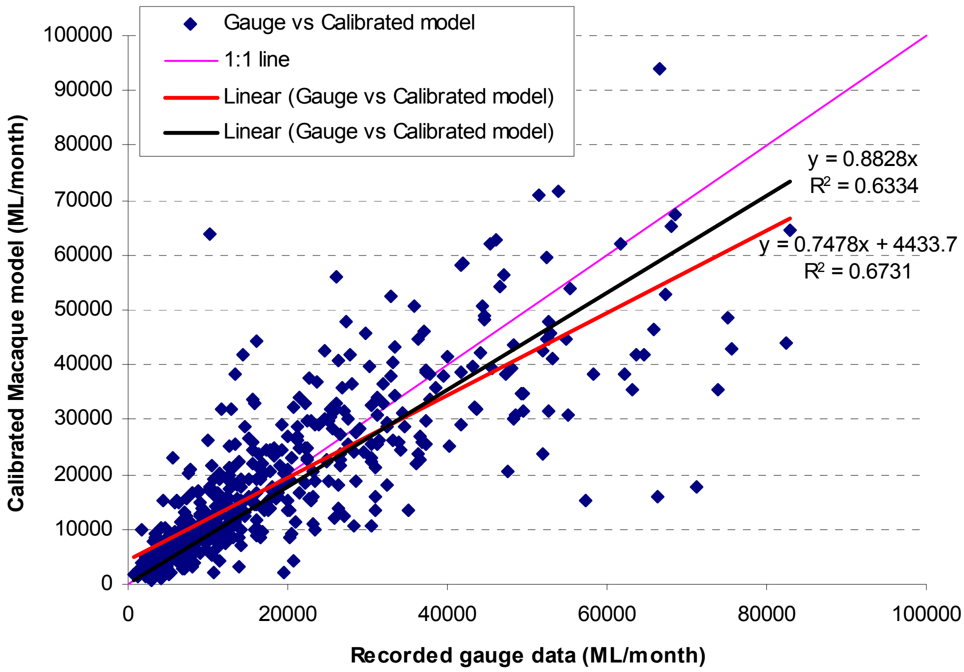


Figure 4-6 Scatter plot of actual and modelled monthly flows for the Big River catchment

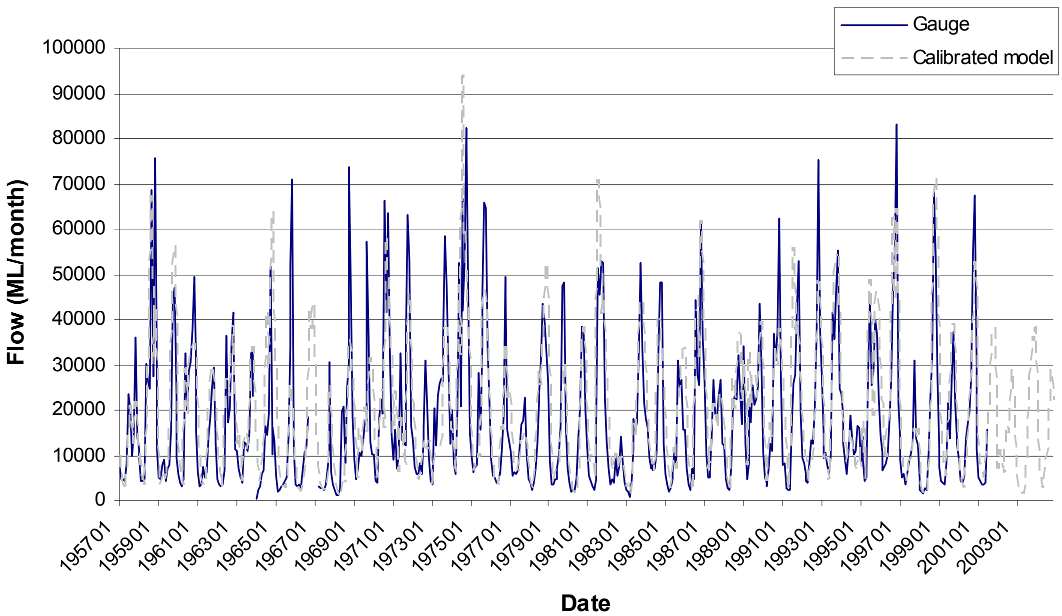
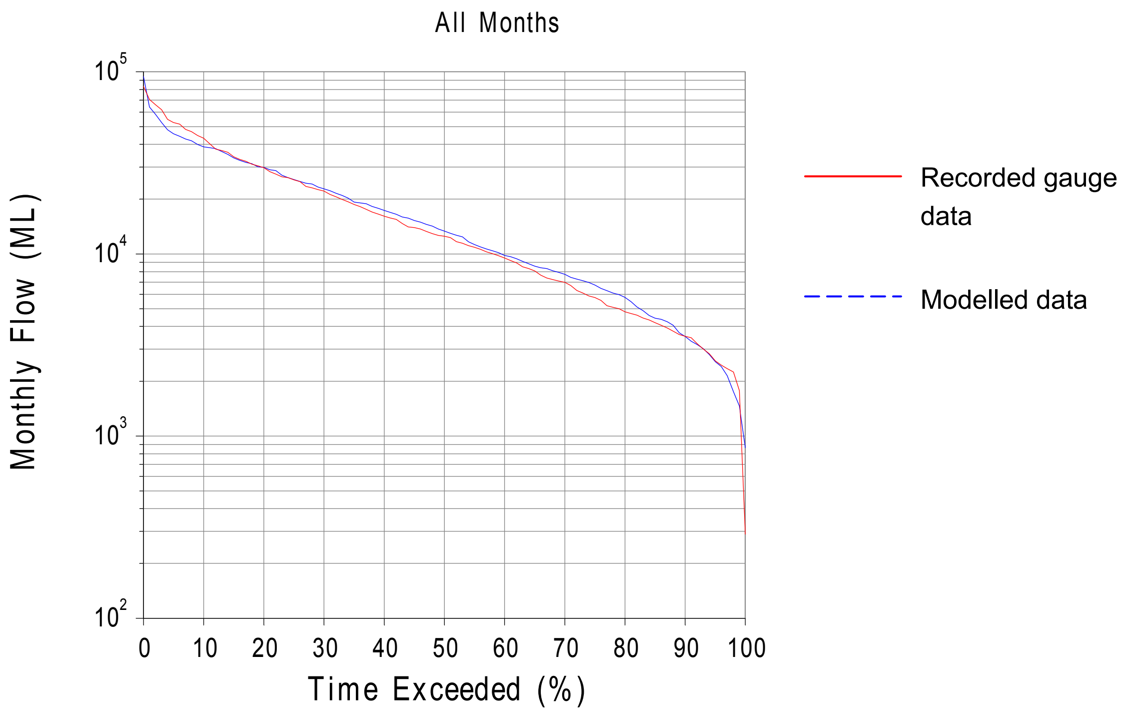
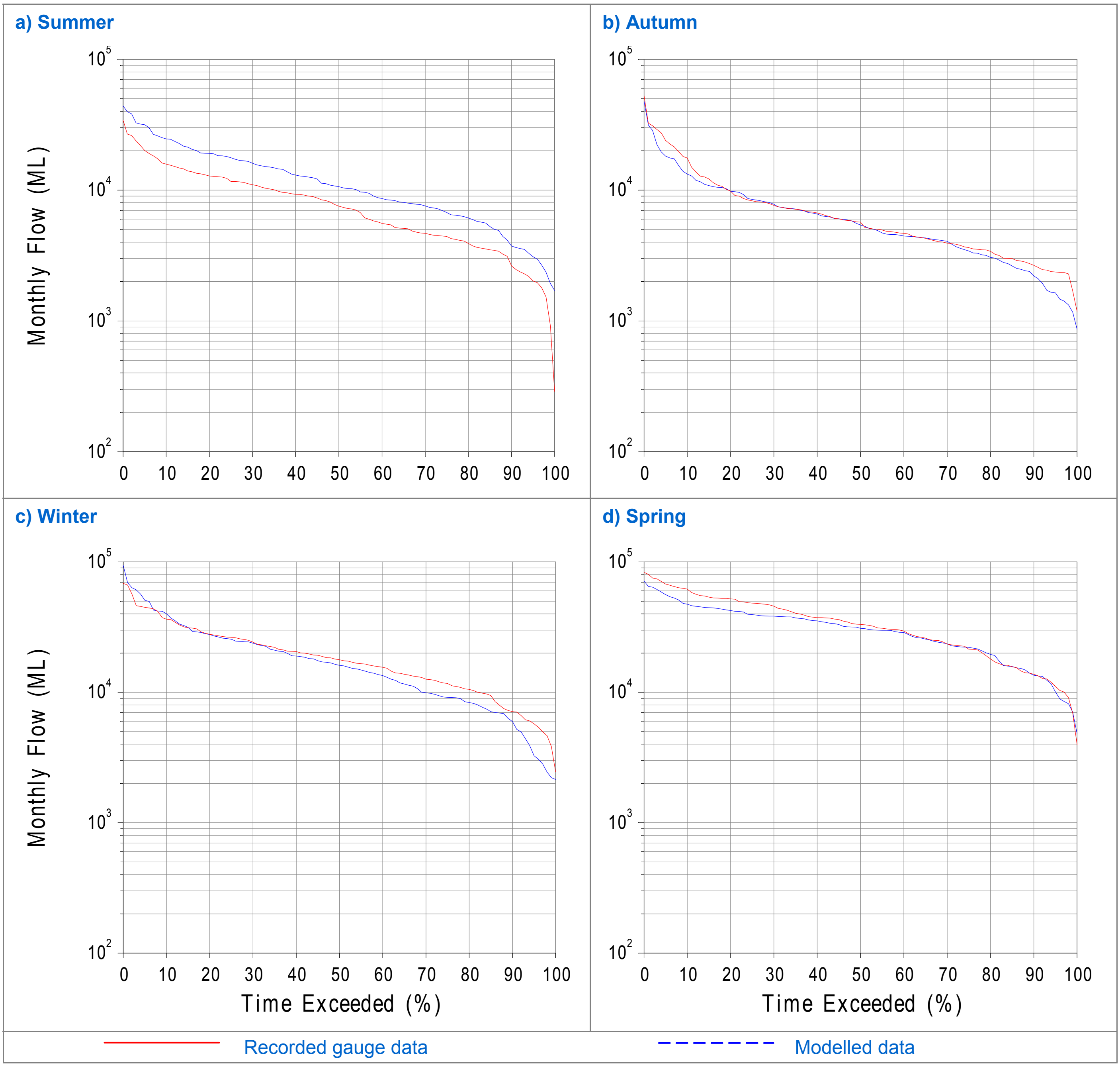


Figure 4-7 Comparison of the recorded and modelled monthly timeseries for the Big River catchment

The flow duration curves for this model run provides further indication of the suitability of the calibrated model for application when considering seasonal impacts on streamflow. When considering all months of the year (Figure 4-8), Macaque closely follows the properties of the gauged streamflow record. In summer, the model over predicts streamflow but the model is quite accurate in replicating the streamflow conditions during other seasons, (Figure 4-9).



- **Figure 4-8 Monthly flow duration curve for all months for the Big River catchment**



- **Figure 4-9 Seasonal monthly flow duration curves for the Big River catchment**

A summary of the seasonal statistics are provided in Table 4-4. While the model appears to have difficulty matching the flows in summer, in all other months the seasonal mean flows are within ±6% of the recorded data. The limited ability for Macaque to replicate the flows perfectly, most noticeably in summer, is likely to be due to the combination of several issues including:

- Limited availability of rainfall data in the catchment. Only one rainfall gauge is located within the catchment, which does not allow for a good representation of the spatial distribution of rainfall.
- Possible slight errors in the saturated area. Small errors in the saturated area can lead to significant variations in the predicted streamflow due to the algorithms within Macaque, particularly for the drier seasons.

Despite the difference between the predicted and recorded data for summer months, it should be noted that summer represents only a small fraction of the annual streamflow in the catchment (approximately 10%). Consequently, although the percentage difference between the gauge and model results appears to be relatively high, this volume reflects only a small proportion of the total flow. Hence, the likely impacts of this variation on the results of later simulations (Section 5.3) were considered minimal.

- **Table 4-4 Big River catchment calibration results**

	Annual	Monthly		Seasonal Mean (ML/season)			
	Mean Flow (ML/yr)	Standard Deviation (ML/month)	Coefficient of Efficiency	Summer	Autumn	Winter	Spring
Big River Gauge	224223	16262		24069	22318	56481	97577
Macaque Model	222216	14903	0.665	39420	21661	59730	94990
Difference (ML)	2005	1459		15351	-657	3250	-2588
Difference (%)	0.89	8.5		63.7	-2.9	5.7	-2.6

4.5.2 Livingstone Creek catchment

As for the Big River catchment, several runs were undertaken to achieve calibration of the Macaque model. A summary of the runs completed is presented in Appendix A. Table 4-5 presents a summary of the calibration results and Table 4-6 provides the parameter values used to achieve this calibration.

Table 4-5 Calibration results for the Livingstone Creek catchment

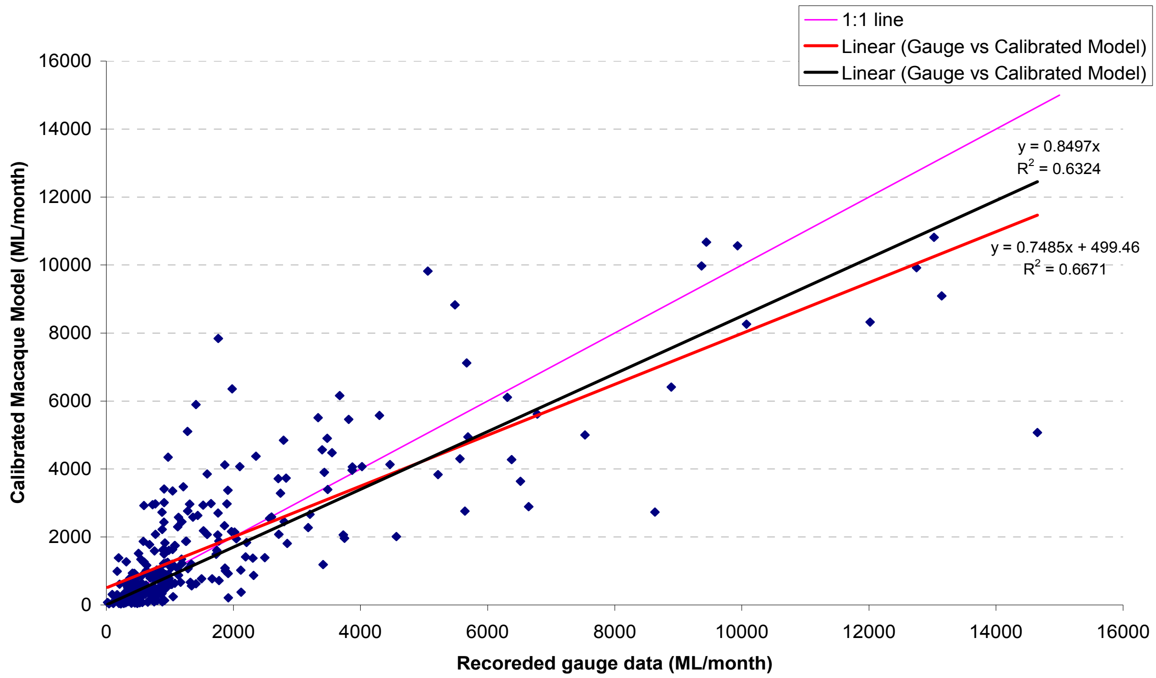
Data source	Mean Annual Flow (ML)	Monthly Standard Deviation (ML)	Monthly Coefficient of Variation	Monthly Coefficient of Efficiency
Recorded	21624	2360	0.109	
Modelled	21472	2162	0.101	0.656

Table 4-6 Calibration parameters for the Livingstone Creek catchment

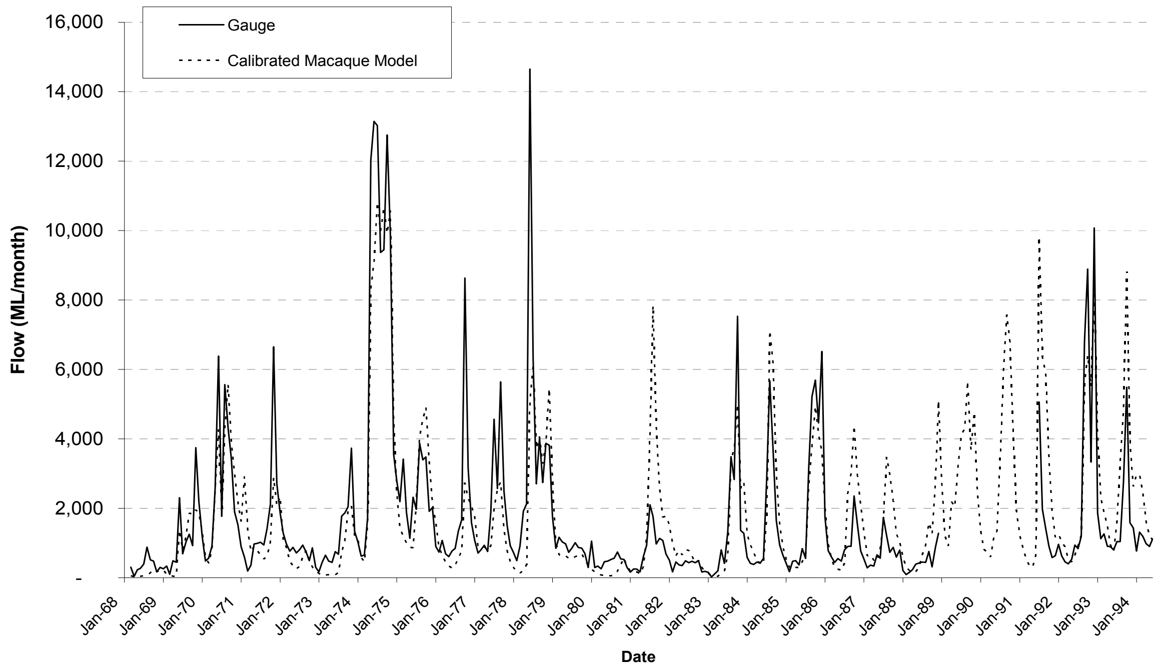
Parameter	Value
Rainfall Scalar	0.985
Hydraulic Gradient	0.975
Maximum/Minimum termperature lapse rate	0.005

A good fit between the actual and predicted streamflow for the Livingstone Creek catchment was achieved when using the above parameters. This calibration gives a difference in mass balance of 0.7%, and a standard deviation within 9% of that of the recorded streamflow data. The coefficient of efficiency is relatively high compared to that achieved for other calibration runs.

The scatter plot (Figure 4-10) shows the relationship between the predicted and the gauged data. As for the Big River catchment, the model tends to under predict flows. The gradient of the black trendline, which passes through the origin, is less than that of the 1:1 line (shown in pink). However, due to the size of the flows that are under predicted, and the fact that some flows are actually over predicted, the model results in a mass balance. The timeseries of the monthly flows in Figure 4-11 shows how the recorded and modelled flows compare over time.



- **Figure 4-10 Scatter plot of actual and modelled monthly flows for the Livingstone Creek catchment**



- **Figure 4-11 Comparison of the recorded and modelled monthly timeseries for the Livingstone Creek catchment**

The ability of the model to replicate the flow characteristics of the Livingstone Creek catchment is presented in the following flow duration curves. When considering flows in all months (Figure 4-12), the model slightly under predicts the low flows, and slightly over predicts the high to mid range flows. However, a match in the overall annual mass balance is achieved.

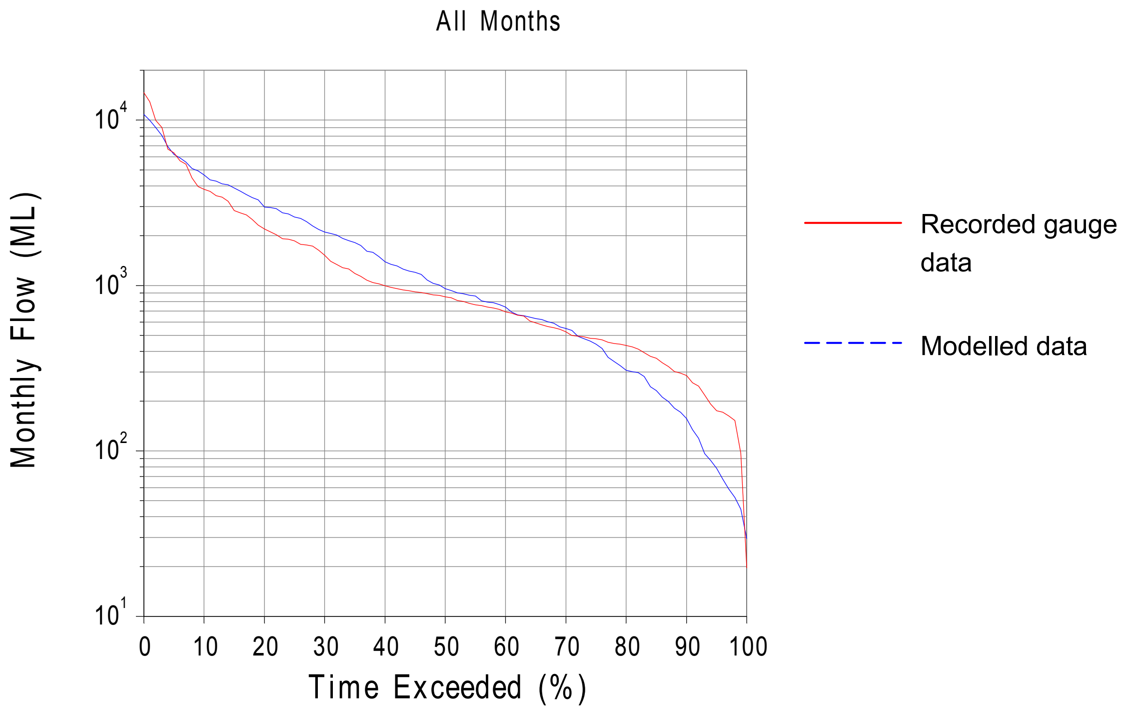
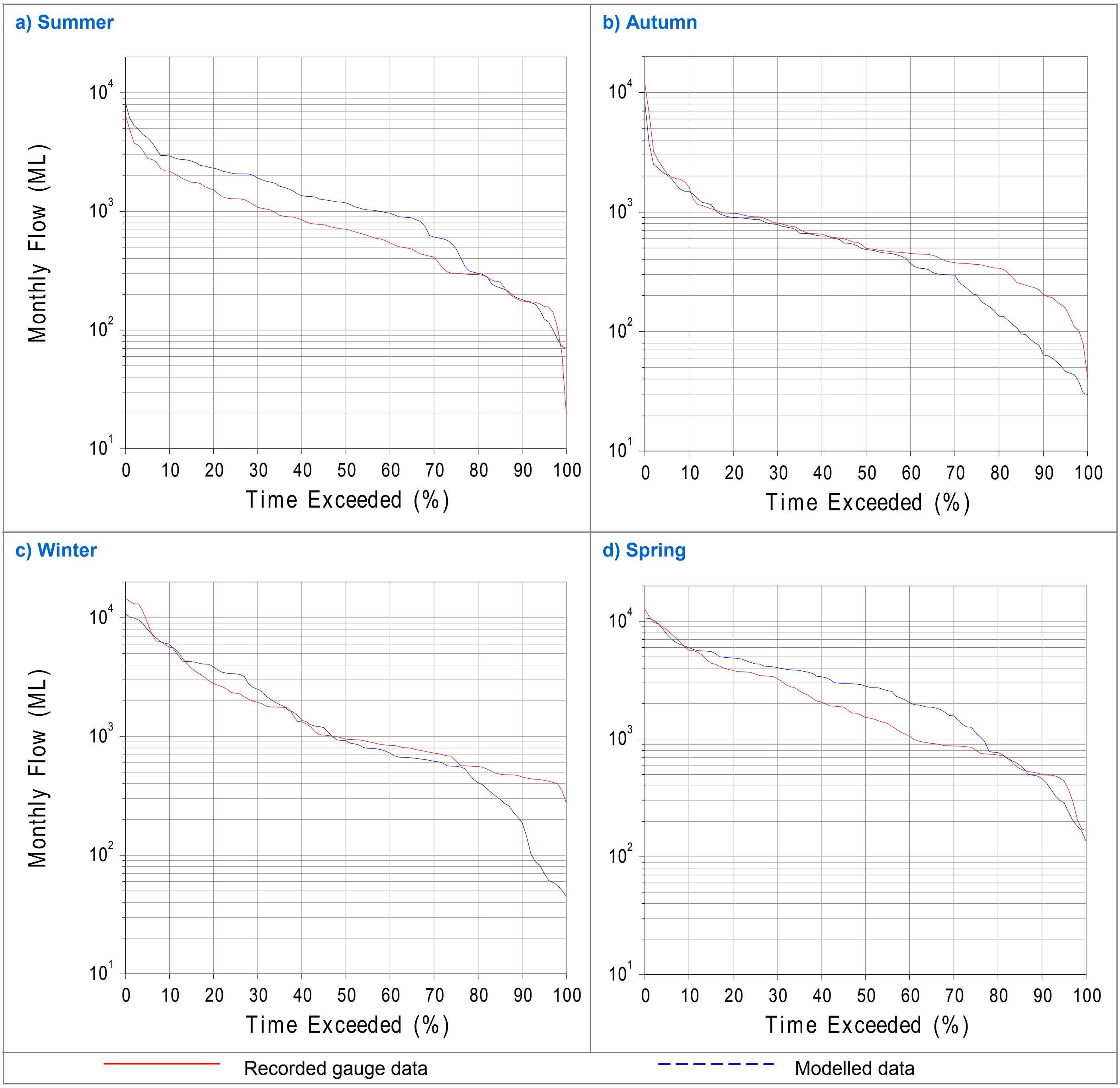


Figure 4-12 Monthly flow duration for all months for the Livingstone Creek catchment

During the summer months, Macaque tends to over predict the high and mid range monthly flows (Figure 4-13). The low flows are replicated relatively well. The high flows during autumn months are well replicated, however the model tends to under predict the low flows. During winter, there is a relatively good match between the recorded and modelled flows, except in the range of low flows. In spring, the mid range flows are over predicted by Macaque, whereas low and high flows are well replicated.



■ **Figure 4-13 Seasonal monthly flow duration curves for the Livingstone Creek catchment**

As described for the Big River catchment, discrepancies between the predicted and recorded data are likely to result from the combination of several small inconsistencies between actual conditions and modelled conditions. In particular, the limited availability of rainfall data in the area is likely to have a significant impact. No rainfall gauges with extended periods of record are present within the Livingstone Creek catchment. Hence, a gauge outside the catchment (Omeo comparison at Omeo) has been used for this modelling task, however, it is possible that the conditions within the catchment are slightly different from those observed at Omeo. Additionally, spatial variation in rainfall cannot be adequately assessed due to the lack of rainfall gauges at higher elevations. Possible errors in the modelled saturated area and inconsistencies in energy balances relating to evapotranspiration are also likely to have an impact on the streamflows predicted by Macaque.

A summary of the calibration outcomes for the Livingstone Creek catchment are presented in Table 4-7. While the predicted seasonal mean flows do not match the recorded data as well as the calibration outcomes for Big River, the results were deemed acceptable for the purposes of this task.

- **Table 4-7 Livingstone Creek catchment calibration results**

	Annual	Monthly		Seasonal Mean (ML/season)			
	Mean Flow (ML/yr)	Standard Deviation (ML/month)	Coefficient of Efficiency	Summer	Autumn	Winter	Spring
Livingstone Creek Gauge	21624	2360		3053	2666	6838	7720
Macaque Model	21473	2163	0.656	3651	1803	5818	7902
Difference (ML)	151	197		598	-863	-1020	182
Difference (%)	0.7	8.3		19.6	-32.4	-14.9	2.4

4.6 Calibration summary

Calibration of Macaque for both the Big River and Livingstone Creek catchments was undertaken by primarily modifying the following Macaque parameters:

- Rainfall scalar (I_p_precipitation_scalar).
- Hydraulic gradient (I_p_ratio_hydraulic_to_surface_gradient).
- Lapse rate (for both max and min temperature) (I_p_min/max_temperature_elevation_lapse_rate).

The parameter values obtained from the calibration process are listed in Table 4-8. These values are considered to produce a model output that most accurately reflects the recorded data in the catchment. This calibration was confirmed by considering properties such as the mean annual flow, standard deviation of monthly flows, coefficient of efficiency, and flow duration curves. The results obtained from the calibration of these two catchments indicate that the model is capable of adequately replicating the seasonal streamflow conditions and can be used to consider the seasonal responses of streamflows following a bushfire.

- **Table 4-8 Calibration parameter values for Big River and Livingstone Creek catchments**

Catchment	Rainfall scalar	Hydraulic gradient	Lapse rate
Big River at Joker Creek	0.88	0.985	0.005
Livingstone Creek at Omeo	0.958	0.975	0.005

5. Simulation experiments to estimate changes in seasonal runoff

In order to consider the estimated changes to runoff on a seasonal basis following a bushfire, the calibrated models obtained for both the Big River and Livingstone Creek catchments were used in various simulation experiments. These simulation experiments were designed to provide specific information about the within-year effects of the bushfires.

5.1 Method

Similar methods were used to run the simulations for both the Big River and Livingstone Creek catchments. While the calibration runs provided the appropriate parameter values (for the rainfall scalar, hydraulic gradient and lapse rate) for each catchment (refer to Table 4-8), manipulation of other model inputs was required to establish a set of scenarios that provided representative future climate and vegetation conditions. The inputs used for the simulations were based on those used in the calibration phase, as supplied by the Forest Science Centre. However, for use in the simulation experiments, these inputs were modified to reflect various possible changes to catchment conditions, as described below. Specifically, all simulations required the following modified inputs:

- Forest age maps – the entire catchment was assumed to be burnt at the start of the simulation.
- Daily rainfall timeseries – typical rainfall conditions were applied for the simulation experiments.
- Minimum and maximum daily temperature timeseries – typical temperature conditions were applied for the simulation experiments.

5.2 Selection of a representative climate sequence

Typical climatic conditions were utilised in order to observe the impact of the bushfire without influence from climatic variation throughout the simulation. That is, consistent climatic inputs were necessary to isolate the vegetation-driven trends in runoff from climatic trends. In order to generate typical rainfall and temperature records, a 10 year representative period of climatic conditions was repeated 11 times to produce a 110 year record. Ten years was selected as an appropriate period to repeat as it allowed for variability in climatic inputs to be adequately observed. A shorter repeating period would be limited in providing information on the inter-year variability. A longer period would contain too much variation in climatic conditions to enable isolation of the forest age trend from the climate driven trends.

The Omeo Comparison rainfall gauge was used to identify the typical decade because it has an extended period of record (data available from 1888). Ten year periods within the record were then investigated and the mean annual rainfall and standard deviation of these periods was compared to the long term average conditions. The decade between 1991 and 2000 was selected as the most representative, as it had a similar mean and standard deviation to the long term average. Additionally, data during this period was available at all other climate stations required for the Big River and Livingstone Creek catchments. Furthermore, the relatively recent warming trend would be evident in the temperature data for the 1990s, which is considered to be closer to potential future climatic conditions than an earlier decade in the record would have been. Table 5.1 compares the long term rainfall conditions at Omeo Comparison to those of the 1991-2000 decade.

- **Table 5-1 Key characteristics of the Omeo Comparison rain gauge (station number 083025)**

Period	1888-2005	1991-2000
Mean annual rainfall (mm/y)	677.7	687.0
Standard deviation (mm/y)	136.2	119.6

Data for temperature and rainfall (at the appropriate rainfall gauging station) was obtained for the 1991-2000 period and repeated 11 times to generate an extended record of 110 years. This allows the runoff predicted by Macaque to be compared in each of the 10 decades as the forest matures. Furthermore, seasonal comparisons between decades can be made. A 110 year record was established to provide a 10 year 'warm up' period, followed by 10 decades of simulation period.

The forest age is specified in Macaque by providing information on the date and location of bushfires. As described at the start of this section, all simulations were modelled assuming the entire catchment was burnt at the start of the simulation. Based on these representative climate conditions and the use of a 110 year climate series, this initial fire occurred after the 10 year 'warm up' period. Thus, the catchment was burnt at the start of the formal simulation period and the streamflow response could be observed over the subsequent 100 year period considered in the simulations. This provided 10 decades for seasonal comparisons. The type of forest cover was consistent for the warm up and simulation period and based on the conditions specified in the particular scenario.

5.3 Scenarios

Specific simulations were designed to investigate the seasonal streamflow response to bushfires. These experiments involved further manipulation of the Macaque inputs to model particular catchment conditions. Specifically, each simulation required modification of the:

- Catchment digital elevation model (to explore the impact of changes in snowmelt) and/or
- Forest species map.

Five experiments were undertaken for both the Big River and Livingstone Creek catchments, as outlined below.

5.3.1 Big River Catchment

Simulation 1: Base Case

This scenario provided the Base Case to which subsequent experiments were compared. The DEM, forest species map, precipitation coefficient maps and base station elevation remain unchanged from the calibration runs. As outlined above, the forest age map was modified to replicate a bushfire 10 years into the simulation. This simulation utilised the 110 year typical rainfall records discussed above. As for the calibration runs, one rainfall timeseries was prepared for each month, with the entries on all days of the corresponding month as per the full record. The entries of all days of other months were entered as 0. Twelve records were prepared to match the twelve precipitation coefficient maps. The extended ‘average’ temperature record (110 years) was also used as input. These inputs are summarised in Table 5-2, with the key changes from the calibration runs indicated in bold.

Table 5-2 Macaque Input Data for Simulation 1: Base Case

Input Data	Source
Catchment digital elevation model	40 m grid size DEM for Hinnomunjie catchment used to extract Big River DEM data
Forest species map	Map of actual forest type and cover
Forest age maps	**Bushfire throughout entire catchment after 10 years of simulation**
Daily rainfall timeseries	**Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record.** **Big River: Shannon Vale (083035)** **12 records used as input (one for each month)**
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	**Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.**
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

Simulation 2: Mountain Ash Forest

This simulation modified the Base Case simulation, by replacing the original forest species map. In this case the entire catchment was assumed to be covered with Mountain Ash forest. All other inputs of the Base Case remain unchanged. The data inputs for this simulation are detailed in Appendix C.

Simulation 3: Mixed Species Forest

This simulation is similar to Simulation 2, however, the forest cover was modified to a Mixed Species forest. As for Simulation 2, all other Base Case inputs remain unchanged. A list of the inputs is provided in Appendix C.

Simulation 4: Snowgum Forest
This simulation is similar to Simulations 2 and 3, however, the forest cover was modified to a Snowgum forest. As for Simulation 2, all other Base Case inputs remain unchanged. A list of the inputs is provided in Appendix C.

Simulation 5: Lowered Catchment Elevation
Simulation 5 reverted back to the original forest type and cover (as per the Base Case simulation), but modified the catchment DEM. The catchment was effectively lowered to reduce the height of elevated areas in the catchment. By effectively warming the catchment, but retaining the Base Case rainfall series, this allowed the impacts of snowmelt on the streamflow response to be assessed. The Big River catchment was lowered to reduce the minimum elevation to close to 0 m AHD by consistently reducing (by 636 m) the height over the entire catchment area. The timeseries of precipitation was the same as was used in the base case but by lowering the catchment elevation, all of the precipitation that would have been modelled as snow by Macaque in the Base Case would be modelled as rain in Simulation 5. These inputs are summarised in Appendix C.

A summary of the simulations undertaken for the Big River catchment is provided in Table 5-3.

- **Table 5-3 Summary of Big River simulation inputs**

Scenario	DEM	Forest Species	Rainfall gauge
1 (Base Case)	Actual	Actual	Shannon Vale
2	Actual	Mountain Ash	Shannon Vale
3	Actual	Mixed Species	Shannon Vale
4	Actual	Snowgum	Shannon Vale
5	Lowered to 0 m AHD	Actual	Shannon Vale

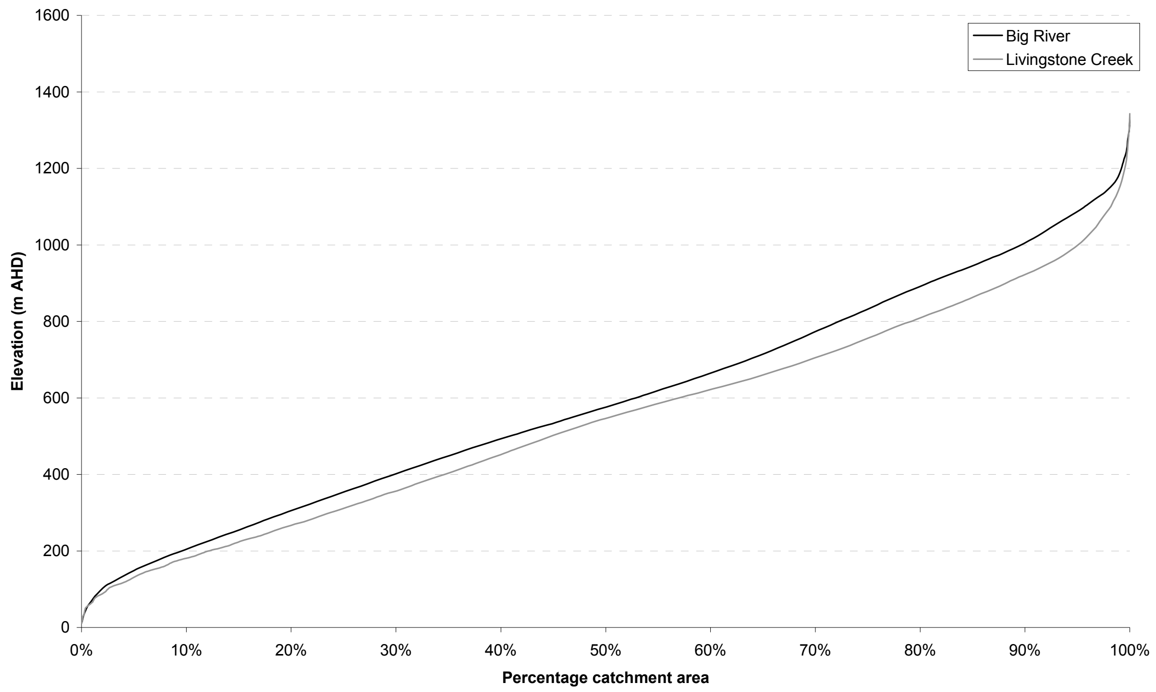
5.3.2 Livingstone Creek Catchment

Simulations consistent with those described for the Big River catchment were also undertaken on the Livingstone Creek catchment. The inputs for these simulations are comparable to those described above. It should be noted that for Simulation 5, the Livingstone Creek catchment was lowered by 643 m to reduce the minimum elevation to close to 0 m AHD.

Additional simulations were completed for the Livingstone Creek catchment, as outlined below.

Simulation 6: Livingstone Creek Lowered and Stretched Catchment Elevation

As a result of lowering the elevations in simulation 5, the minimum elevation of both the Big River and Livingstone Creek catchments was close to 0 m AHD, although the maximum elevation of the catchments was quite different. Simulation 6 involved further modifying the lowered Livingstone Creek catchment DEM used in simulation 5 to make it more comparable to the Big River catchment. This provides an opportunity to assess the impact of the catchment conditions on the streamflow response. By stretching the Livingstone Creek catchment by a factor of 1.51, the resulting catchment is similar to Big River in terms of the range of elevation levels covered and the percentage of catchment area at a given elevation (Figure 5-1). These inputs are summarised in Appendix C.



- **Figure 5-1 Catchment Elevation Characteristics for Lowered Catchments and Stretched Livingstone Creek Catchment**

Simulation 7: Livingstone Creek Lowered and Stretched Catchment Elevation, Big River Rainfall Series

In order to further compare the Livingstone Creek and Big River catchments, the Big River rainfall series (Shannon Vale) was used as an additional input to simulation 5. With an elevation profile similar to Big River, and the same rainfall series used as input, this simulation provides an opportunity to understand some of the key drivers of streamflow in the catchments. The inputs for this scenario are summarised in Appendix C.

Simulation 8: Livingstone Creek Lowered and Stretched Catchment Elevation, Big River Rainfall Series, Mixed Species Forest Cover

Simulation 7 was further modified by covering the entire Livingstone Creek catchment area with Mixed Species forest. The inputs for this scenario are summarised in Appendix C.

A summary of the simulations undertaken for the Livingstone Creek catchment is provided in Table 5-4.

- **Table 5-4 Summary of Livingstone Creek simulation inputs**

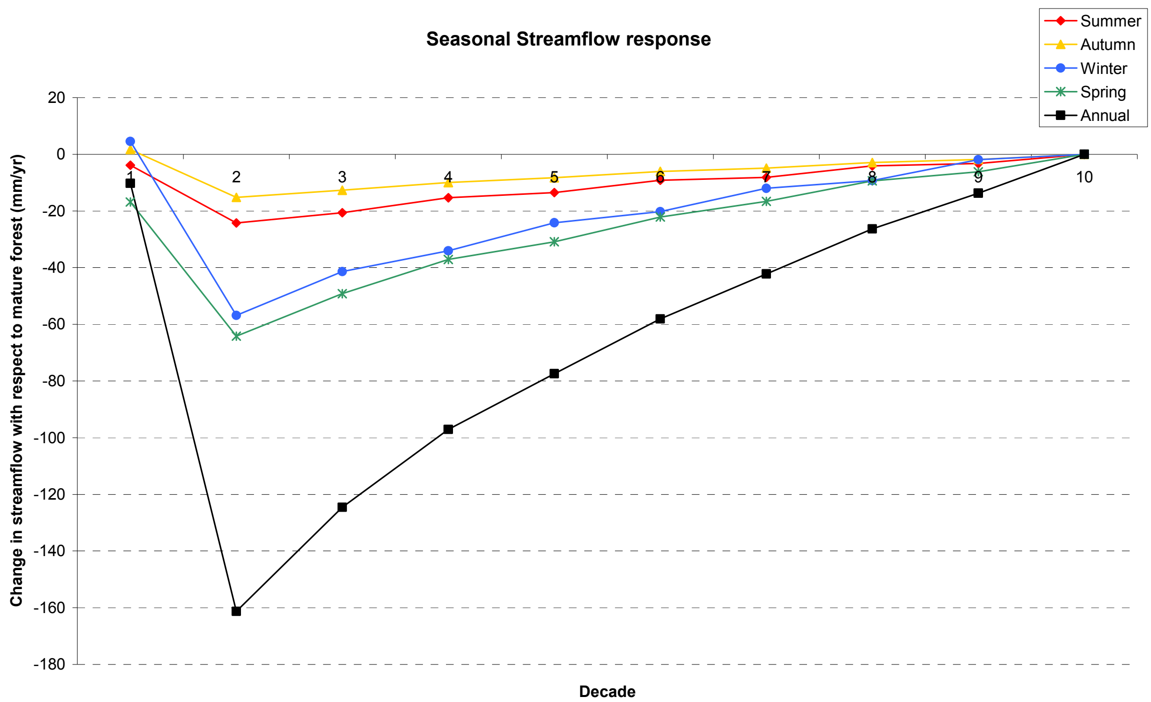
Scenario	DEM	Forest Species	Rainfall gauge
1 (Base Case)	Actual	Actual	Omeo
2	Actual	Mountain Ash	Omeo
3	Actual	Mixed Species	Omeo
4	Actual	Snowgum	Omeo
5	Lowered to 0 m AHD	Actual	Omeo
6	Lowered and stretched	Actual	Omeo
7	Lowered and stretched	Actual	Shannon Vale
8	Lowered and stretched	Mixed Species	Shannon Vale

5.4 Results

5.4.1 Simulation 1: Base Case

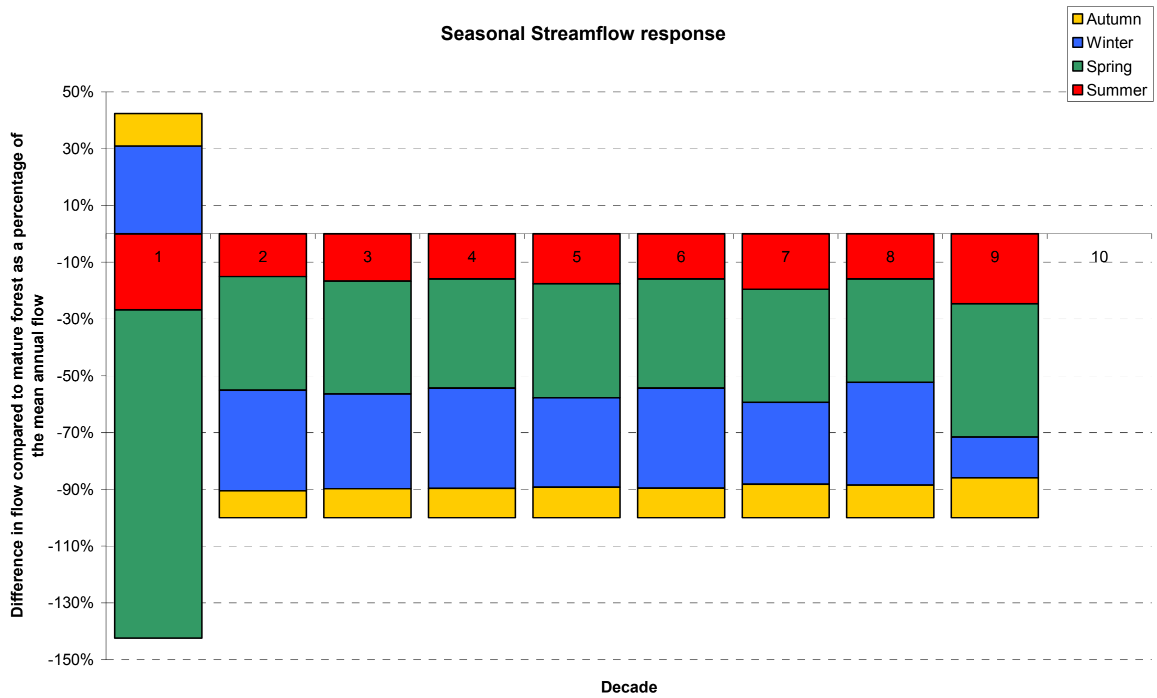
For consistency with the Task 1 (Broadscale Assessment) results, model outputs for the simulations are presented as the change in streamflow with respect to mature forest conditions. For the purposes of this project, it was assumed the forest reaches maturity within 100 years of a bushfire.

Results of the Base Case simulation for the Big River catchment are presented in Figure 5-2 and Figure 5-3. The difference in streamflow compared to a mature forest for each season is displayed in Figure 5-2. The seasonal response to the bushfire is noticeably different for each season. However, regardless of the season, the temporal pattern tends to follow the 'Kuczera curve' shape. Both autumn and winter indicate an increase in streamflow during the first decade, whereas summer and spring experience a decline in streamflow. The overall (annual) response in this first decade is a slight reduction in streamflow. In all other decades, the estimated streamflow is less than that occurring in a mature forest. The response in each season is noticeably different, with winter and spring tending to experience larger absolute declines in streamflow than summer and autumn. The combination of these responses sums to the overall annual streamflow response to the bushfire.



▪ **Figure 5-2 Change in streamflow with respect to mature forest (decade 10) for the Big River Base Case**

The relative response in each season compared to the overall mean annual flow in any decade is displayed in Figure 5-3. As described above, the overall response in decade 1 is a combination of expected increases in streamflow during winter and autumn, and anticipated declines in streamflow in summer and spring. The overall magnitude of the spring and summer reductions in streamflow in decade 1 outweigh the autumn and winter increases in streamflow, resulting in a net decline on an annual basis. In all other decades, the overall streamflow response in all seasons is a reduction in flow compared to that of a mature forest.



- **Figure 5-3 Difference in flow compared to a mature forest as a percentage of the mean annual flow for the Big River Base Case**

Figure 5-3 suggests that the relative contributions of each season to the overall streamflow response for decades 2-9 varies only slightly over time. This is confirmed in Table 5-5, which presents the seasonal changes to flow in each decade. Over the duration of the simulation (excluding decade 1), the predicted change to streamflow does not vary significantly for any given season. The average seasonal streamflow response is also provided.

Table 5-5 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow

Decade	Summer	Autumn	Winter	Spring
1	-27%	11%	31%	-116%
2	-15%	-9%	-35%	-40%
3	-17%	-10%	-33%	-40%
4	-16%	-10%	-35%	-38%
5	-18%	-11%	-31%	-40%
6	-16%	-10%	-35%	-38%
7	-20%	-12%	-29%	-40%
8	-16%	-11%	-36%	-36%
9	-25%	-14%	-14%	-47%
10	-	-	-	-
AVERAGE decades 2-9	**-18%**	**-11%**	**-31%**	**-40%**

As for Big River, the seasonal response for the Livingstone Creek catchment under Base Case conditions follows the 'Kuczera curve' shape. In contrast to the Big River catchment, the response in the first decade results in an increase in streamflow in all seasons. A reduction in streamflow is observed for all subsequent decades.

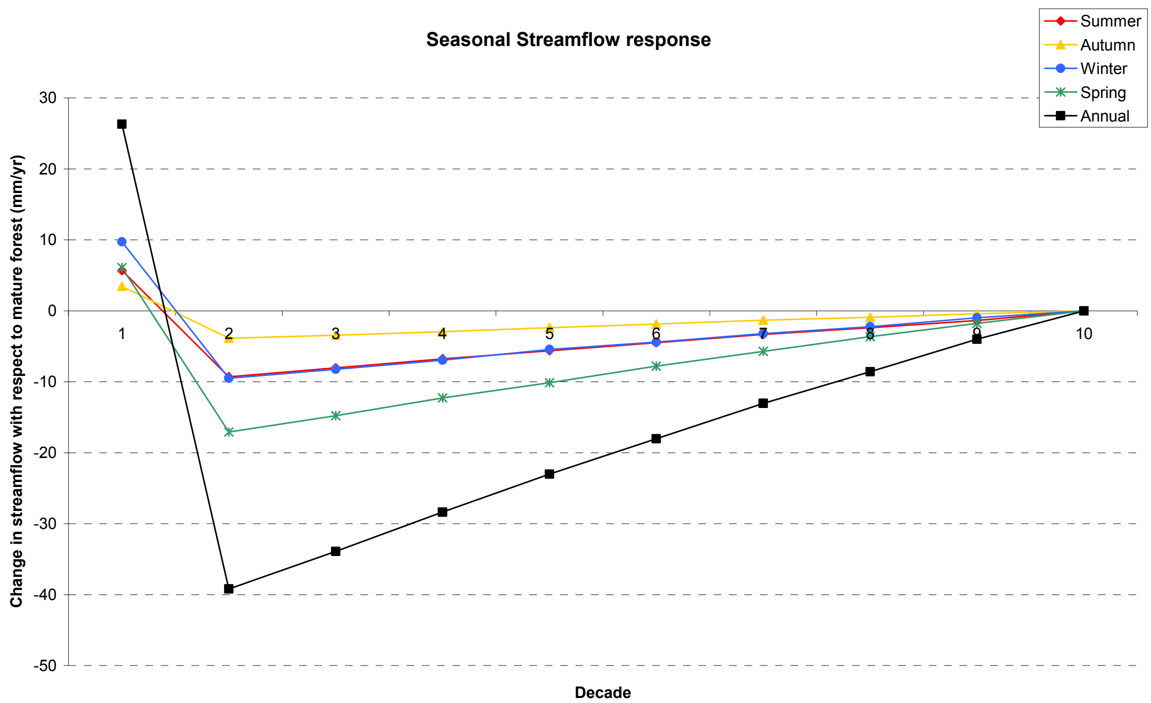
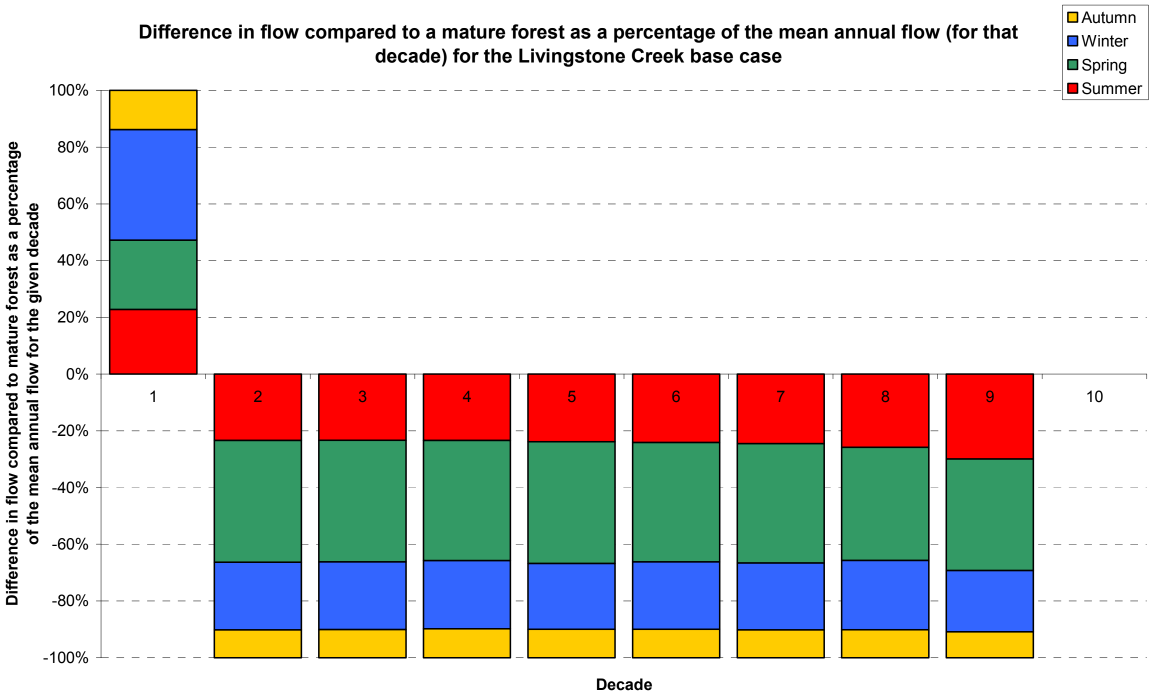


Figure 5-4 Change in streamflow with respect to mature forest (decade 10) for the Livingstone Creek Base Case

The seasonal change to streamflow relative to the mean annual flow in the given decade is constant over the duration of the model simulation (with the exception of decade 1). This observation is consistent with the results of the Big River catchment Base Case.



- **Figure 5-5 Difference in flow compared to a mature forest as a percentage of the mean annual flow for the Livingstone Creek Base Case**

Table 5-6 below presents the seasonal changes in streamflow in the Livingstone Creek catchment over the full duration of the model simulation. As for the Big River results, there is very little difference in the seasonal change in streamflow response over time.

- **Table 5-6 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow**

Decade	Summer	Autumn	Winter	Spring
1	23%	14%	39%	24%
2	-23%	-10%	-24%	-43%
3	-23%	-10%	-24%	-43%
4	-23%	-10%	-24%	-42%
5	-24%	-10%	-23%	-43%
6	-24%	-10%	-24%	-42%
7	-25%	-10%	-24%	-42%
8	-26%	-10%	-24%	-40%
9	-30%	-9%	-22%	-39%
10	-	-	-	-
AVERAGE decades 2-9	**-25%**	**-10%**	**-24%**	**-42%**

5.4.2 Other Simulations

Results for all other simulations were prepared as per the Base Case results. All results were consistent with the Base Case outcomes to the extent there was no significant variation in the seasonal contribution to total streamflow response for the duration of the simulation period (with the exception of decade 1). Consequently, the results for these simulations have been summarised to provide the average seasonal change for the specific conditions. Full results for each simulation are provided in Appendix D.

The results for the Big River catchment are presented in Table 5-7, with the Base Case results provided for comparison. When comparing the various simulations for a given season, the difference in the seasonal streamflow response is relatively small.

The most significant change from the Base Case is for Simulation 5, with the catchment elevation lowered significantly, for which the proportional reduction in winter flows is increased by 6%. In Simulation 5, the winter precipitation that occurred as snowfall in the Base Case (Simulation 1) was converted to rain and Simulation 5 has no snowmelt runoff. Catchment soil moisture is also lower in spring, summer and autumn for Simulation 5 than Simulation 1 but catchment soil moisture is similar for winter between Simulations 1 and 5. Since the soil moisture for winter is less affected by the reduction in catchment elevation associated with the change from snow to rain, the proportional contribution to the increase in evapotranspiration from the winter season is increased. Conversely, in summer and autumn the soil becomes drier under Simulation 5 for both the mature and burnt forest, reducing the proportional contributions of summer and autumn to the increase in evapotranspiration for the burnt forest by 4% and 2%, respectively.

Changes in the forest type for the entire catchment (Simulations 2 to 4) do not have an appreciable impact on the seasonality of the change in streamflow response. Selection of either Mountain Ash forest or Mixed Species forest (Simulations 2 and 3) result in seasonal changes of less than 2% in any of the seasonal outputs from the Base Case.

- **Table 5-7 Summary of Macaque simulation results for the Big River catchment: seasonal percentage contributions to the reduction in mean annual flow for regrowth forest compared with mature forest**

Simulation	Summer	Autumn	Winter	Spring
1. Base Case	18%	11%	31%	40%
2. Mountain Ash Forest	16%	9%	32%	42%
3. Mixed Species Forest	17%	11%	32%	41%
4. Snowgum Forest	19%	14%	30%	37%
5. Lowered Elevation	14%	9%	37%	39%

Results for the Livingstone Creek catchment are displayed in Table 5-8. Like the results for the Big River catchment, variation in the predicted streamflow changes for a given season are relatively small.

Changing the elevation of the catchment (Simulation 5) causes virtually no change from the Base Case for Livingstone Creek because the snowmelt component was already very low in the Base Case. Lowering the catchment elevation and then “stretching” the DEM (Simulation 6), which effectively increases the slopes across the entire catchment, also results in virtually no change in the seasonality of the impacts from the Base Case.

Changing the entire catchment to either Mountain Ash or Mixed Species (Simulations 2 and 3) results in a larger proportion of the flow reduction in spring (increasing from 42% to 48% and 46%, respectively) and a lower proportion of the streamflow impacts in autumn and winter.

Applying the Big River rainfall series to the lowered and stretched DEM (Simulation 7) caused the proportional impact to shift so that the proportional reduction in winter increased by 4% (from Simulation 6) but the proportional reduction in summer decreased by 5% (from Simulation 6). This suggests that proportional effects on streamflows will be more concentrated in summer in catchments with lower mean annual rainfall totals (like Livingstone Creek) and more concentrated in winter in catchments with higher mean annual rainfall totals (like Big River), ignoring the snowmelt effects.

- **Table 5-8 Summary of Macaque simulation results for the Livingstone Creek catchment: seasonal percentage contributions to the reduction in mean annual flow for regrowth forest compared with mature forest**

Simulation	Summer	Autumn	Winter	Spring
1. Base Case	25%	10%	24%	42%
2. Mountain Ash Forest	25%	8%	19%	48%
3. Mixed Species Forest	24%	9%	21%	46%
4. Snowgum Forest	25%	12%	27%	36%
5. Lowered Elevation	26%	8%	22%	43%
6. Livingstone Creek Lowered & Stretched Elevation	26%	13%	22%	39%
7. Livingstone Creek Lowered & Stretched Elevation, Big River Rainfall Series	21%	12%	26%	40%
8. Livingstone Creek Lowered & Stretched Elevation, Big River Rainfall Series, Mixed Species Forest Cover	21%	11%	26%	43%

The Baseflow Index (BFI) is calculated as the baseflow divided by the totalflow over a concurrent period. The BFI represents a relative contribution of baseflow to total streamflow on a standardised basis for comparison between different sites. It is an indicator of hydrogeological conditions and provides an indication of the connection between groundwater and surface water systems. The BFI values for each of the simulation experiments are provided in Table 5-9. The BFI for the Big River and Livingstone Creek base case shows a slight difference in the groundwater-surface water interaction for these two catchments. The impacts of the simulation changes on the BFI also differ for the two catchments, indicating that catchment characteristics are important in determining baseflow contributions.

- **Table 5-9 BFI values for simulation experiments**

Simulation	Big River	Livingstone Creek
1. Base Case	0.62	0.60
2. Mountain Ash Forest	0.60	0.64
3. Mixed Species Forest	0.61	0.63
4. Snowgum Forest	0.64	0.67
5. Lowered Elevation	0.80	0.53
6. Livingstone Creek Lowered & Stretched Elevation	-	0.65
7. Livingstone Creek Lowered & Stretched Elevation, Big River Rainfall Series	-	0.67
8. Livingstone Creek Lowered & Stretched Elevation, Big River Rainfall Series, Mixed Species Forest Cover	-	0.69

5.5 Discussion

There was very little variation in the proportional contribution in each season to the reduction in annual streamflow between the Macaque model experiments. The largest variations in the seasonal proportions were about 5% from the average values. This indicates that the seasonality of the streamflow impacts is remarkably consistent between the Big River and Livingstone Creek catchments, even though they have very different catchment characteristics.

However, there was some variation between the Big River and Livingstone Creek catchments, most noticeably between the Base Case summer/winter contributions to streamflow. In the Livingstone Creek catchment, the summer and winter flows were similar for the Base Case (both around 25% of the total flow), whereas flows in the Big River catchment were more than 10% different in these two seasons. This is perhaps a result of the different elevations of the catchments (and hence the contribution of snow to the overall streamflow).

The simulations did reveal some subtle changes in the seasonality of impacts due to physiographic catchment characteristics. Changing the forest type caused very small (less than 2% changes) in the seasonal proportions of mean annual flow reduction for the Big River catchment. Livingstone Creek was more sensitive to change in forest type. Changing to either all Mountain Ash or all Mixed Eucalypt from the actual forest distribution map caused a shift in proportional impact from autumn/winter to spring of about 5%. Reducing the catchment elevation increases the proportional impact in winter and reduces the proportional impact in summer for catchments, such as Big River, which naturally have significant snow melt contribution to runoff.

Overall, it was considered appropriate to ignore these subtle changes in the seasonality of streamflow reductions so that the results could be more broadly applied across the study area without having to explicitly take account of catchment characteristics. The average proportional contributions to reductions in mean annual flow, as estimated from the thirteen model simulations, were therefore adopted for transposition across the study area.

The average of the thirteen model simulations (five for Big River and eight for Livingstone Creek) revealed that 21% of the mean annual reduction in flow would be experienced in summer, 11% in autumn, 27% in winter and 41% in spring.

6. Application of results to bushfire catchments

Due to the availability of data for the Hinnomunjie catchment (part of the Dartmouth catchment), the Macaque modelling was undertaken on the Big River and Livingstone Creek sub-catchments. However, the 2003 alpine bushfires affected a much larger area, burning over one million hectares of National Parks, reserves, State Forests, and grazing land in Victoria and New South Wales. In order to fully understand the overall streamflow impacts resulting from the bushfire, the modelling results presented in previous sections of this report were transposed to all other areas of the affected region.

6.1 Bushfire affected catchments

In the Broadscale Assessment undertaken as Task 1 of the Bushfire Recovery Program (Murray-Darling Basin Commission, 2007), the area affected by the 2003 bushfires was divided into a number of catchments. These were chosen to ensure all major tributaries within the region were considered, and that the impact of the bushfires on locations of importance to water resource managers was able to be identified. The same catchments were considered in this project, as described in Table 6-1.

Table 6-1 Study Catchments

Catchment Name		Area (km^2)	% of Area Burnt
Northern Catchments	Buffalo	1140	34
	Corryong	485	76
	Dartmouth	3579	90
	Kiewa	421	90
	Mitta Mitta d/s Dartmouth Dam	652	91
	Ovens	1237	62
	Upper Murray	2400	82
	Other Northern	807	87
Southern Catchments	Buchan	849	77
	Dargo	533	90
	Snowy	9563	32
	Tambo	893	67
	Wongungurra	730	62
	Other Southern	251	99

The area covered by a particular forest type within each catchment is presented in Table 6-2. These vegetation categories are consistent with those used in Task 1 (Broadscale Assessment). It should be noted that several assumptions about the forest cover were incorporated into Task 1 for modelling purposes, including:

- Mountain Ash includes all forests dominated by *Eucalyptus regnans* and *E. delegatensis.*
- Snowgum forests are dominated by *E. pauciflora.*
- All other eucalypt species are considered within the Mixed Eucalypt category,.

- Areas covered by pine plantations are contained within the 'not treed' category, as these were assumed to have very little contribution to changes in water yield due to the small area they cover.

Typically, most catchments are dominated by Mixed Eucalypt and Mountain Ash species. As different eucalypt species respond differently to fire, this has implications for the overall catchment response.

- **Table 6-2 Catchment area covered by particular forest type**

Catchment		Forest type			
		Mountain Ash	Mixed Eucalypt	Snowgum	Not treed
Northern Catchments	Buffalo	5%	91%	1%	4%
	Corryong	20%	75%	5%	0%
	Dartmouth	12%	74%	8%	6%
	Kiewa	35%	27%	30%	7%
	Mitta Mitta d/s Dartmouth Dam	20%	74%	1%	5%
	Ovens	10%	83%	2%	5%
	Upper Murray	8%	86%	5%	1%
Southern Catchments	Buchan	9%	86%	4%	1%
	Dargo	6%	91%	3%	1%
	Snowy	1%	86%	9%	4%
	Tambo	8%	83%	2%	8%
	Wongungurra	18%	79%	3%	1%

The severity of the bushfire in each affected catchment is presented in

Table 6-3. This data is consistent with that provided in the Broadscale Assessment, and was sourced from the Department of Sustainability and Environment (Victoria) and Department of Environment and Conservation (NSW). The severity of the fire, combined with the forest type, directly influences the forest response to fire. In general, most catchments were largely affected by a fire of severity level 2.

- **Table 6-3 Catchment area affected by particular fire severity where 1 represents the most extreme fire severity.**

Catchment		Fire Severity			
		1	2	3	Unburnt
Northern Catchments	Buffalo	1%	14%	3%	66%
	Corryong	1%	27%	10%	24%
	Dartmouth	6%	47%	6%	10%
	Kiewa	10%	32%	8%	10%
	Mitta Mitta d/s Dartmouth Dam	3%	33%	15%	9%
	Ovens	1%	27%	9%	38%
	Upper Murray	11%	33%	24%	18%
Southern Catchments	Buchan	23%	29%	1%	23%
	Dargo	6%	41%	13%	10%
	Snowy	3%	10%	15%	68%
	Tambo	6%	28%	4%	33%
	Wongungurra	5%	32%	6%	38%

Consistent with the data used for the Broadscale Assessment, mean annual flow data for each of the Victorian catchments was derived from the Sustainable Diversion Limits project (Sinclair Knight Merz, 2003). Where SDL catchments corresponded with the catchments defined for this project, the mean annual flow was taken directly from the SDL database.

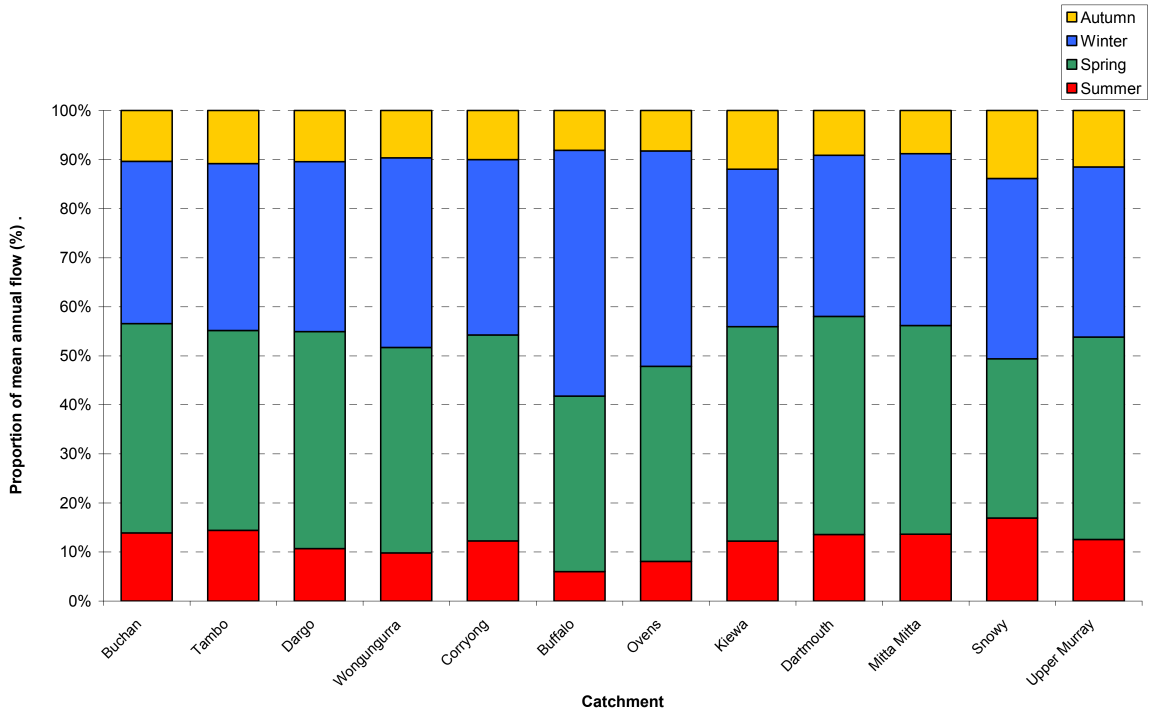
Where SDL catchments did not coincide, mean annual flows were estimated by combining SDL catchments. For the catchments that partially extended into New South Wales (Snowy and Upper Murray), SDL data was unavailable for most of the catchments and a different method was utilised. Flow data for these locations was collected from gauges throughout these catchments and a relationship was derived between mean annual flow and catchment area. This relationship was used to determine the mean annual flows for the catchment areas defined in this project.

The SDL data set is limited to annual information. As the SDL data was not able to provide information about the seasonal streamflows in each of the bushfire affected catchments, further information was obtained from the Flow Stress Ranking project (Sinclair Knight Merz, 2005). While there are slight differences between the SDL and FSR catchments and data sets, it was considered reasonable to assume that the proportion of seasonal flow in each catchment would be consistent for both data sets. Hence, only seasonal proportions of flow rather than absolute values were obtained from the FSR project. The seasonal flow proportions obtained from the FSR were applied to the mean annual flow previously obtained and described above. The streamflow characteristics of the catchments within the bushfire affected area are provided in Table 6-4 and figure 6-1.

- **Table 6-4 Streamflow characteristics**

	Catchment	Mean Flow (ML)				
		Annual	Summer (% MAF)	Autumn (% MAF)	Winter (% MAF)	Spring (% MAF)
Northern Catchments	Buffalo	438,000	26,000 (6%)	36,000 (8%)	219,000 (50%)	157,000 (36%)
Northern Catchments	Corryong	204,000	25,000 (12%)	20,000 (10%)	73,000 (36%)	86,000 (42%)
Northern Catchments	Dartmouth	1,589,000	216,000 (14%)	145,000 (9%)	523,000 (33%)	706,000 (44%)
Northern Catchments	Kiewa	594,000	73,000 (12%)	71,000 (12%)	191,000 (32%)	260,000 (44%)
Northern Catchments	Mitta Mitta (d/s of Dartmouth)	267,000	36,000 (13%)	23,000 (9%)	94,000 (35%)	114,000 (43%)
Northern Catchments	Ovens	553,000	45,000 (8%)	46,000 (8%)	243,000 (44%)	220,000 (40%)
Northern Catchments	Upper Murray	665,000	83,000 (12%)	76,000 (11%)	230,000 (35%)	273,000 (41%)
Southern Catchments	Dargo	177,000	19,000 (11%)	18,000 (10%)	61,000 (34%)	78,000 (44%)
Southern Catchments	Tambo	114,000	16,000 (14%)	12,000 (11%)	39,000 (34%)	46,000 (40%)
Southern Catchments	Wongungarra	293,000	29,000 (10%)	28,000 (10%)	113,000 (39%)	123,000 (42%)
Southern Catchments	Buchan	140,000	19,000 (14%)	14,000 (10%)	46,000 (33%)	60,000 (43%)
Southern Catchments	Snowy	749,000	129,000 (17%)	106,000 (14%)	280,000 (37%)	247,000 (33%)

The seasonal streamflow characteristics are presented in Figure 6-1. In general, autumn flows tend to represent approximately 10% of the mean annual flow. The Snowy catchment has the highest proportion of autumn flows with 14% of the mean annual flow occurring between March and May. Winter, spring and summer flows are more variable across the catchments. During winter, between 32% and 50% of the mean annual flows occur, depending on the catchment. The lowest proportion of winter flows occur in the Kiewa catchment, while the highest proportion occurs in the Buffalo catchment. Spring flows, which are influenced by snowmelt and hence the elevation of the catchment, range between 33% and 44% of the mean annual flow. The Dartmouth catchment has the largest proportion of spring flows whereas the smallest proportion occurs in the Snowy. Summer flows range between 6% and 17% of the mean annual flow. The smallest proportion of summer flows occurs in the Buffalo catchment, while the highest proportion occurs in the Snowy.



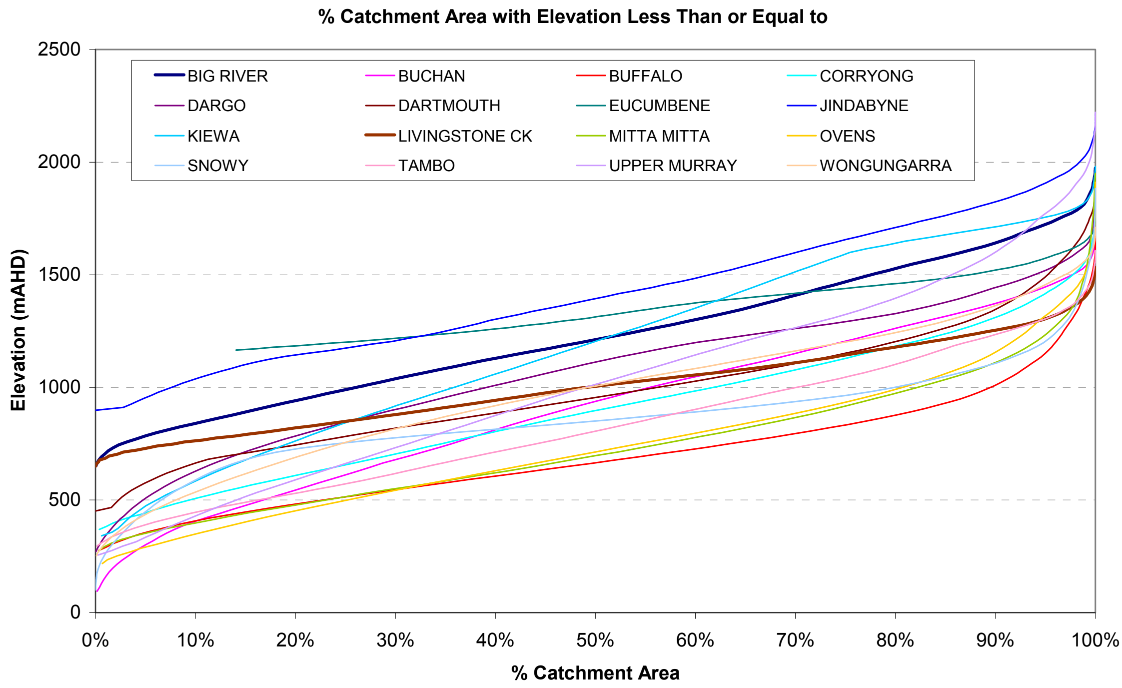
- **Figure 6-1 Recorded seasonal streamflow as a proportion of the mean annual flow for the bushfire affected catchments**

6.2 Comparison of catchment characteristics

In order to reasonably transpose the results of the Macaque modelling from Big River and Livingstone Creek to the wider bushfire area, it was necessary to check that the two modelled catchments have characteristics that are representative of the whole affected area. The distributions of elevation, slope, aspect and Multi-Resolution Valley Bottom Flatness (MRVBF, defined below) were compared for Big River, Livingstone Creek and the all of the other (larger) bushfire affected catchments. If the distributions of these characteristics for Big River and Livingstone Creek lie within the spread of distributions from all of the bushfire affected catchments, and preferably span the spread of distributions, then it helps to justify our approach of applying the same seasonal proportions to the annual estimates of streamflow reductions.

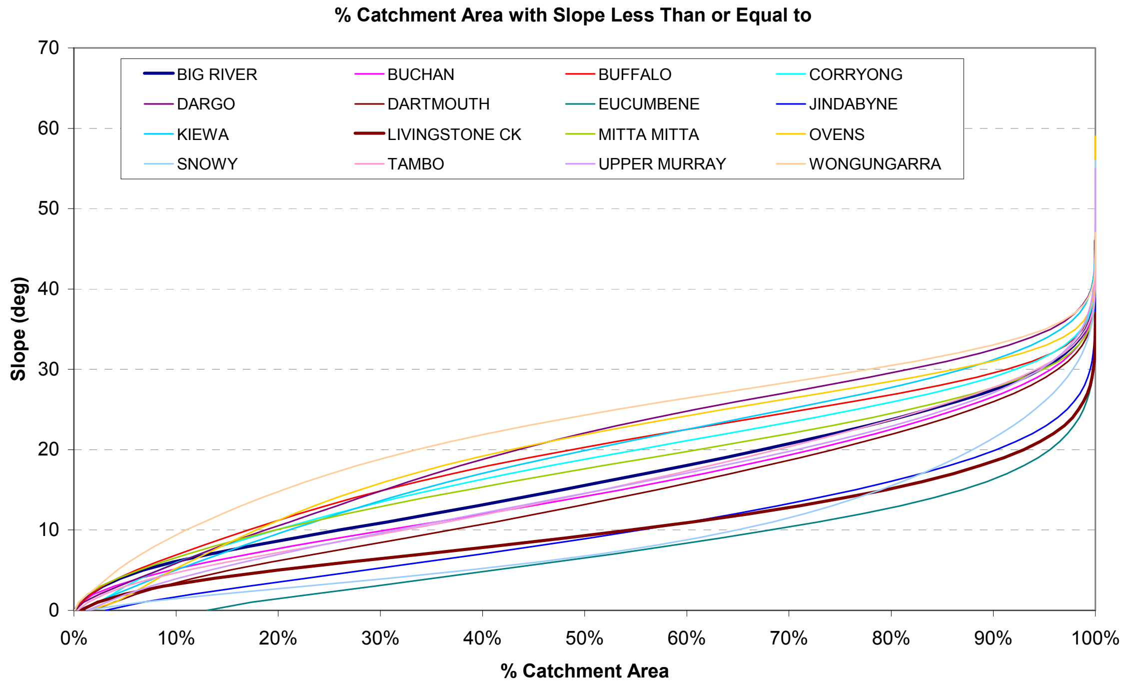
The elevation characteristics of the burnt catchments are presented in Figure 6-2. In general, the lowest parts of the study catchments tend to be between 100 m AHD and 1,000 m AHD, while the most elevated regions range between 1,500 m AHD and slightly over 2,000 m AHD. The main implication of the differences in the distributions of elevation are that the higher elevated catchments receive snowfall in winter whilst those at lower elevations receive virtually no snowfall.

The Livingstone Creek catchment represents one of the less elevated catchments of the study area, with the entire catchment below 1,500 m AHD. There is virtually no snowfall in the Livingstone Creek catchment and therefore virtually no contribution of snowmelt to spring streamflows. In contrast, the Big River catchment contains some of the most elevated areas burnt in the 2003 bushfires and has considerable volumes of snowmelt runoff in the winter of most years. In terms of maximum elevations, Livingstone Creek and Big River (shown in bold in Figure 6-2) encompass the range of conditions in the study area. Given the consistency in the results for changes in streamflow seasonality in Livingstone Creek and Big River, then the model results from these two catchments should be able to be more broadly applied across the bushfire affected region without explicitly taking account of differences in maximum or mean catchment elevation.



- **Figure 6-2 Catchment elevation characteristics for the bushfire affected area**

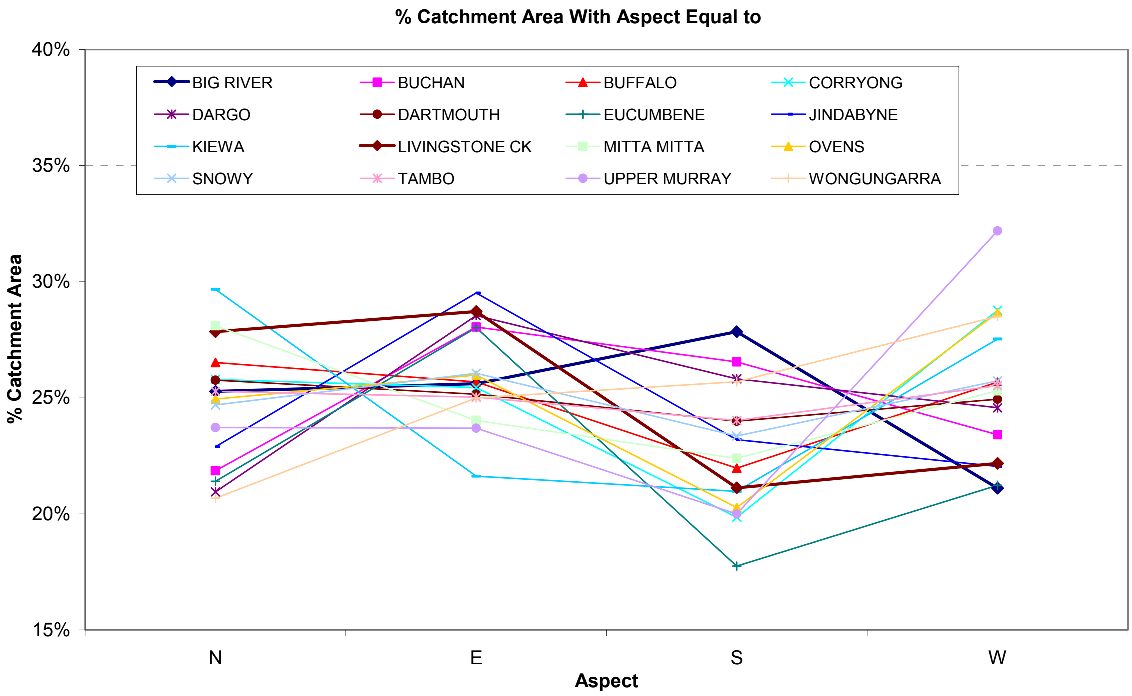
The slope characteristics of the catchments affected by the 2003 bushfires are presented in Figure 6-3. All catchments range in slope between 0° and approximately 40°. The Big River and Livingstone Creek catchments (shown in bold in Figure 6-3) are relatively consistent with the other catchments with regard to the slope profile across the burnt area. If there is consistency between the results for changes in streamflow seasonality between Livingstone Creek and Big River then the model results from these two catchments should be able to be more broadly applied across the bushfire affected region without explicitly taking account of differences between catchments in the distribution of slopes.



■ **Figure 6-3 Catchment slope characteristics for the bushfire affected area**

The proportion of catchment area facing a particular aspect for each of the burnt catchments is presented in Figure 6-4. The north facing slopes, which are over-represented in the Livingstone Creek catchment, would have higher exposure to solar radiation, which increases rates of tree growth and evapotranspiration. Big River has an over-representation of south facing slopes and would have lower rates of tree growth and evapotranspiration. Considering only the influence of aspect and in the absence of any other factors, Big River would be expected to have higher than average rates of runoff while Livingstone Creek would have lower runoff rates. Livingstone Creek has the third largest proportion of north facing slopes of all of the catchments considered and Big River has the largest proportion of south facing slopes.

If there is consistency between the results for changes in streamflow seasonality between Livingstone Creek and Big River then the model results from these two catchments should be able to be more broadly applied across the bushfire affected region without explicitly taking account of differences between catchments in the aspect of hillslopes.



- **Figure 6-4 Catchment aspect characteristics for the bushfire affected area**

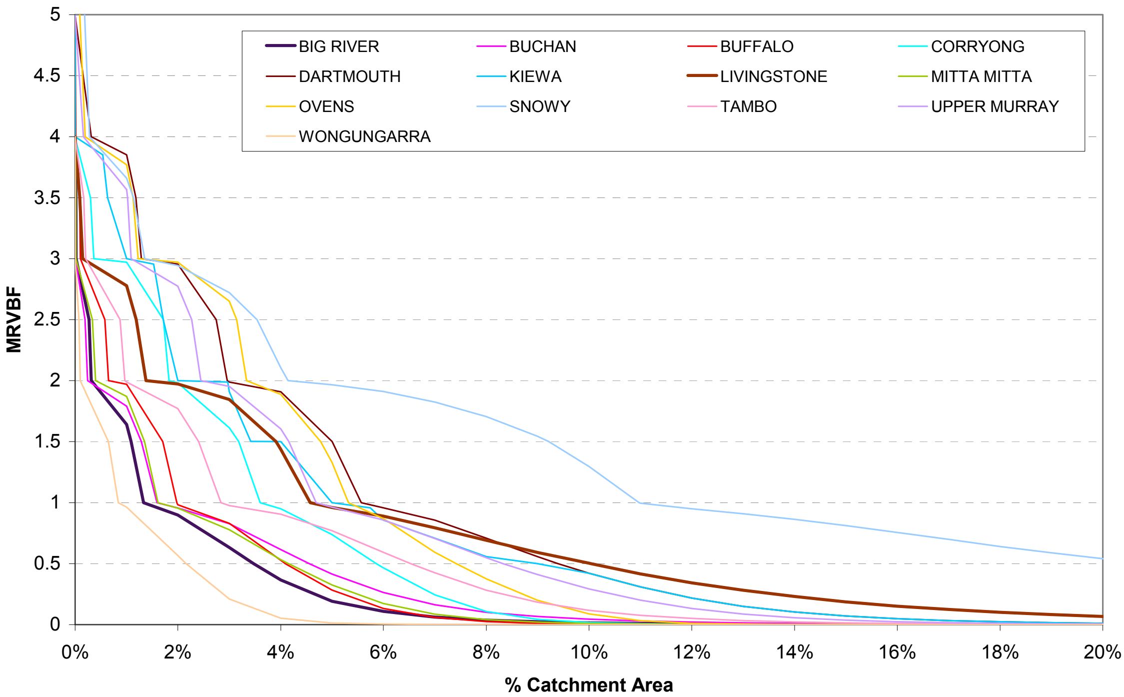
The Multi Resolution Valley Bottom Flatness (MRVBF) algorithm uses a digital elevation model (DEM) to identify valley bottoms based on local topographic features (Gallant and Dowling, 2003). It generates an index value that divides the slope into classes of flatness, where:

- Values less than 0.5 are not considered valley bottoms.
- Values between 0.5-1.5 are the steepest and smallest resolvable valley bottoms for fine resolution DEMs.
- Values greater than 1.5 reflect flatter and larger valley bottoms.

The MRVBF characteristics of the fire affected catchments are presented in Figure 6-5. For all catchments, the majority of the catchment area is made up of landscapes that are not considered valley bottoms. In most cases, less than 10% of the catchment is valley bottom area.

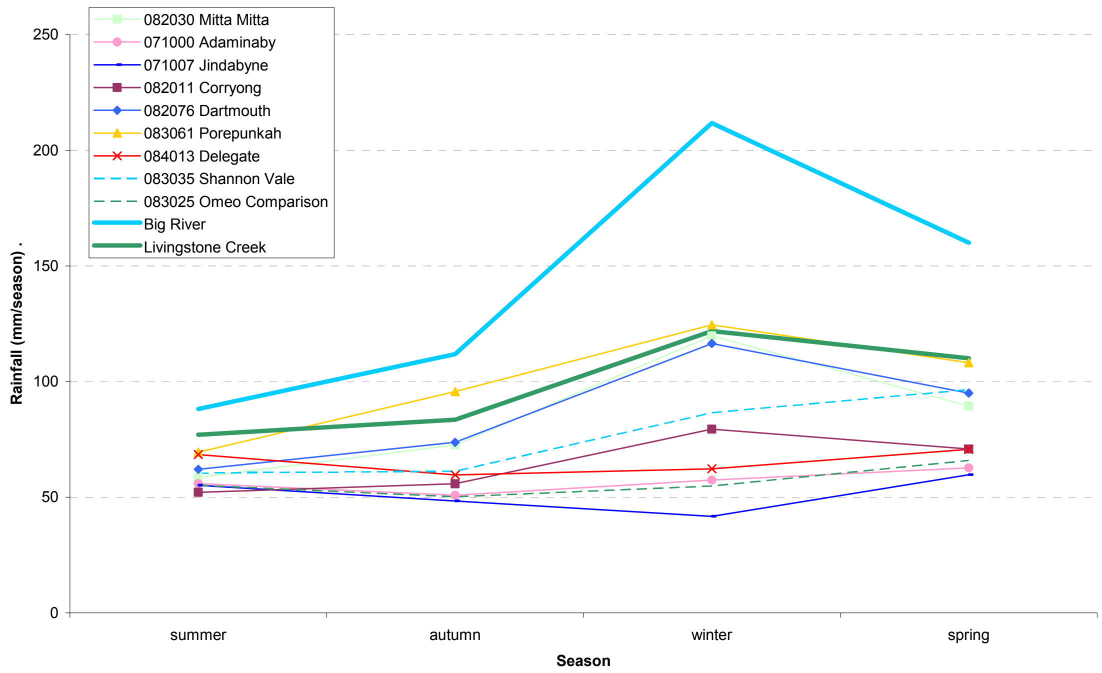
The Big River and Livingstone Creek catchments (indicated in bold in Figure 6-5) are at the higher and lower limits of the spread of MRVBF distributions. The Big River catchment has 3.5% of the catchment area with an MRVBF value greater than 0.5, which is the second lowest in terms of floodplain area of all of the catchments considered. The Livingstone Creek catchment has 10% of the catchment area with an MRVBF value greater than 0.5 and has the second highest proportion of floodplain of all of the catchments considered.

If there is consistency between the results for changes in streamflow seasonality between Livingstone Creek and Big River then the model results from these two catchments should be able to be more broadly applied across the bushfire affected region without explicitly taking account of differences in the proportion of floodplain in the catchment.

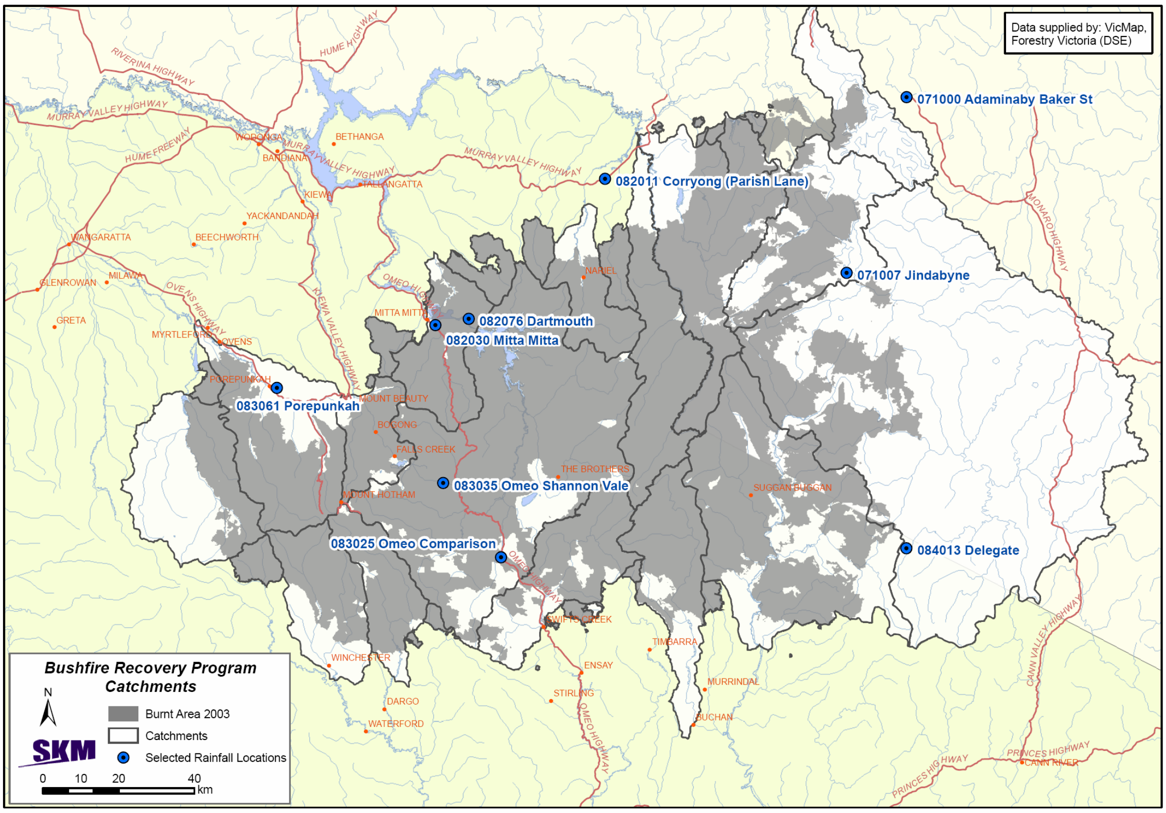


- **Figure 6-5 Catchment MRVBF characteristics for the bushfire affected area**

The rainfall seasonality of selected locations within the bushfire affected area is presented in Figure 6-6. The location of these rainfall gauges is presented in Figure 6-7. The Shannon Vale gauge is located within the Big River catchment, while the Omeo Comparison gauge is located within the Livingstone Creek catchment. These rainfall gauges were used as inputs in the Macaque model for the relevant catchment area. The bold lines represent the catchment average rainfall as predicted by Macaque. In most catchments, a peak in rainfall occurs during winter. This response is consistent with that predicted by Macaque for the Big River and Livingstone Creek catchments. While the total rainfall for the modelled catchments is generally greater than the recorded information in other catchments, for the purposes of this study it was considered that the general seasonal trends were consistent and the Big River and Livingstone Creek catchments could be considered generally representative of the bushfire affected area.



■ **Figure 6-6 Rainfall seasonality of selected locations within the bushfire affected area**



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- **Figure 6-7 Location of rainfall gauges used for seasonality comparison**

6.3 Summary outcome of comparison of catchment characteristics

A hypothesis has been made that the seasonal proportions obtained from the Macaque modelling for the Big River and Livingstone Creek catchments can be applied to the annual estimates of streamflow reductions without explicitly considering other catchment characteristics. This is a reasonable approach because:

- The results of the Macaque modelling (in Section 5) show that the seasonal proportions of the annual reduction in streamflow are similar for both the Big River and Livingstone Creek catchments.
- The distributions of catchment characteristics for Big River and Livingstone Creek roughly span the spread of distributions from all of the catchments in the bushfire affected region. Specifically:
  - Big River has a relatively high maximum elevation (and therefore significant snowmelt runoff) but Livingstone Creek has a low maximum elevation (and very little snowmelt contribution to runoff).
  - Big River is among the steeper catchments but Livingstone Creek is one of the flatter catchments.
  - Big River has one of the largest proportions of south facing slopes but Livingstone Creek has predominantly north facing slopes.
  - Big River has the second smallest proportion of floodplain area but Livingstone Creek has the second largest proportion of floodplain area.
  - The rainfall characteristics of the Big River and Livingstone Creek catchments show similar seasonal trends to other recorded rainfalls in the bushfire affected area.

It is recognised that the seasonal distribution of rainfall could influence the seasonal distribution of the changes in streamflow, and therefore it would be desirable to undertake further research into the sensitivity of the modelled response to the seasonality of rainfall.

6.4 Application of Simulation Results across the Bushfire Region

The various catchment characteristics considered above indicate that the Big River and Livingstone Creek catchments are relatively typical of the entire area burnt by the 2003 alpine bushfires. These two catchments provide a good basis for understanding the general topographical features of the study area. As a result, the Big River and Livingstone Creek catchments can be considered representative catchments, and the results presented in Section 5.4 can be transposed to cover the entire study area.

The results presented earlier indicate that there is very little variation in the predicted change in streamflow for a given season for each of the simulations. This similarity in results provides an opportunity to simply extrapolate the results: an average of all simulations can be taken, generating a single value for each season that represents the expected change to streamflow as a proportion of the mean annual flow.

Although there were variations in the proportional contributions to reduced streamflow between the Macaque simulation runs, there is also a good degree of agreement and consistency. A simple average of the proportional reduction from all 13 simulations was therefore taken.

The application of these seasonal ratios across the entire bushfire affected area is presented in Table 6-5. The long term change in streamflow, identified through the Task 1 Broadscale Assessment study, considers the effect of the bushfire as well as the anticipated streamflow for a no-fire scenario. For each of the study catchments, the maximum negative difference between the fire and no-fire scenarios is given. These values represent the maximum change in streamflow compared to the anticipated conditions assuming no fire had occurred. The results presented from the Task 1 Broadscale Assessment are those calculated for the Best Estimate case, which assumes:

- Fire severity 1: For all forest types, individual trees may or may not be killed, however the overall forest response will be hydrologically similar to a regrowth forest;
- Fire severity 2: Mountain Ash forest responds as per Fire Severity 1. For Mixed Species and Snowgum forests, 60% of the forest is considered to be consistent with a regrowth scenario. In the long term, the water use of this component is equivalent to that observed in a forest made up of new trees. The remaining 40% of the forest is not significantly affected by the fire, and the hydrology is similar to that of a recovered forest.
- Fire severity greater than level 2: The fire has no effect on the water use of the forest. In the long term, the hydrological conditions are equivalent to those likely if the original forest recovered completely.

For example, based on the results of the Task 1 Broadscale Assessment, the annual streamflow within the Buffalo catchment is expected to reduce by a maximum of 37 GL around 25 years after the fire. Using the seasonal proportions identified through the modelling (refer to the discussion in Section 5), this annual reduction translates to a 8 GL reduction in summer (21% of 37 GL), a 4 GL reduction in autumn (11% of 37 GL), a 10 GL reduction in winter (27% of 37 GL) and a 15 GL reduction in spring (41% of 37 GL). Seasonal streamflow impacts for each bushfire affected catchment were calculated in this manner.

Table 6-5 presents the expected seasonal impact corresponding to the maximum reduction in annual flow for each of the study catchments. As the largest percentage impact occurs in spring, most of the change to streamflow for each catchment occurs at this time. However, due to the size and characteristics of some catchments, the most significant impact (spring) in that catchment is still volumetrically smaller than the smallest percentage impact (autumn) of other catchments. For example, a maximum reduction in streamflow of 15 GL is expected in spring in the Buffalo catchment. In the Dartmouth catchment, however, the change in spring is 152 GL while the reduction in autumn is expected to be 39 GL, which is more than double the spring volume in the Buffalo catchment.

The total maximum reduction in streamflow in the Murray River is 859 GL, around 25 years after the fire. On a seasonal basis, the majority of this reduction is expected during spring (354 GL). At the Gippsland Lakes, the total maximum reduction in streamflow is approximately 195 GL (occurring around 25 years after the fire), of which the largest reduction (80 GL) occurs during spring.

- **Table 6-5 Maximum seasonal difference in streamflow between fire and no fire scenario based on the results of the experimental simulations**

Catchment		Change in streamflow (ML)				
		Annual *	Summer (21%)	Autumn (11%)	Winter (27%)	Spring (41%)
Northern Catchments	Buffalo	-37,000	-8,000	-4,000	-10,000	-15,000
	Corryong	-32,000	-7,000	-3,000	-9,000	-13,000
	Dartmouth	-368,000	-79,000	-39,000	-99,000	-152,000
	Kiewa	-30,000	-6,000	-3,000	-8,000	-12,000
	Mitta Mitta (d/s of Dartmouth)	-45,000	-10,000	-5,000	-12,000	-19,000
	Ovens	-87,000	-19,000	-9,000	-23,000	-36,000
	Upper Murray	-215,000	-46,000	-23,000	-58,000	-89,000
	Other Northern	-45,000	-10,000	-5,000	-12,000	-19,000
	Total for River Murray (d/s of confluence with Ovens)	-859,000	-184,000	-91,000	-230,000	-354,000
Southern Catchments	Dargo	-62,000	-13,000	-7,000	-17,000	-26,000
	Tambo	-37,000	-8,000	-4,000	-10,000	-15,000
	Wongungarra	-79,000	-17,000	-8,000	-21,000	-33,000
	Other Southern	-17,000	-4,000	-2,000	-5,000	-7,000
	Total for Gippsland Lakes	-195,000	-42,000	-21,000	-52,000	-80,000
	Buchan	-86,000	-18,000	-9,000	-23,000	-35,000
	Snowy	-168,000	-36,000	-18,000	-45,000	-69,000

* Note: Annual change in streamflow obtained from the 'best estimate' in Task 1 Broadscale Assessment (Murray-Darling Basin Commission, 2007).

The above information can be put into context by comparing these predicted reductions to the observed average streamflow conditions. Figure 6-1 displays the recorded average seasonal streamflow data, presented as a proportion of the recorded mean annual streamflow in that catchment. Typically, winter and spring have the largest flows, while summer and autumn flows represent a much smaller fraction of the total recorded streamflow.

Table 6-6 combines the data contained in Table 6-5 and Figure 6-1 to show the percentage change in streamflow within each catchment on an annual and seasonal basis. For example, an average summer flow of 26,400 ML is recorded for the Buffalo catchment. If no bushfires were to occur over the following 25 or so years and the summer flow represented the same proportion of the mean annual flow, the mean summer flow would grow to an average of 27,000 ML. Based on the results of the experimental simulations, a reduction of 8,000 ML/year is expected to occur in summer from this no-fire seasonal flow as a result of a bushfire. The resulting flow in summer would be 29% lower than currently recorded.

The predicted reduction in streamflow is expected to have a significant effect on water availability in some catchments. For example, on an annual basis, the maximum reduction in streamflow in the Buchan catchment is expected to be 57%. When considering the seasonal changes in the Buchan catchment, the impacts are more severe with summer flows reduced by up to 87% as a result of the fire. While other seasons are not affected as significantly, reductions of 46% to 58% are still predicted for the Buchan catchment during autumn, winter and spring.

Table 6-6 indicates that the other catchments are not impacted as significantly as the Buchan catchment . Nonetheless, the reductions in streamflow within the catchments are not trivial. The lowest expected change is predicted for the Kiewa catchment, with maximum annual reduction of 5%. Seasonally, the Kiewa could expect flows to be reduced by between 4 and 9% of the current levels.

- **Table 6-6 Predicted maximum reduction in streamflow relative to a no-fire scenario as a result of bushfire**

Catchment		Change in streamflow (%)				
		Annual *	Summer	Autumn	Winter	Spring
Northern Catchments	Buffalo	-8%	-29%	-11%	-4%	-9%
	Corryong	-15%	-27%	-16%	-11%	-15%
	Dartmouth	-22%	-35%	-26%	-18%	-21%
	Kiewa	-5%	-9%	-4%	-4%	-5%
	Mitta Mitta (d/s of Dartmouth)	-16%	-25%	-19%	-12%	-15%
	Ovens	-15%	-40%	-19%	-9%	-16%
	Upper Murray	-30%	-52%	-28%	-23%	-30%
Southern Catchments	Dargo	-33%	-66%	-33%	-26%	-31%
	Tambo	-31%	-46%	-30%	-24%	-31%
	Wongungarra	-25%	-55%	-27%	-17%	-25%
	Buchan	-57%	-87%	-58%	-46%	-55%
	Snowy	-24%	-30%	-18%	-18%	-30%

* Note: Annual change in streamflow obtained from the ‘best estimate’ in Task 1 Broadscale Assessment (Murray-Darling Basin Commission, 2007). There are small differences between the annual total and the sum of the seasonal totals due to rounding of values to nearest 1000 ML/season.

Maximum reductions in mean seasonal flows were estimated from the pre-fire conditions, as shown in Table 6-7. The total annual reductions presented in this table were derived from the Best Estimate case in the Broadscale Assessment study. The patterns in seasonal reduction are similar to those revealed from the no-fire comparison, with the largest absolute reductions in flow occurring in winter and spring in most catchments. The total changes for the comparison with the pre-fire mean are lower than for the comparison with the no-fire case because the no-fire case assumes that there would have been a gradual increase in mean flows over the coming decades. Using the Buffalo catchment as an example again, a maximum reduction of 37 GL/year is expected in mean annual flow when compared with the no-fire case but this only represents a maximum reduction of 26 GL/year in the pre-fire mean annual flow. The spring contributions to these reductions for the Buffalo catchment are 15 GL when compared with the no-fire case and 11 GL when compared with the pre-fire mean seasonal flow.

- **Table 6-7 Maximum seasonal difference in streamflow between fire and pre-fire (2003) mean seasonal flows**

Catchment		Change in streamflow (ML)				
		Annual *	Summer	Autumn	Winter	Spring
Northern Catchments	Buffalo	-26,000	-7,000	-3,000	-4,000	-11,000
	Corryong	-26,000	-6,000	-3,000	-6,000	-11,000
	Dartmouth	-320,000	-72,000	-34,000	-83,000	-130,000
	Kiewa	-20,000	-5,000	-2,000	-5,000	-8,000
	Mitta Mitta (d/s of Dartmouth)	-29,000	-7,000	-3,000	-6,000	-12,000
	Ovens	-65,000	-17,000	-7,000	-14,000	-27,000
	Upper Murray	-170,000	-40,000	-18,000	-42,000	-70,000
	Other Northern	-36,000	-8,000	-4,000	-10,000	-15,000
	Total for River Murray (d/s of confluence with Ovens)	-692,000	-163,000	-74,000	-171,000	-284,000
Southern Catchments	Dargo	-51,000	-12,000	-5,000	-13,000	-21,000
	Tambo	-31,000	-7,000	-3,000	-8,000	-13,000
	Wongungarra	-58,000	-15,000	-6,000	-13,000	-24,000
	Other Southern	-15,000	-3,000	-2,000	-4,000	-6,000
	Total for Gippsland Lakes	-155,000	-37,000	-17,000	-38,000	-63,000
	Buchan	-74,000	-17,000	-8,000	-19,000	-30,000
	Snowy	-230,000	-46,000	-26,000	-68,000	-89,000

* Note: Annual change in streamflow obtained from the 'best estimate' in Task 1 Broadscale Assessment (Murray-Darling Basin Commission, 2007). There are small differences between the annual total and the sum of the seasonal totals due to rounding of values to nearest 1000 ML/season.

Table 6-8 shows the percentage reductions in mean seasonal flows expected for the period of maximum impact when compared with the pre-fire mean annual flow case. The seasonal patterns are similar to those revealed in the comparison with the no-fire case, with the forecast percentage reductions in summer and autumn flows being larger than the percentage reductions in the winter and spring flows in each catchment. The most significantly affected catchment would be the Buchan catchment, with the maximum reduction in mean annual flow 53% of the pre-fire mean and the maximum reduction in mean summer flow 86% of the pre-fire mean.

- **Table 6-8 Predicted maximum reduction in streamflow relative to pre-fire (2003) mean annual flow as a result of bushfire**

Catchment		Change in streamflow (%)				
		Annual *	Summer	Autumn	Winter	Spring
Northern Catchments	Buffalo	-6%	-27%	-8%	-2%	-7%
	Corryong	-13%	-24%	-14%	-9%	-12%
	Dartmouth	-20%	-33%	-24%	-16%	-18%
	Kiewa	-3%	-7%	-3%	-3%	-3%
	Mitta Mitta (d/s of Dartmouth)	-11%	-20%	-14%	-7%	-10%
	Ovens	-12%	-38%	-16%	-6%	-12%
	Upper Murray	-26%	-48%	-23%	-18%	-26%
Southern Catchments	Dargo	-29%	-64%	-29%	-21%	-26%
	Tambo	-27%	-43%	-26%	-20%	-28%
	Wongungarra	-20%	-52%	-22%	-12%	-19%
	Buchan	-53%	-86%	-54%	-41%	-51%
	Snowy	-30%	-36%	-25%	-24%	-36%

* Note: Annual change in streamflow obtained from the 'best estimate' in Task 1 Broadscale Assessment (Murray-Darling Basin Commission, 2007).

Due to the spatial extent of the bushfire affected area, climatic conditions can vary across the region. Due to the interaction between rainfall and streamflow, the mean annual rainfall in each catchment has implications for the streamflow in that catchment. This information was used to provide some further understanding of the results presented in Table 6-6. In particular, a very weak negative trend was observed between mean annual rainfall and mean annual runoff. This indicates that catchments with low mean annual rainfalls are slightly more likely to experience larger proportional impacts on streamflow, as would be expected, because evapotranspiration from the regrowth forest forms a greater percentage of the overall water balance in low rainfall catchments.

The estimates of changes in seasonal streamflows have been estimated across the entire bushfire affected region by transposing Macaque model simulations from two sub-catchments of the Mitta Mitta River upstream of Dartmouth. They are regional estimates of streamflow impacts that are appropriate for a broadscale assessment. To derive more robust estimates of actual seasonal impacts in a particular catchment, it would be advisable to carry out a detailed study that would involve calibration and application of the Macaque model to that catchment.

7. Conclusion

A simulation approach was adopted to estimate the seasonal effects on streamflow of the 2003 bushfires across the bushfire affected catchments. The Macaque model was calibrated and applied to two sub-catchments of the Mitta Mitta River located upstream of Dartmouth Dam, Livingstone Creek and Big River. Macaque is a daily catchment model, which has detailed parametrisation based on physical properties, with key spatial parameters including topography, precipitation, vegetation leaf area index and soils. Macaque was calibrated to gauged streamflow data for the two sub-catchments. Simulation experiments were conducted with Macaque to assess the seasonality of changes in water yield changes based on consideration of spatial and temporal changes in topography, forest species and rainfall.

The average of the thirteen Macaque model simulations (five for Big River and eight for Livingstone Creek) revealed that 21% of the mean annual reduction in flow would be experienced in summer, 11% in autumn, 27% in winter and 41% in spring. In all of the model simulations, the seasonality of the change in mean annual runoff was consistent between the second and ninth decades after the bushfire.

There was very little variation in the proportional contribution of each season to the reduction in annual streamflow between the Macaque model experiments. The largest variations in the seasonal proportions were about 5% from the average values. This indicates that the seasonality of the streamflow impacts is remarkably consistent between the Big River and Livingstone Creek catchments, even though they have very different catchment characteristics.

The average proportional contributions to reductions in mean annual flow, as estimated from the thirteen model simulations, were therefore adopted for transposition across the study area. The distributions of elevation, slope, aspect and floodplain extent (MRVBF) for Livingstone Creek and Big River catchments generally span the spread of distributions for these characteristics from all of the catchments in the bushfire affected region. This justifies the approach of applying the seasonal impact proportions for the Big River and Livingstone Creek simulations across the bushfire affected region without explicitly taking account of variations in physiographic characteristics.

It is recognised however that the seasonal distribution of rainfall could influence the seasonal distribution of the changes in streamflow, and therefore it would be desirable to undertake further research into the sensitivity of the modelled response to the seasonality of rainfall.

Seasonal estimates of reduction in flow were estimated by multiplying the annual estimates of flow reduction from the Task 1 report (Murray-Darling Basin Commission, 2007) by the seasonal proportional effects. These were then subtracted from the estimates of pre-fire runoff for each season for each catchment to estimate the changes in mean seasonal streamflow that would be expected for the maximum impact period, approximately 20 to 30 years after the fire. The predicted percentage impacts on mean summer flows were greater in all of the bushfire affected catchments than the predicted percentage impacts on mean annual flows. Conversely, the predicted percentage impacts on mean winter flows were less in all of the bushfire affected catchments than the predicted percentage impacts on mean annual flows. Percentage reductions in mean spring and autumn flows were similar to the percentage reduction in mean annual flows.

The estimates of changes in seasonal streamflows have been estimated across the entire bushfire affected region by transposing Macaque model simulations from two sub-catchments of the Mitta Mitta River upstream of Dartmouth. They are regional estimates of streamflow impacts appropriate for a broadscale assessment. To derive more robust estimates of actual seasonal impacts in a particular catchment, it would be advisable to carry out a detailed study that would involve calibration and application of the Macaque model to that catchment.

8. References

Farley, K.A., Jobbagy, E.G. and Jackson, R.B. (2005) Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology* **11,** 1565-1576.

Gallant, J.C. and Dowling, T.I. (2003) A multiresolution index of valley bottom flatness for mapping depositional areas. *Water Resources Research* **39**, 1347-1359.

Lane, P., Best, A., Hickel, K. and Zhang, L. (2003) *The Effect of Afforestation on Flow Duration Curves.* Cooperative Research Centre for Catchment Hydrology Technical Report 03/13.

Murray-Darling Basin Commission (2007) *Impact of the 2003 Alpine Bushfires on Streamflow - Broadscale water yield assessment*. Prepared by Sinclair Knight Merz for the Victorian Department of Sustainability and Environment and the Murray-Darling Basin Commission.

Peel, M., Watson, F., Vertessy, R., Lau, A.,. Watson, I., Sutton, M. and Rhodes, B. (2000) *Predicting the water yield impacts of forest disturbance in the Maroondah and Thompson catchments using the Macaque Mode*l. Cooperative Research Centre for Catchment Hydrology Technical Report 00/14

Peel, M.C., Watson, F. and Vertessy, R. (2002) *Modelling of low flows in the North Esk River using the Macaque Model.* Report prepared for the Launceston City Council.

Silberstein, R., Best, A., Hickel, K.¸ Gargett, T. and Adhitya, A. (2004) *The Effect of Clearing on Native Forest on Flow Regime.* Cooperative Research Centre for Catchment Hydrology Technical Report 04/04.

Sinclair Knight Merz (1998) *ESFM Project: Water Quality and Quantity for the Upper and Lower North East, Southern RFA Regions*. In conjunction with CSIRO Land and Water. Project Number NA 61/ESFM.

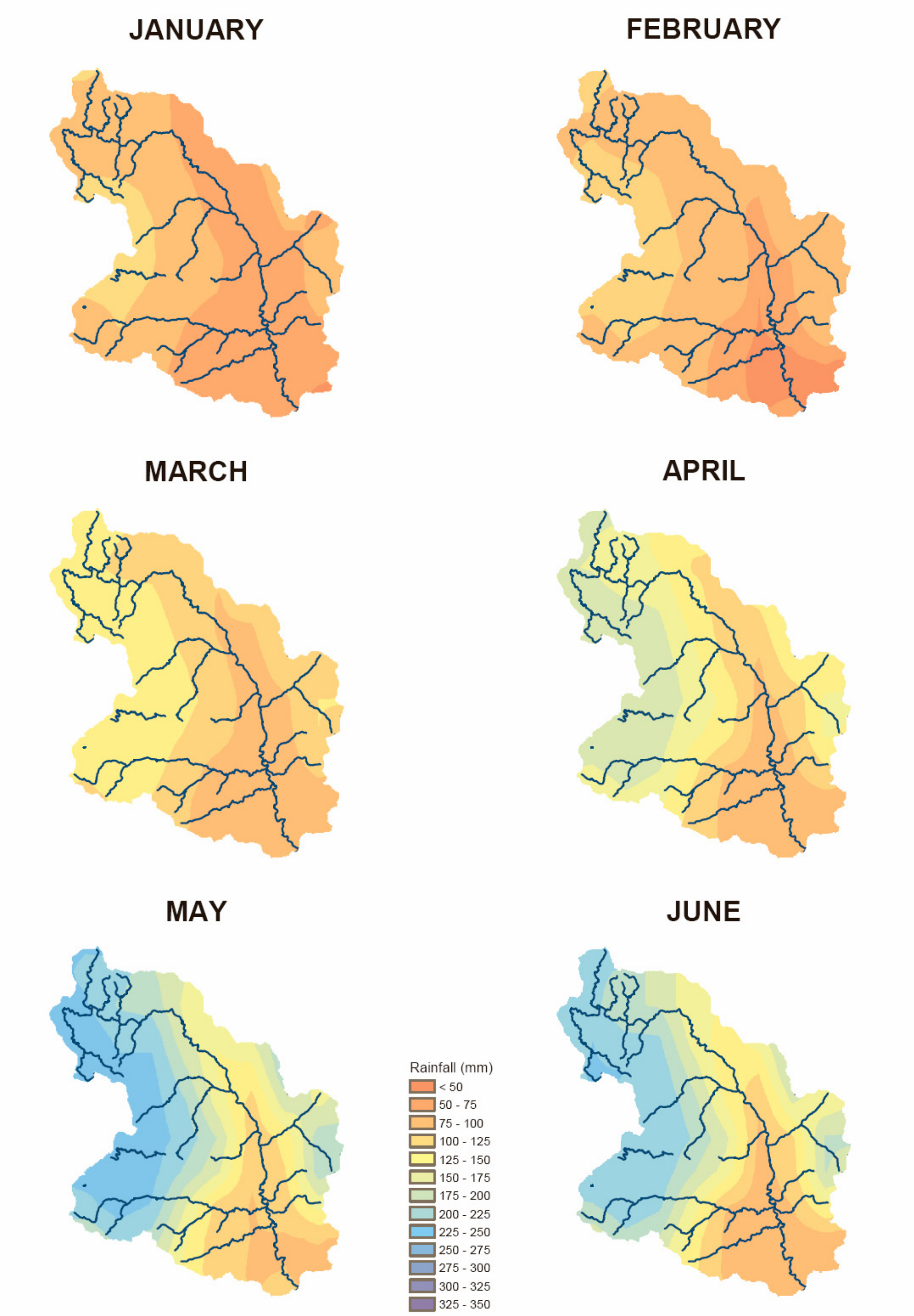
Sinclair Knight Merz (2003) *Sustainable Diversion Limits Project: Estimation of Sustainable Diversion Limit Parameters over Winterfill Periods in Victorian Catchments*. Final Report to the Department of Sustainability and Environment, Victoria.

Sinclair Knight Merz (2005) *Development and Application of a Flow Stressed Ranking Procedure*. Final Report to the Department of Sustainability and Environment, Victoria.

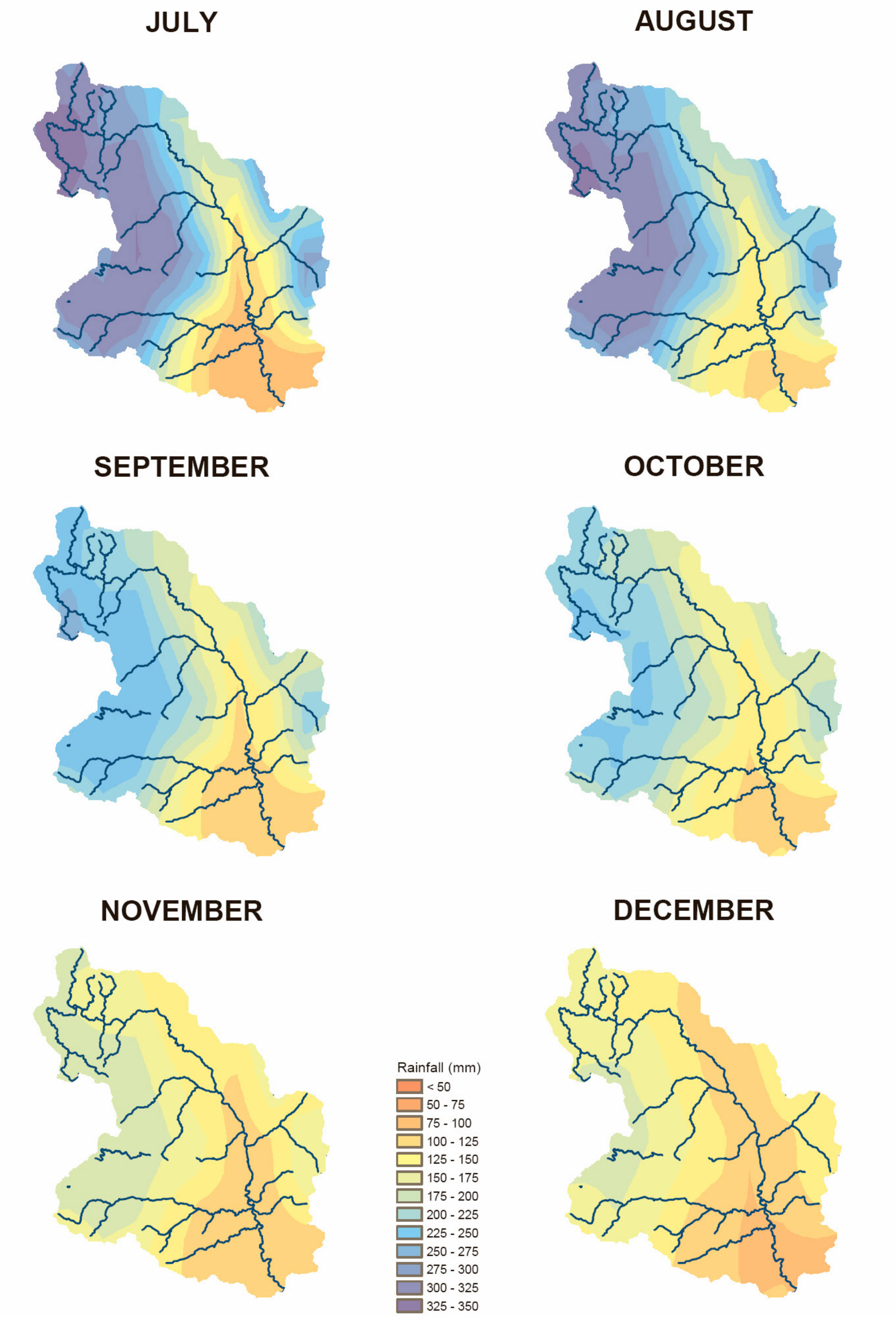
Watson, F. (1999) *Large scale, long term, physically based modelling of the effects of land use change on forest water yield*. PhD Dissertation. Department of Civil and Environmental Engineering, University of Melbourne, Australia,

Zhang, L., Dowling, T., Hocking, M., Morris, J., Adams, G., Hickel, K., Best, A. and Vertessy, R. (2003) Predicting the effects of large-scale afforestation on annual flow regime and water allocation: an example for the Goulburn-Broken catchments. Technical Report 03/5, Cooperative Research Centre for Catchment Hydrology.

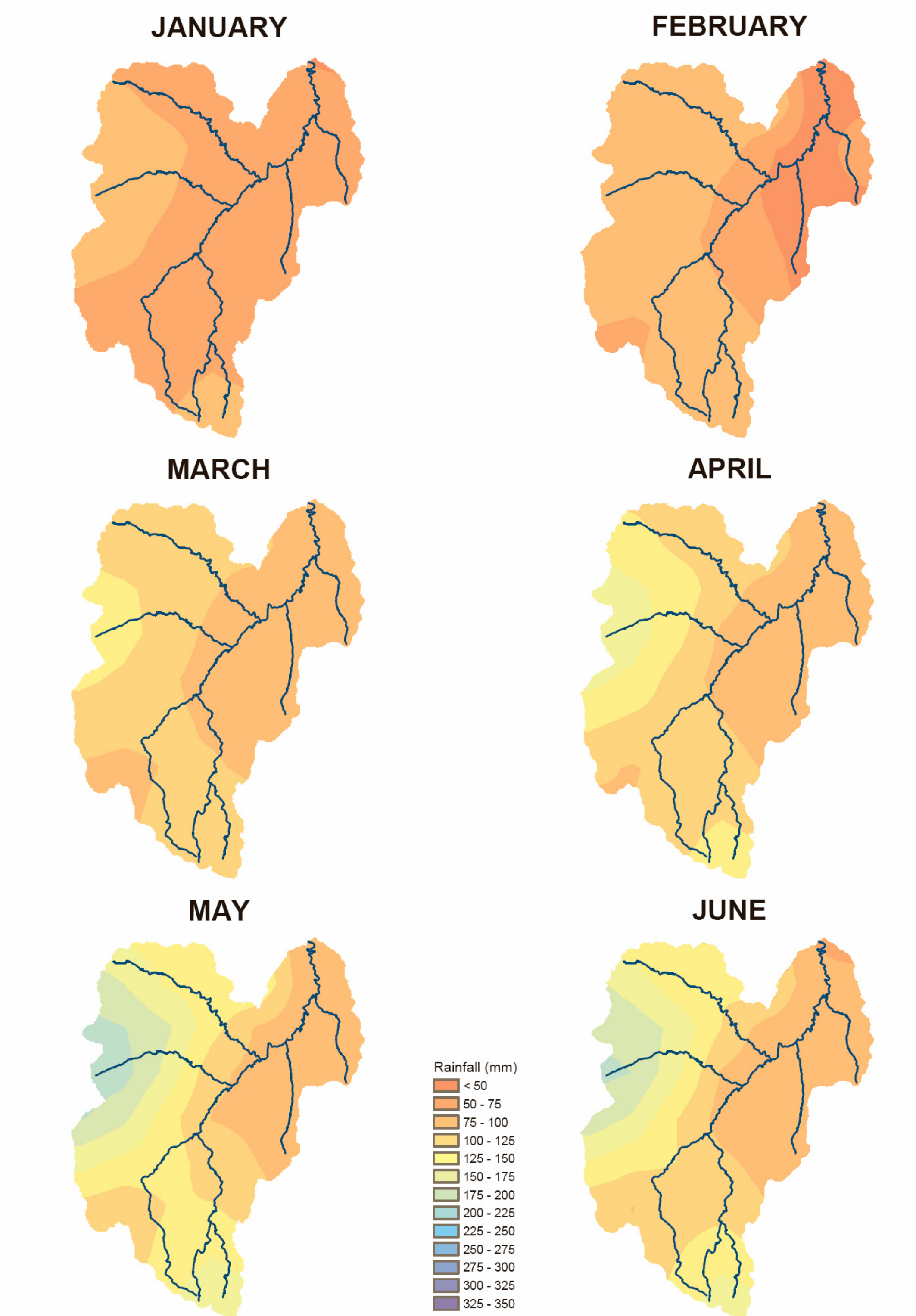
Appendix A Gridded Average Monthly Rainfall



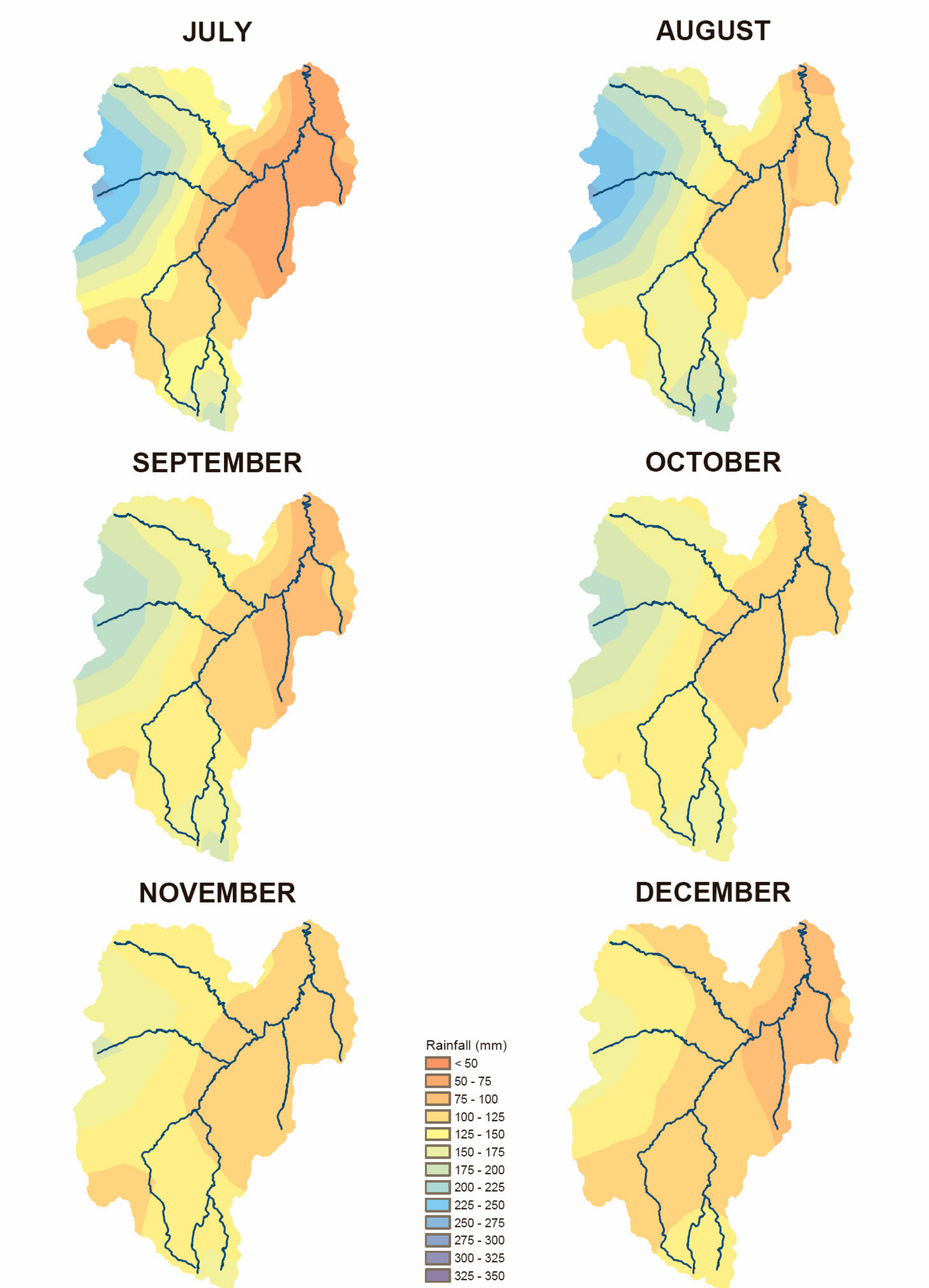
- **Figure A-1 Gridded Average Monthly Rainfall for the Big River catchment (January – June)**



- **Figure A-2 Gridded Average Monthly Rainfall for the Big River catchment (July – December)**



- **Figure A-3 Gridded Average Monthly Rainfall for the Livingstone Creek catchment (January – June)**



- **Figure A-4 Gridded Average Monthly Rainfall for the Livingstone Creek catchment (July – December)**

Appendix B Calibration Runs

The following tables cover all calibration runs undertaken, including those for which the input precipitation scalar map was on an annual time scale. However, as described in Section 4, it was considered more accurate to use monthly precipitation scalar maps for input into Macaque. The column labelled 'Annual/Monthly precipitation coefficient maps' indicates the time period input maps used. The key statistics for the recoded river gauge is highlighted in bold for comparison.

For the Big River catchment, parameters from Run 23 were adopted for the simulation experiments in Section 7. For the Livingstone Creek catchment, parameters from Run 15 were adopted. These values are shown in bold.

- **Table B-8-1 Calibration Runs for the Livingstone Creek catchment**

Run number	Macaque Parameters			Annual/ Monthly precipitation coefficient maps	Mean Annual Flow (ML)	Standard Deviation (ML)	Coefficient of Variation	Coefficient of Efficiency
	Rainfall scalar	Hydraulic Gradient	Maximum/ Minimum temperature lapse rate (°C/m)					
Livingstone Creek Gauge					**21624**	**2360**	**0.109**	
1	0.90	0.969	0.007	Annual	34560	2541	0.074	0.240
2	0.850	0.969	0.007	Annual	26360	2042	0.077	0.517
3	0.850	0.985	0.007	Annual	28150	3030	0.108	0.270
4	0.850	0.975	0.007	Annual	26350	2880	0.109	0.499
5	0.750	0.975	0.007	Annual	12270	2179	0.178	0.403
6	0.800	0.975	0.007	Annual	19190	1764	0.092	0.560
7	0.750	0.985	0.007	Annual	13610	1752	0.129	0.48
8	0.817	0.975	0.007	Annual	21550	1923	0.089	0.566
9	0.817	0.975	0.005	Annual	17810	1713	0.096	0.558
10	0.830	0.975	0.005	Annual	19720	1866	0.095	0.573
11	0.843	0.975	0.005	Annual	21670	2008	0.093	0.572
12	1	0.975	0.005	Monthly	46373	3934	0.085	-0.8
13	0.9	0.975	0.005	Monthly	14706	1603	0.109	0.602
14	0.867	0.975	0.005	Monthly	11634	1345	0.116	0.495
15	**0.958**	**0.975**	**0.005**	**Monthly**	**21472**	**2162**	**0.101**	**0.656**

- **Table B-8-2 Calibration Runs for the Big River catchment**

Run number	Macaque Parameters			Annual/ Monthly precipitation coefficient maps	Mean Annual Flow (ML)	Standard Deviation (ML)	Coefficient of Variation	Coefficient of Efficiency
	Rainfall scalar	Hydraulic Gradient	Maximum/ Minimum temperature lapse rate (°C/m)					
Big River Gauge					**224222**	**16362**	**0.073**	
1	1	0.985	0.005	Annual	270337	17205	0.083	0.462
2	0.93	0.985	0.005	Annual	251733	15765	0.063	0.550
3	0.93	0.985	0.007	Annual	250447	15158	0.061	0.274
4	0.85	0.985	0.007	Annual	203865	12629	0.062	0.339
5	0.75	0.985	0.007	Annual	149312	9643	0.065	0.222
5	0.82	0.985	0.007	Annual	187079	11715	0.063	0.326
6	0.8876	0.99	0.007	Annual	225495	13796	0.061	0.328
7	0.8876	0.99	0.007	Annual	232388	16415	0.071	0.350
8	0.87	0.99	0.007	Annual	221916	15796	0.071	0.373
9	0.871	0.99	0.007	Annual	222505	15834	0.071	0.372
10	0.871	0.99	0.005	Annual	205945	15264	0.074	0.604
11	0.955	0.99	0.005	Annual	255815	18472	0.072	0.490
12	0.904	0.99	0.005	Annual	225219	16496	0.073	0.585
13	0.904	0.99	0.005	Monthly	194889	17016	0.087	0.600
14	1	0.99	0.005	Monthly	246989	22008	0.089	0.271
15	0.961	0.99	0.005	Monthly	228890	19846	0.087	0.469
16	0.961	0.979	0.005	Monthly	260773	16469	0.063	0.485
17	0.961	0.97	0.005	Monthly	254801	13360	0.052	0.521
18	0.911	0.979	0.005	Monthly	233114	13812	0.059	0.621
19	0.911	0.985	0.005	Monthly	235964	15929	0.068	0.637
20	0.826	0.979	0.005	Monthly	187721	10920	0.058	0.586
21	0.905	0.985	0.005	Monthly	235964	15929	0.067	0.637
22	0.903	0.985	0.005	Monthly	234861	15864	0.068	0.638
23	**0.88**	**0.985**	**0.005**	**Monthly**	**222216**	**14903**	**0.067**	**0.665**
24	0.88	0.99	0.005	Monthly	185046	16023	0.087	0.607

Appendix C Input Data for the Simulations

The following tables summarise the input data used for each of the simulations. For the Base Case, key changes to the data inputs from the calibration runs are shown in bold. For all other simulations, variations in data from the Base Case are identified in bold.

Table C-1 Macaque Input Data for Simulation 1: Base Case

Input Data	Source
Catchment digital elevation model	40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data
Forest species map	Map of actual forest type and cover
Forest age maps	**Bushfire throughout entire catchment after 10 years of simulation**
Daily rainfall timeseries	**Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record.** **Big River: Shannon Vale (083035)** **Livingstone Creek: Omeo Comparison (083025)** **12 records used as input (one for each month)**
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	**Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.**
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

Table C-2 Macaque Input Data for Simulation 2: Mountain Ash Forest

Input Data	Source
Catchment digital elevation model	40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data
Forest species map	**Map of entire catchment covered by Mountain Ash forest**
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record. Big River: Shannon Vale (083035) Livingstone Creek: Omeo Comparison (083025)
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

Table C-3 Macaque Input Data for Simulation 3: Mixed Species Forest

Input Data	Source
Catchment digital elevation model	40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data
Forest species map	**Map of entire catchment covered by Mixed Species forest**
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record. Big River: Shannon Vale (083035) Livingstone Creek: Omeo Comparison (083025)
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

▪ Table C-4 Macaque Input Data for Simulation 4: Snowgum forest

Input Data	Source
Catchment digital elevation model	40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data
Forest species map	**Map of entire catchment covered by Snowgum forest**
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record. Big River: Shannon Vale (083035) Livingstone Creek: Omeo Comparison (083025)
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

- **Table C-5 Macaque Input Data for Simulation 5: Lowered Catchment Elevation**

Input Data	Source
Catchment digital elevation model	**40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data.** **Elevation of the catchments reduced** ▪ **Big River lowered by 636m** ▪ **Livingstone Creek lowered by 643m**
Forest species map	Map of actual forest type and cover
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record. Big River: Shannon Vale (083035) Livingstone Creek: Omeo Comparison (083025)
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

- **Table C-6 Macaque Input Data for Simulation 6: Livingstone Creek Lowered and Stretched Catchment Elevation**

Input Data	Source
Catchment digital elevation model	**40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data.** **Elevation of the catchment reduced** ▪ **Livingstone Creek lowered by 643 m** **Livingstone Creek catchment stretched by a factor of 1.51**
Forest species map	Map of actual forest type and cover
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record. Livingstone Creek: Omeo Comparison (083025)
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

- **Table C-7 Macaque Input Data for Simulation 7: Livingstone Creek Lowered and Stretched Catchment Elevation, Big River Rainfall Series**

Input Data	Source
Catchment digital elevation model	**40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data.** **Elevation of the catchment reduced** ▪ **Livingstone Creek lowered by 643 m** **Livingstone Creek catchment stretched by a factor of 1.51**
Forest species map	Map of actual forest type and cover
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	**Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record.** **Big River rainfall gauge (Shannon Vale (083035)) used as input to the Livingstone Creek catchment.**
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timeseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

- **Table C-8 Macaque Input Data for Simulation 7: Livingstone Creek Lowered and Stretched Catchment Elevation, Big River Rainfall Series, Mixed Species Forest Cover**

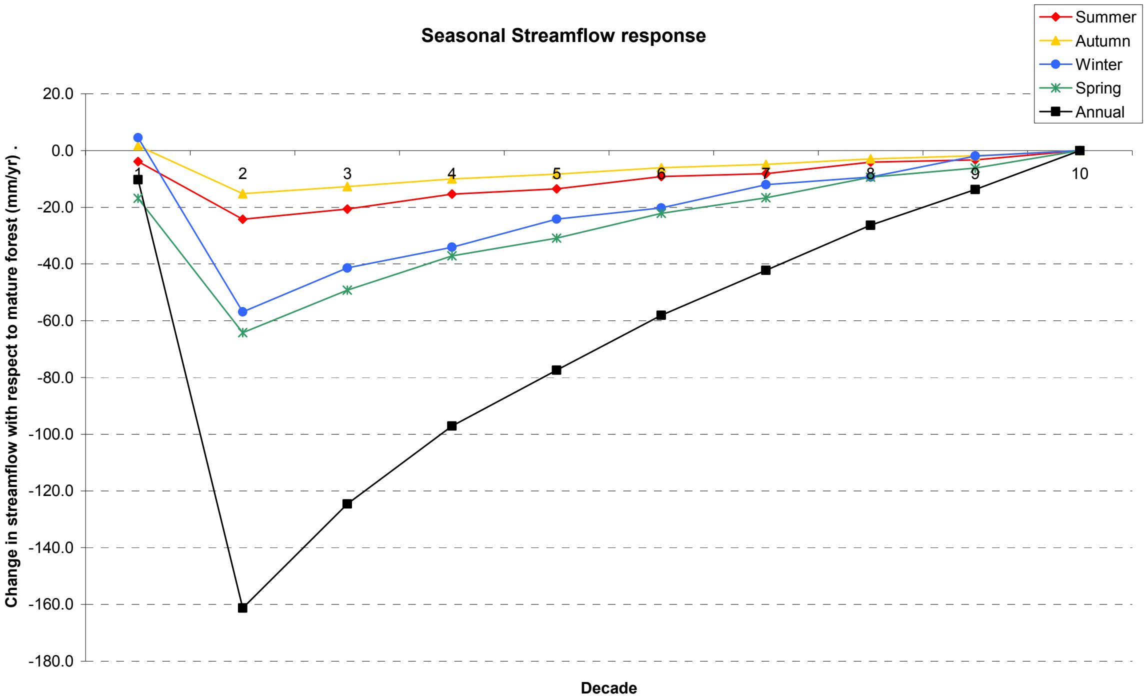
Input Data	Source
Catchment digital elevation model	**40 m grid size DEM for Hinnomunjie catchment used to extract Big River and Livingstone Creek data.** **Elevation of the catchment reduced** ▪ **Livingstone Creek lowered by 643 m** **Livingstone Creek catchment stretched by a factor of 1.51**
Forest species map	**Map of entire catchment covered by Mixed Species forest**
Forest age maps	Bushfire throughout entire catchment after 10 years of simulation
Daily rainfall timeseries	**Ten year representative period (1991-2000) extracted from the appropriate gauge record and repeated to generate 110 year record.** **Big River rainfall gauge (Shannon Vale (083035)) used as input to the Livingstone Creek catchment.**
Precipitation coefficient maps	Generated using gridded monthly rainfall data and a single gauge. 12 maps were used as input, with the associated rainfall timseries records for each of the 12 months.
Daily minimum/maximum temperature timeseries	Ten year representative period (1991-2000) extracted from the Omeo record and repeated to generate 110 year record.
Base station elevation	Elevation of the Omeo temperature station (685 m AHD)

Appendix D Simulation Results

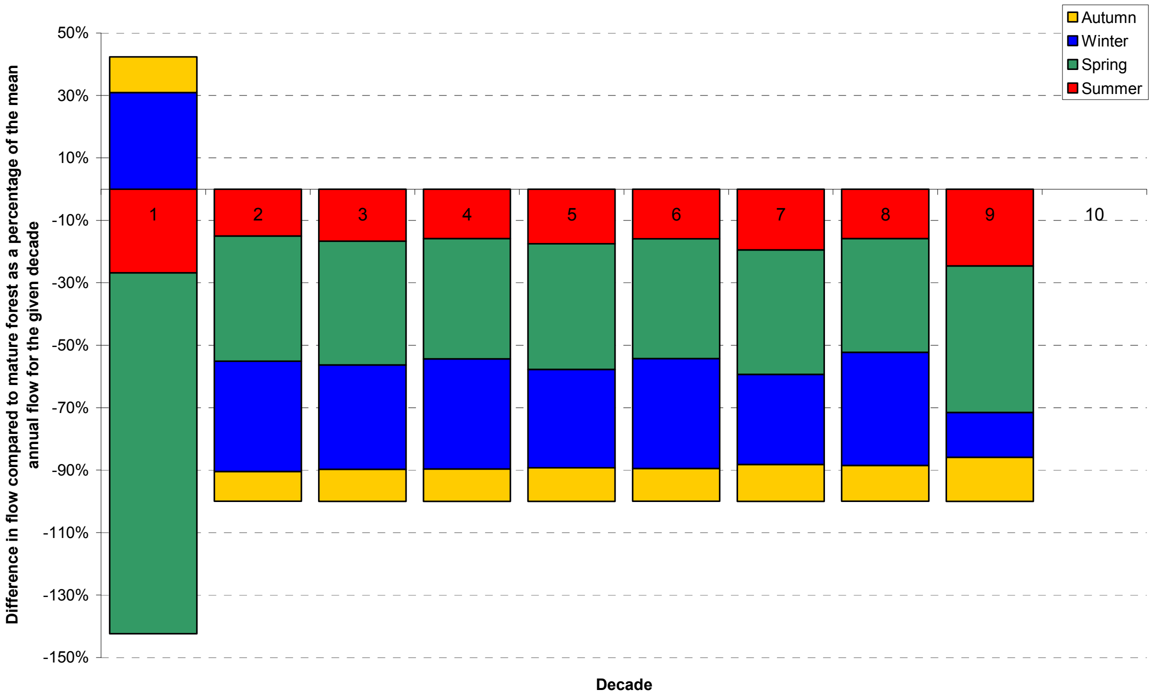
The results of the Big River and Livingstone Creek Base Case simulations are detailed in Section 5.4.1. A summary of the results from all other simulations is provided in Section 5.4.2. Detailed results for each of the simulations are provided below.

D.1 Big River catchment

D.1.1 Simulation Run 1: Base Case



- **Figure D-8-1 Change in streamflow in the Big River catchment with respect to mature forest (decade 10) for Simulation 1 (Base Case)**

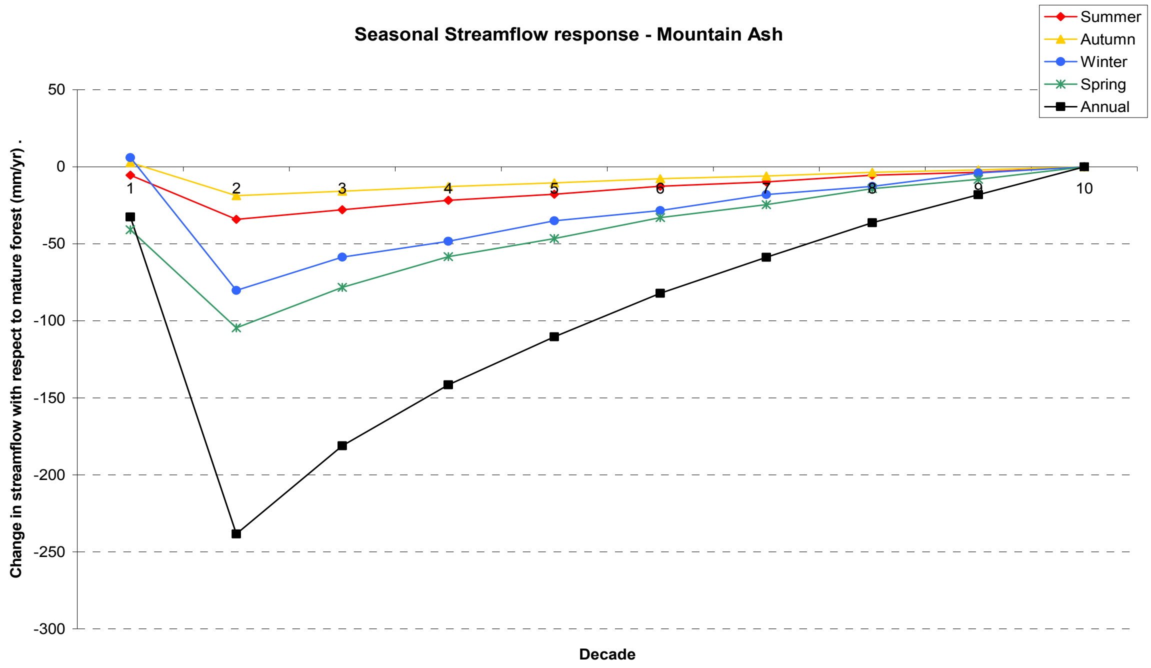


- **Figure D-8-2 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 1 (Base Case)**

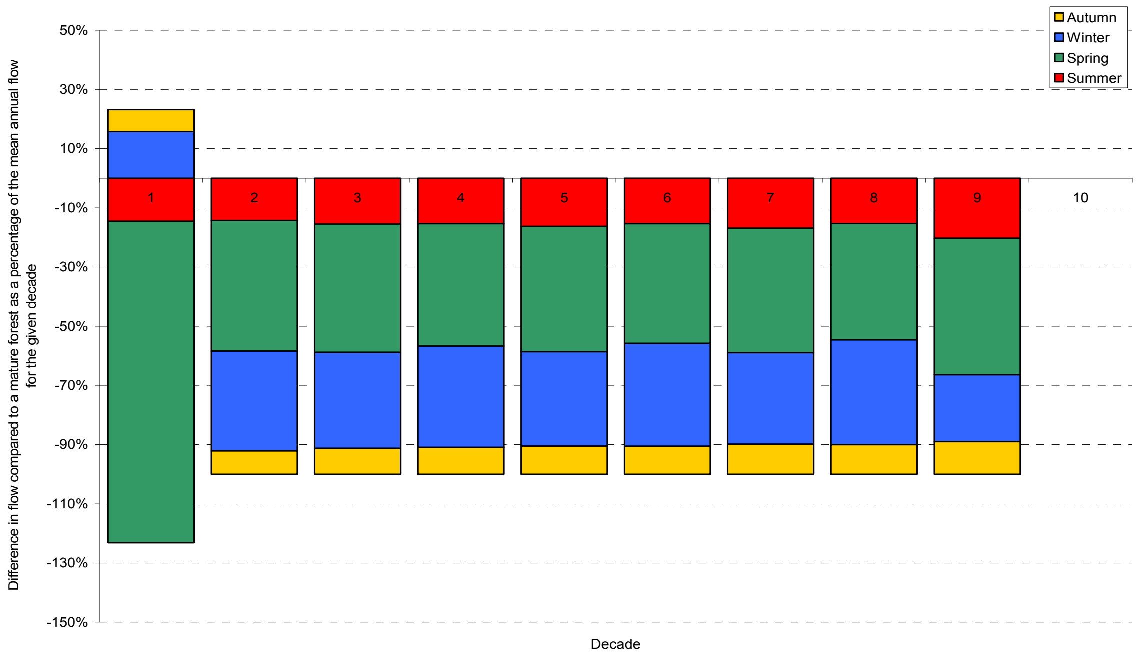
- **Table D-1 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 1 (Base Case)**

Decade	Summer	Autumn	Winter	Spring
1	-27%	11%	31%	-116%
2	-15%	-9%	-35%	-40%
3	-17%	-10%	-33%	-40%
4	-16%	-10%	-35%	-38%
5	-18%	-11%	-31%	-40%
6	-16%	-10%	-35%	-38%
7	-20%	-12%	-29%	-40%
8	-16%	-11%	-36%	-36%
9	-25%	-14%	-14%	-47%
10	-	-	-	-
AVERAGE decades 2-9	**-18%**	**-11%**	**-31%**	**-40%**

D.1.2 Simulation Run 2: Mountain Ash Forest



- **Figure D-8-3 Change in streamflow in the Big River catchment with respect to mature forest (decade 10) for Simulation 2**

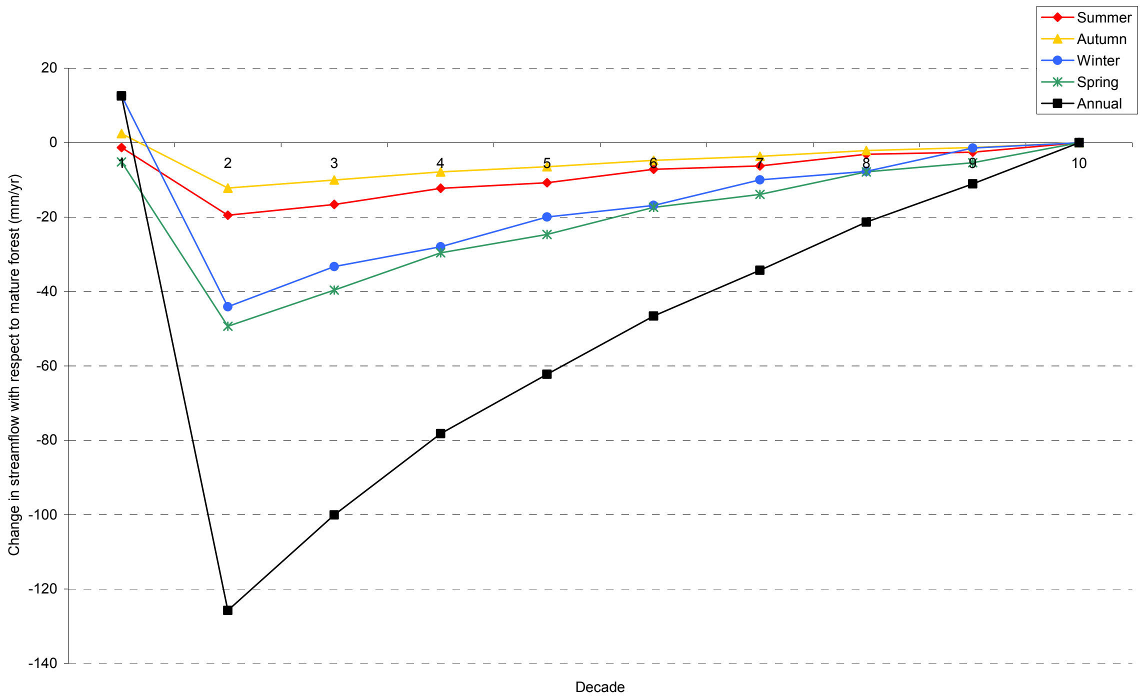


- **Figure D-8-4 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 2**

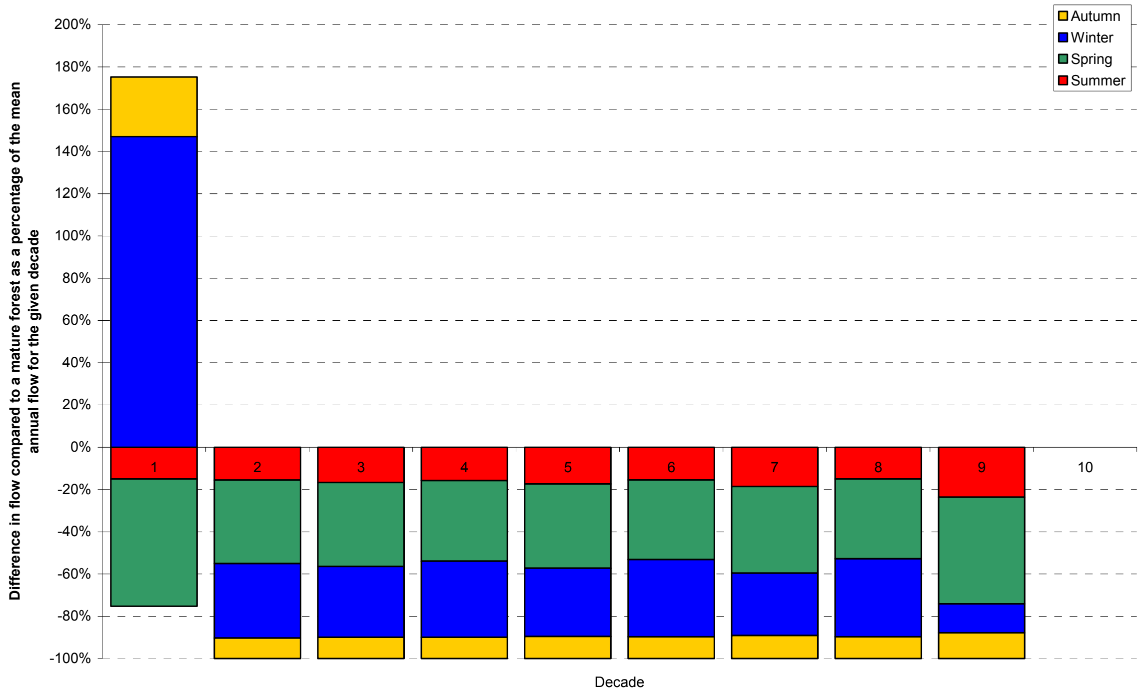
- **Table D-2 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 2**

Decade	Summer	Autumn	Winter	Spring
1	-15%	7%	16%	-109%
2	-14%	-8%	-34%	-44%
3	-15%	-9%	-32%	-43%
4	-15%	-9%	-34%	-41%
5	-16%	-9%	-32%	-42%
6	-15%	-9%	-35%	-40%
7	-17%	-10%	-31%	-42%
8	-15%	-10%	-35%	-39%
9	-20%	-11%	-23%	-46%
10	-	-	-	-
AVERAGE decades 2-9	**-16%**	**-9%**	**-32%**	**-42%**

D.1.3 Simulation Run 3: Mixed Species Forest



- **Figure D-8-5 Change in streamflow in the Big River catchment with respect to mature forest (decade 10) for Simulation 3**

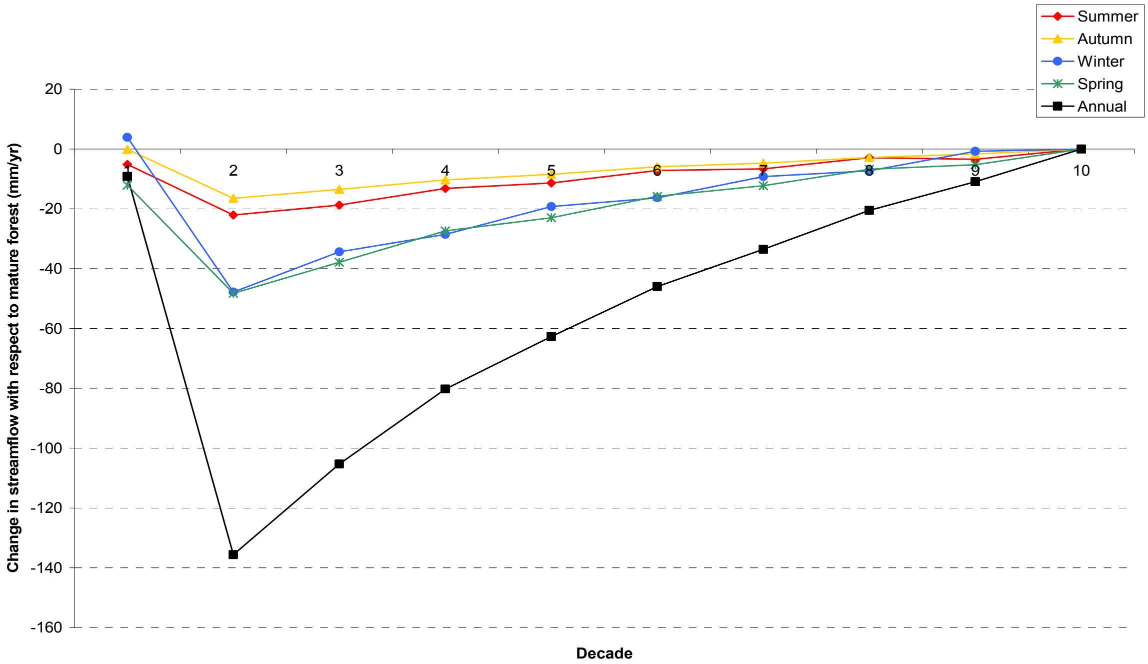


- **Figure D-8-6 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 3**

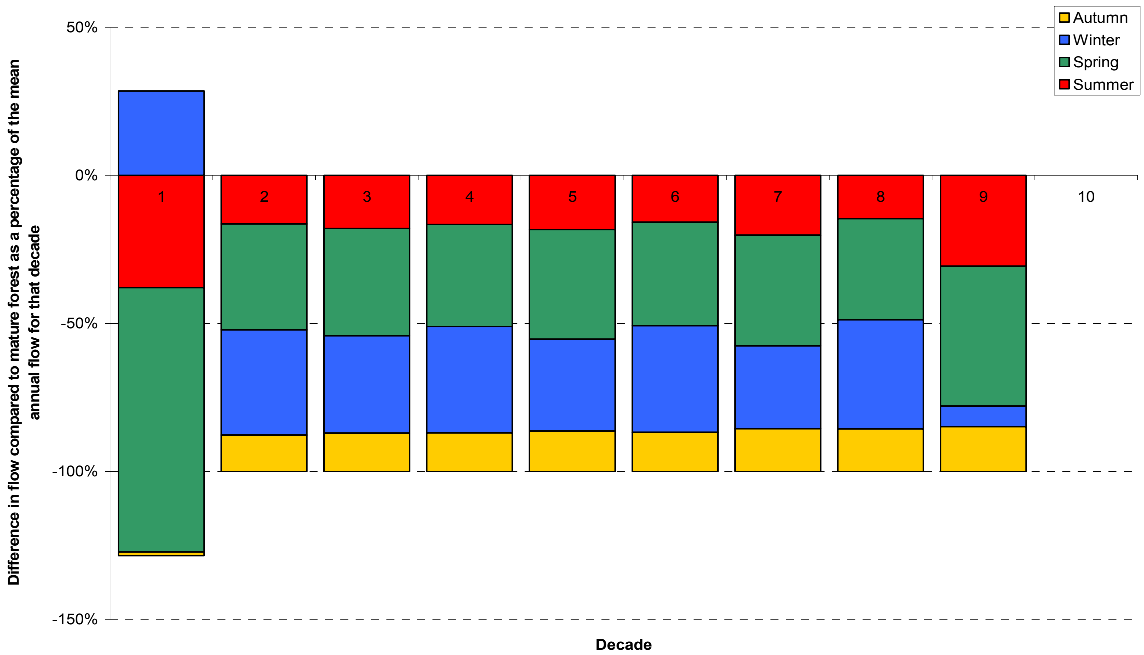
- **Table D-3 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 3**

Decade	Summer	Autumn	Winter	Spring
1	-15%	28%	147%	-60%
2	-16%	-10%	-35%	-39%
3	-17%	-10%	-33%	-40%
4	-16%	-10%	-36%	-38%
5	-17%	-11%	-32%	-40%
6	-15%	-10%	-37%	-38%
7	-19%	-11%	-29%	-41%
8	-15%	-10%	-37%	-38%
9	-24%	-12%	-14%	-50%
10	-	-	-	-
AVERAGE decades 2-9	**-17%**	**-11%**	**-32%**	**-41%**

D.1.4 Simulation Run 4: Snowgum Forest



▪ **Figure D-8-7 Change in streamflow in the Big River catchment with respect to mature forest (decade 10) for Simulation 4**

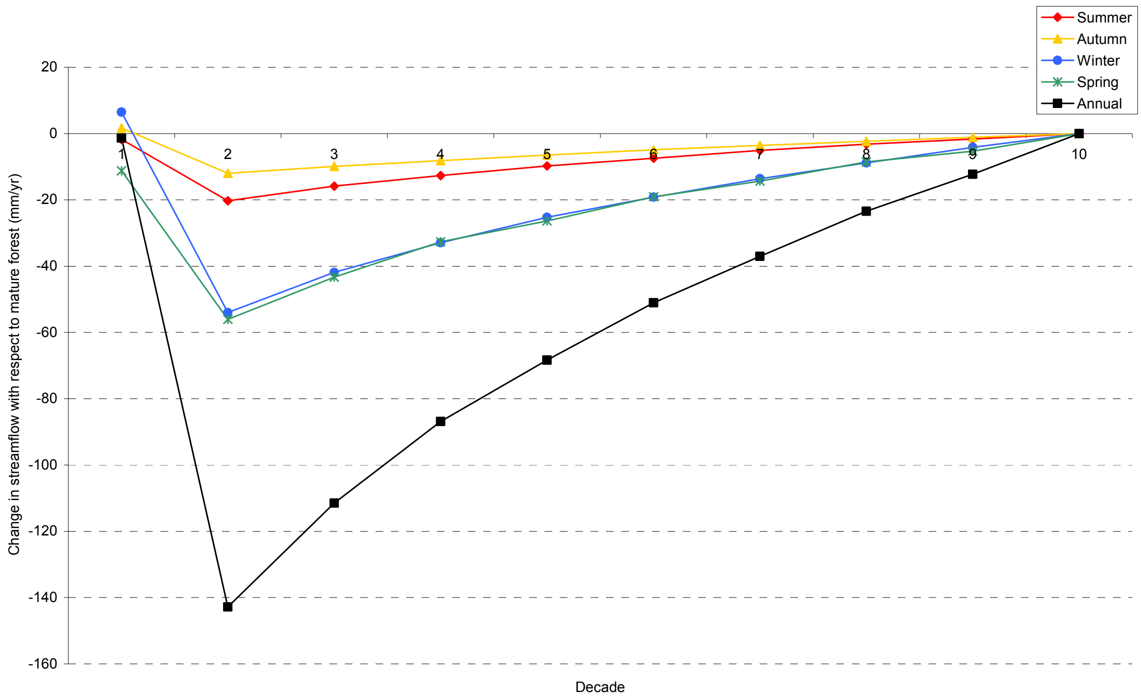


▪ **Figure D-8-8 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 4**

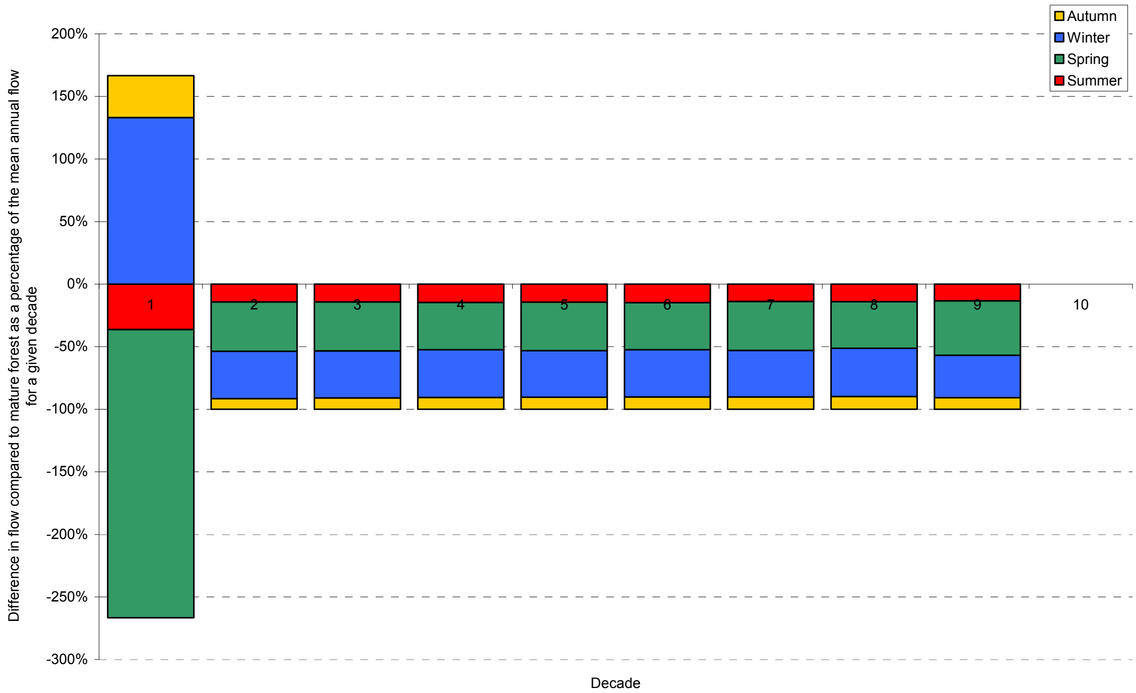
- **Table D-4 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 4**

Decade	Summer	Autumn	Winter	Spring
1	-38%	-1%	28%	-89%
2	-16%	-12%	-36%	-36%
3	-18%	-13%	-33%	-36%
4	-17%	-13%	-36%	-34%
5	-18%	-14%	-31%	-37%
6	-16%	-13%	-36%	-35%
7	-20%	-14%	-28%	-37%
8	-15%	-14%	-37%	-34%
9	-31%	-15%	-7%	-47%
10	-	-	-	-
AVERAGE decades 2-9	**-19%**	**-14%**	**-30%**	**-37%**

D.1.5 Simulation Run 5: Lowered Elevation



- **Figure D-8-9 Change in streamflow in the Big River catchment with respect to mature forest (decade 10) for Simulation 5**



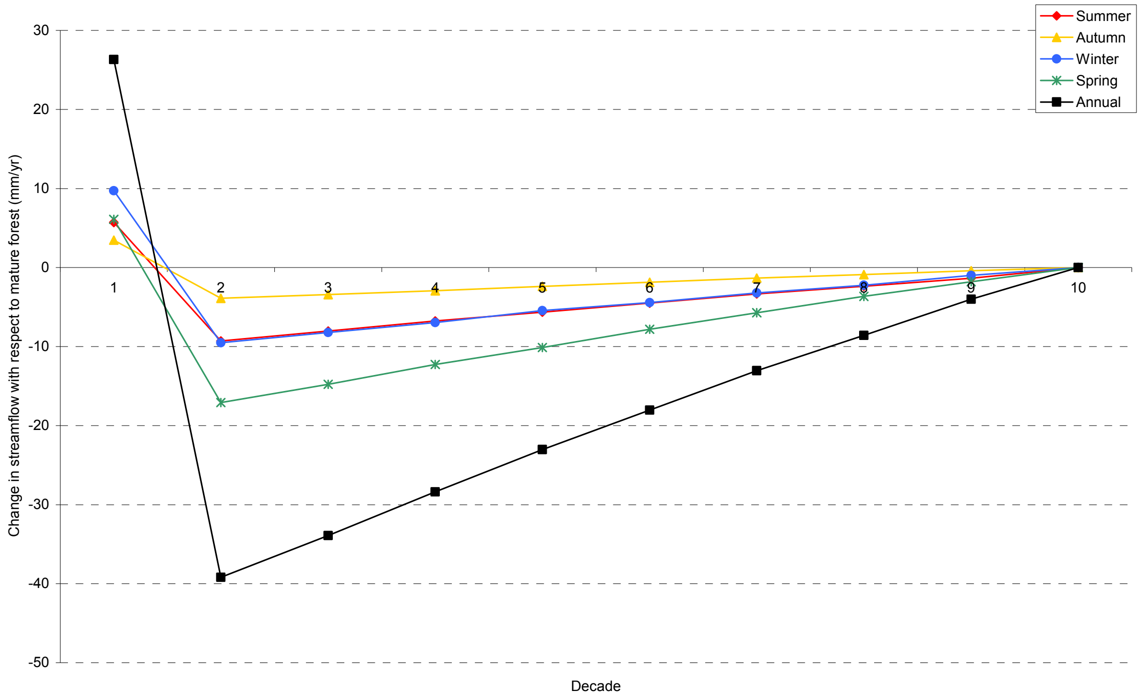
- **Figure D-8-10 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 5**

- **Table D-5 Difference in flow in the Big River catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 5**

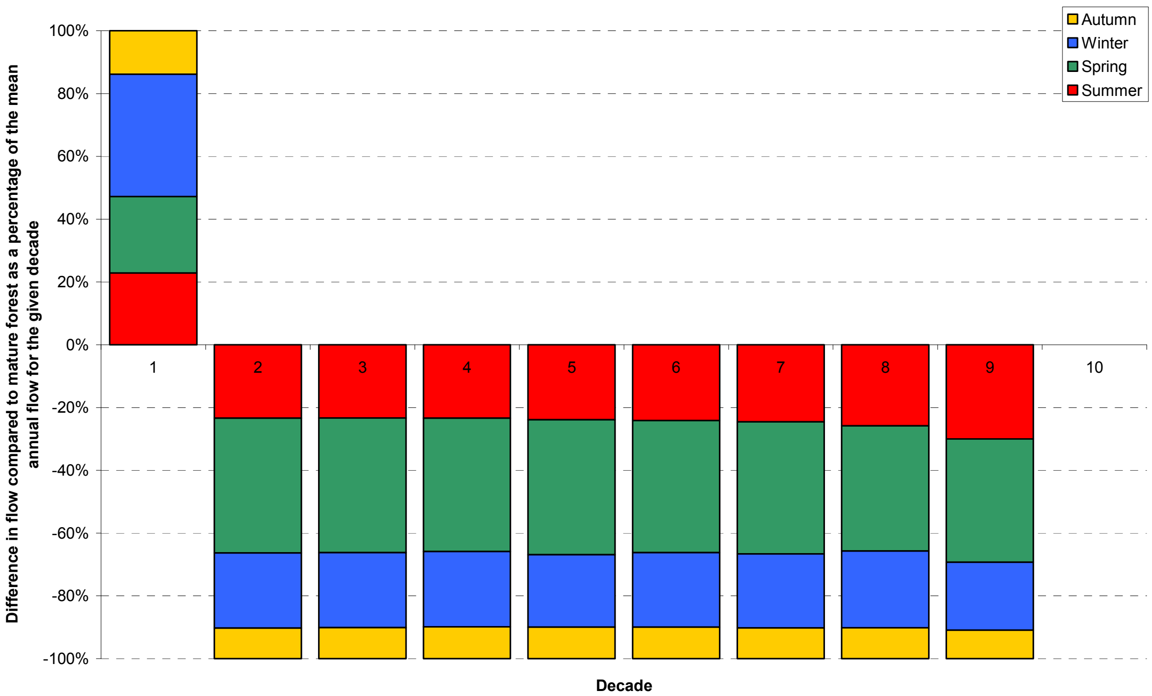
Decade	Summer	Autumn	Winter	Spring
1	-36%	34%	133%	-230%
2	-14%	-8%	-38%	-39%
3	-14%	-9%	-38%	-39%
4	-15%	-9%	-38%	-38%
5	-14%	-10%	-37%	-39%
6	-15%	-10%	-38%	-38%
7	-14%	-10%	-37%	-39%
8	-14%	-10%	-39%	-37%
9	-13%	-9%	-34%	-43%
10	-	-	-	-
AVERAGE decades 2-9	**-14%**	**-9%**	**-37%**	**-39%**

D.2 Livingstone Creek catchment

D.2.1 Simulation Run 1: Base Case



- **Figure D-8-11 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 1 (Base Case)**

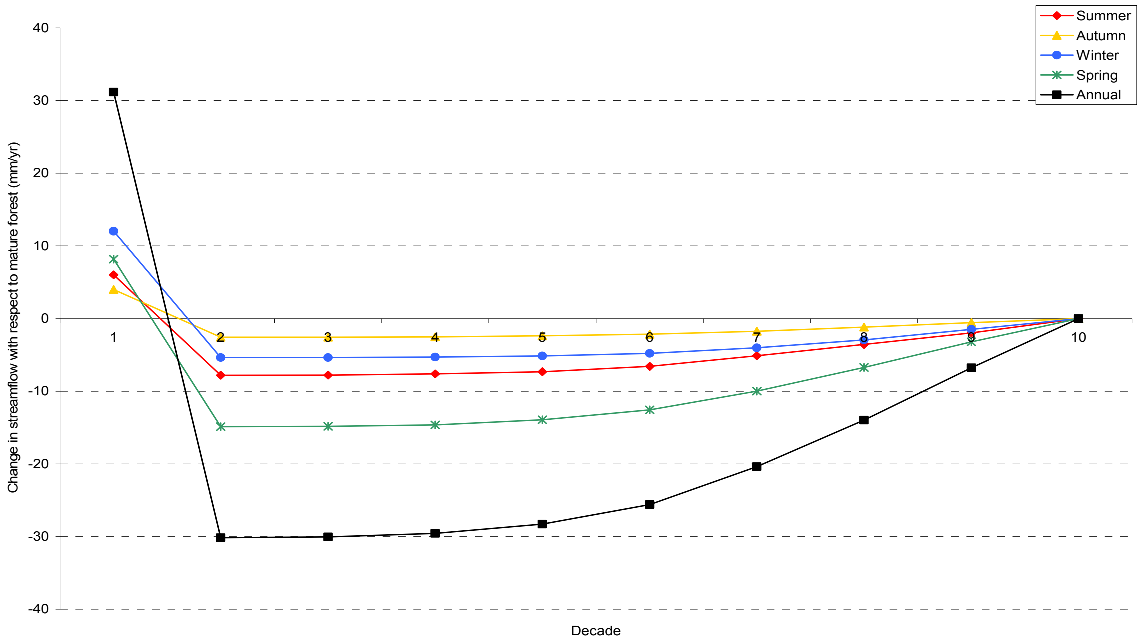


- **Figure D-8-12 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 1 (Base Case)**

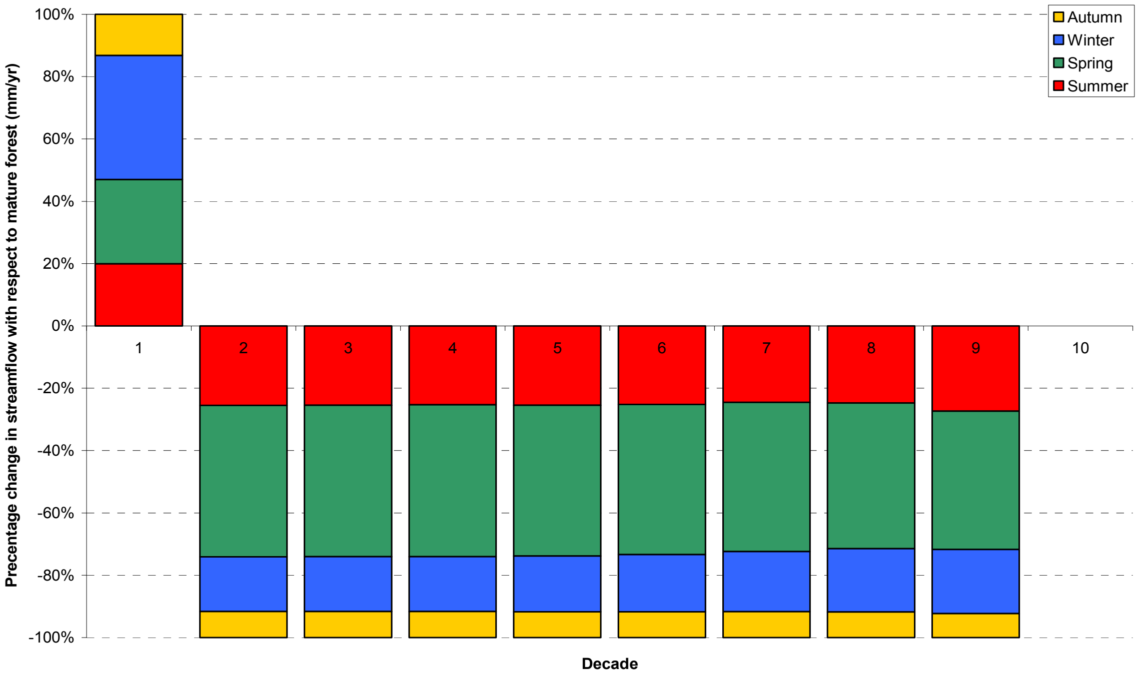
- **Table D-6 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 1 (Base Case)**

Decade	Summer	Autumn	Winter	Spring
1	23%	14%	39%	24%
2	-23%	-10%	-24%	-43%
3	-23%	-10%	-24%	-43%
4	-23%	-10%	-24%	-42%
5	-24%	-10%	-23%	-43%
6	-24%	-10%	-24%	-42%
7	-25%	-10%	-24%	-42%
8	-26%	-10%	-24%	-40%
9	-30%	-9%	-22%	-39%
10	-	-	-	-
AVERAGE decades 2-9	**-25%**	**-10%**	**-24%**	**-42%**

D.2.2 Simulation Run 2: Mountain Ash Forest



- **Figure D-8-13 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 2**

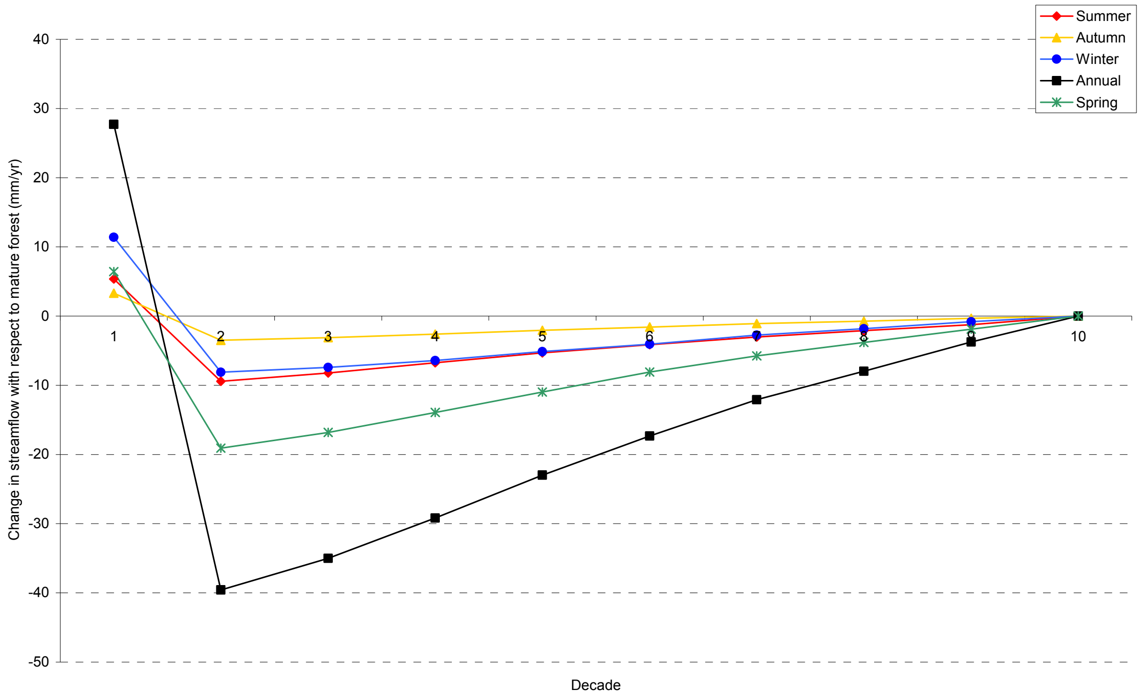


- **Figure D-8-14 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 2**

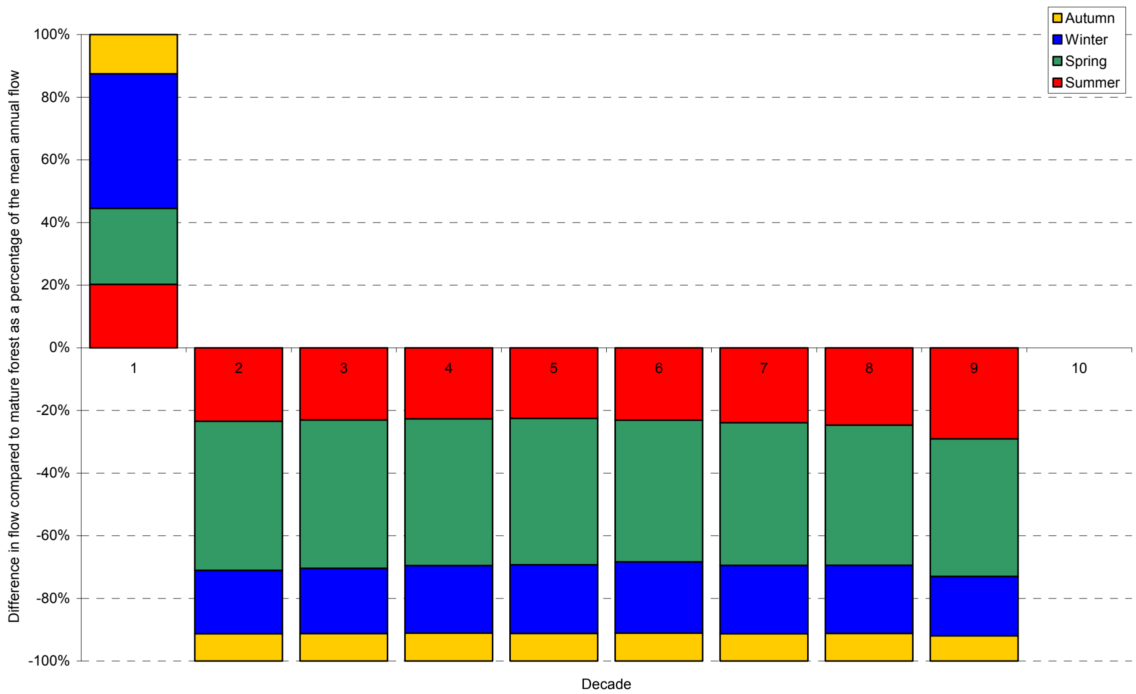
- **Table D-7 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 2**

Decade	Summer	Autumn	Winter	Spring
1	20%	13%	40%	27%
2	-25%	-8%	-18%	-49%
3	-25%	-8%	-18%	-49%
4	-25%	-8%	-18%	-49%
5	-25%	-8%	-18%	-48%
6	-25%	-8%	-18%	-48%
7	-25%	-8%	-19%	-48%
8	-25%	-8%	-20%	-47%
9	-27%	-8%	-21%	-44%
10	-	-	-	-
AVERAGE decades 2-9	**-25%**	**-8%**	**-19%**	**-48%**

D.2.3 Simulation Run 3: Mixed Species Forest



- **Figure D-8-15 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 3**

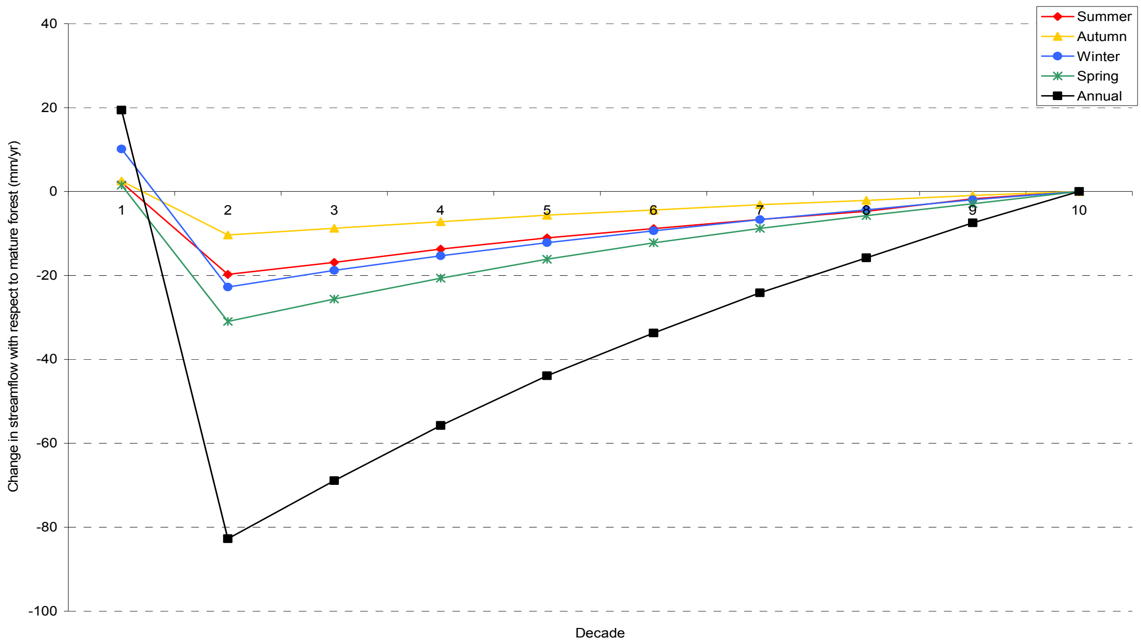


- **Figure D-8-16 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 3**

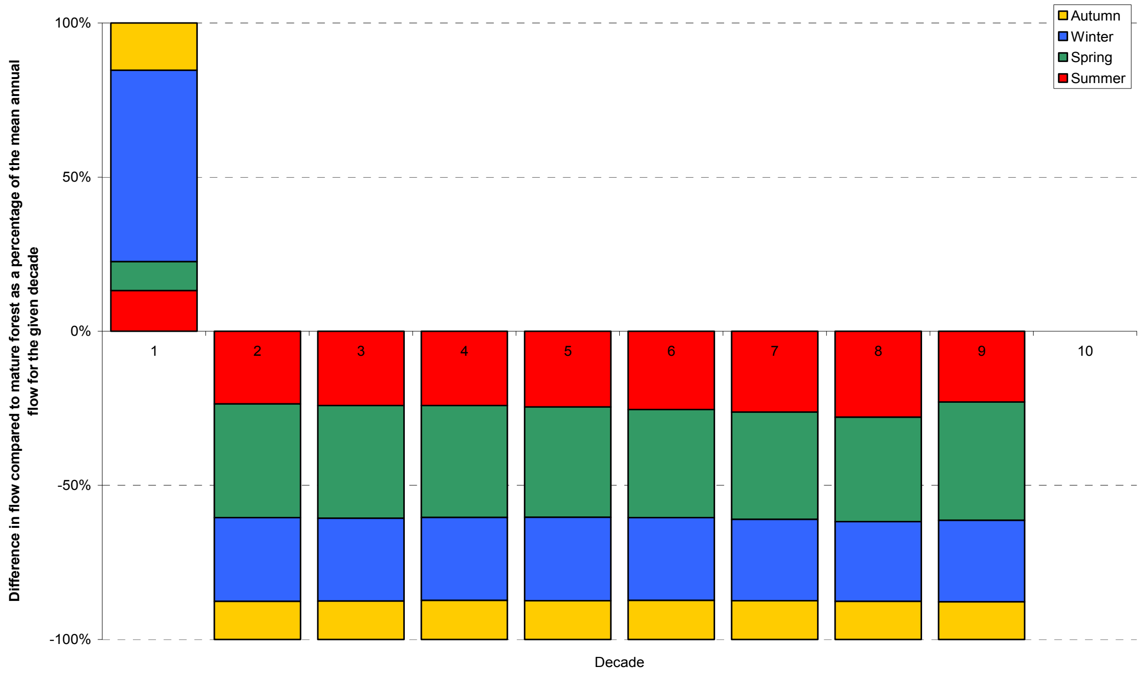
- **Table D-8 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 3**

Decade	Summer	Autumn	Winter	Spring
1	20%	13%	43%	24%
2	-23%	-9%	-20%	-48%
3	-23%	-9%	-21%	-47%
4	-23%	-9%	-22%	-47%
5	-23%	-9%	-22%	-47%
6	-23%	-9%	-23%	-45%
7	-24%	-9%	-22%	-46%
8	-25%	-9%	-22%	-45%
9	-29%	-8%	-19%	-44%
10	-	-	-	-
AVERAGE decades 2-9	**-24%**	**-9%**	**-21%**	**-46%**

D.2.4 Simulation Run 4: Snowgum Forest



- **Figure D-8-17 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 4**

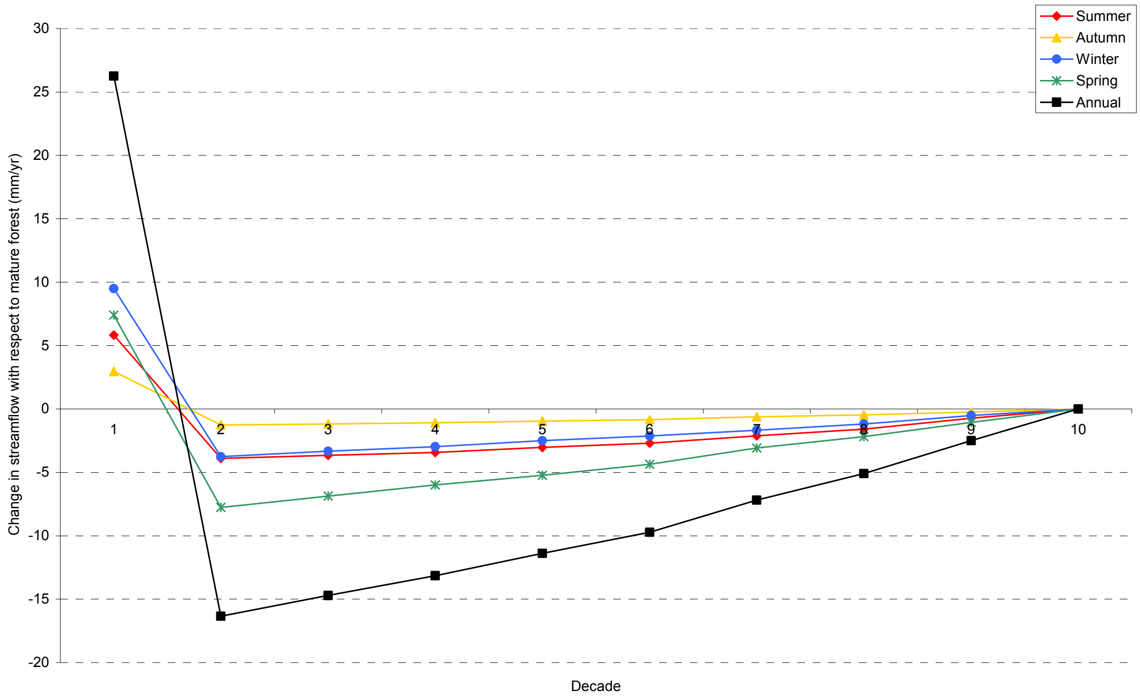


- **Figure D-8-18 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 4**

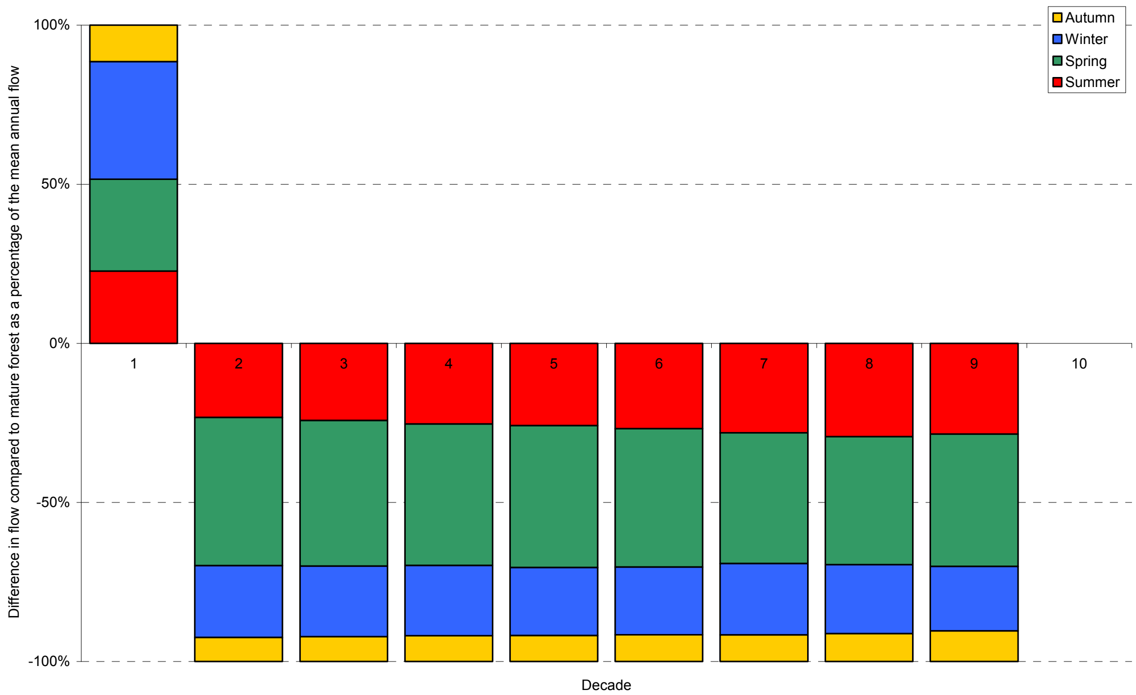
- **Table D-9 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 4**

Decade	Summer	Autumn	Winter	Spring
1	13%	15%	62%	9%
2	-24%	-12%	-27%	-37%
3	-24%	-12%	-27%	-37%
4	-24%	-13%	-27%	-36%
5	-25%	-13%	-27%	-36%
6	-25%	-13%	-27%	-35%
7	-26%	-13%	-26%	-35%
8	-28%	-12%	-26%	-34%
9	-23%	-12%	-26%	-38%
10	-	-	-	-
AVERAGE decades 2-9	**-25%**	**-12%**	**-27%**	**-36%**

D.2.5 Simulation Run 5: Lowered Elevation



- **Figure D-8-19 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 5**

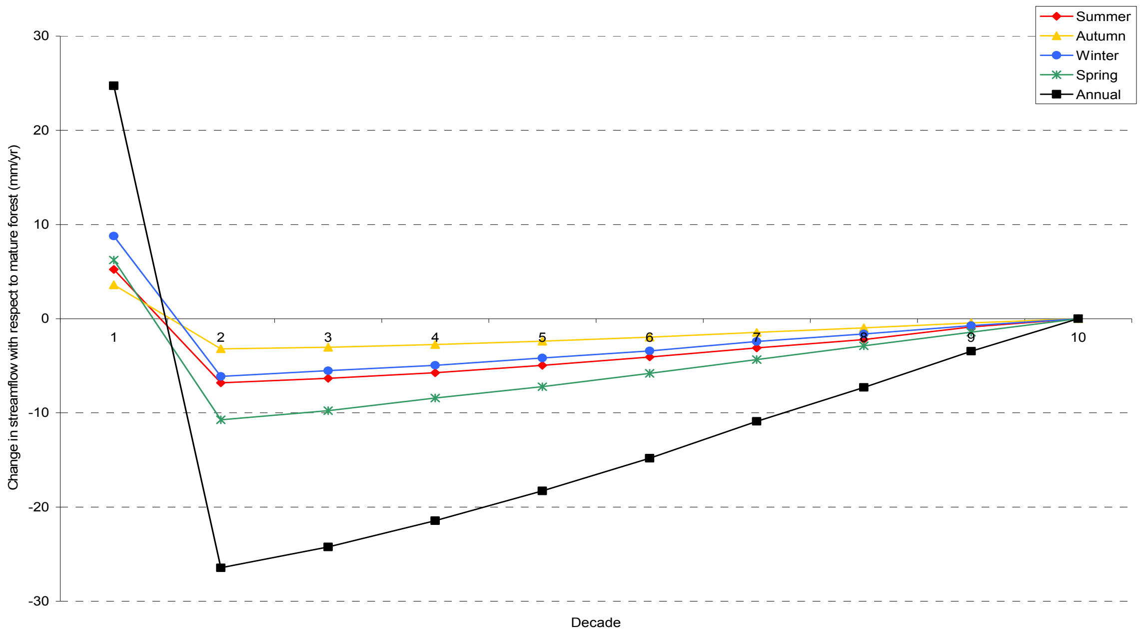


- **Figure D-8-20 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 5**

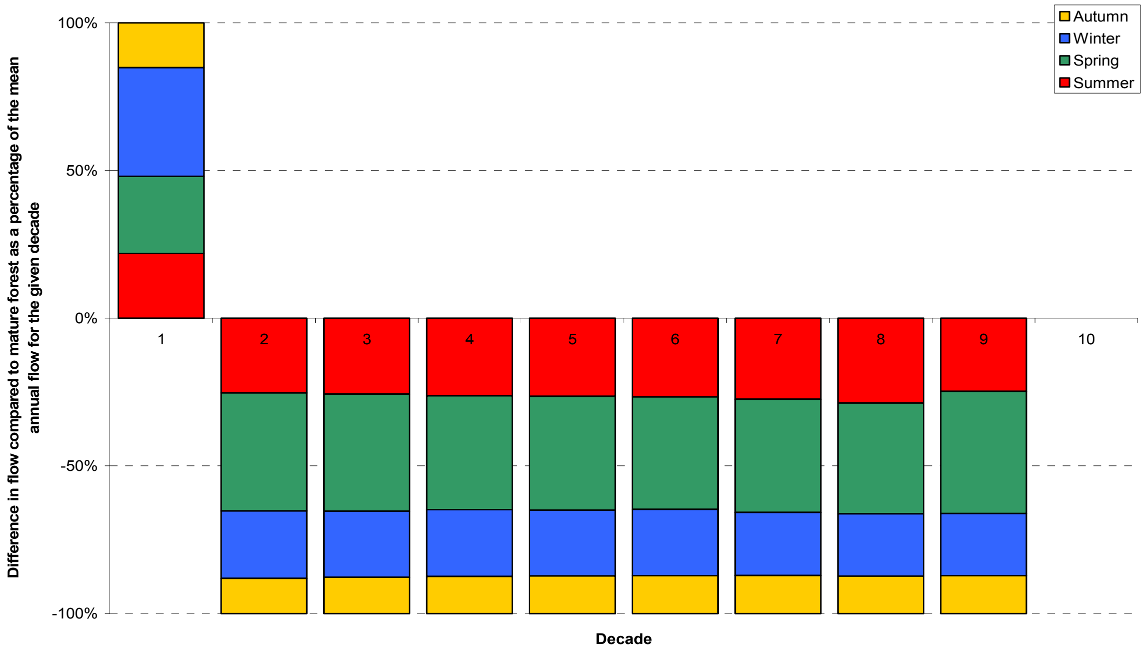
- **Table D-10 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 5**

Decade	Summer	Autumn	Winter	Spring
1	23%	12%	37%	29%
2	-23%	-8%	-23%	-47%
3	-24%	-8%	-22%	-46%
4	-25%	-8%	-22%	-44%
5	-26%	-8%	-21%	-45%
6	-27%	-8%	-21%	-43%
7	-28%	-8%	-22%	-41%
8	-29%	-9%	-22%	-40%
9	-29%	-10%	-20%	-42%
10	-	-	-	-
AVERAGE decades 2-9	**-26%**	**-8%**	**-22%**	**-43%**

D.2.6 Simulation Run 6: Livingstone Creek Lowered and Stretched Elevation



- **Figure D-8-21 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 6**

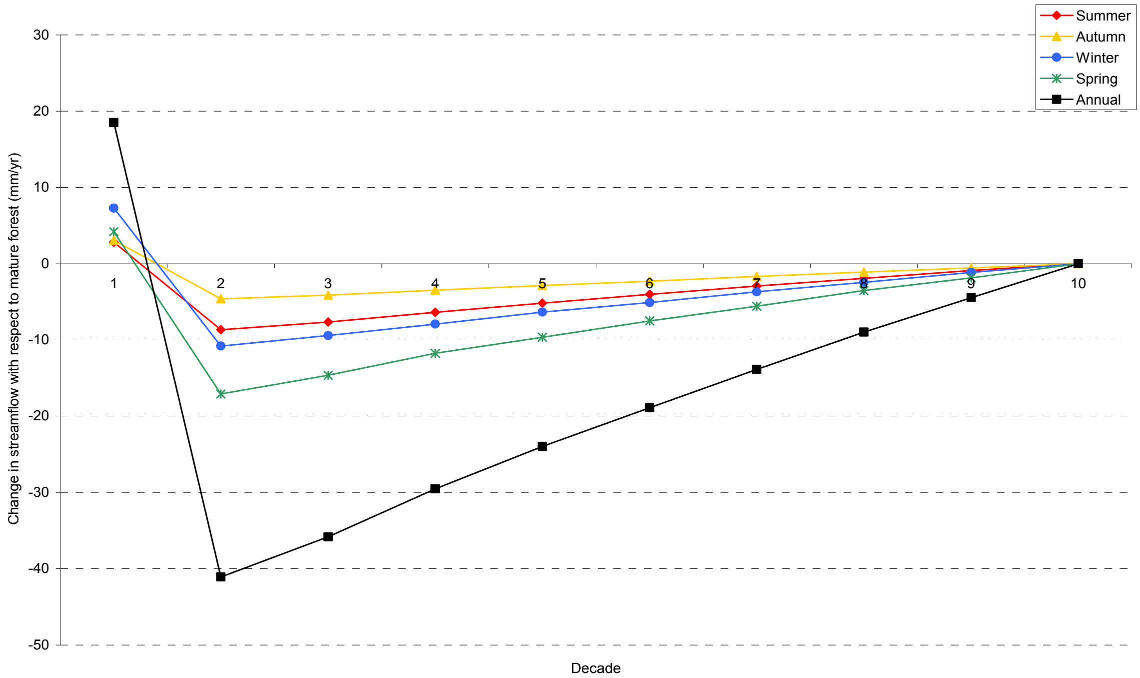


- **Figure D-8-22 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 6**

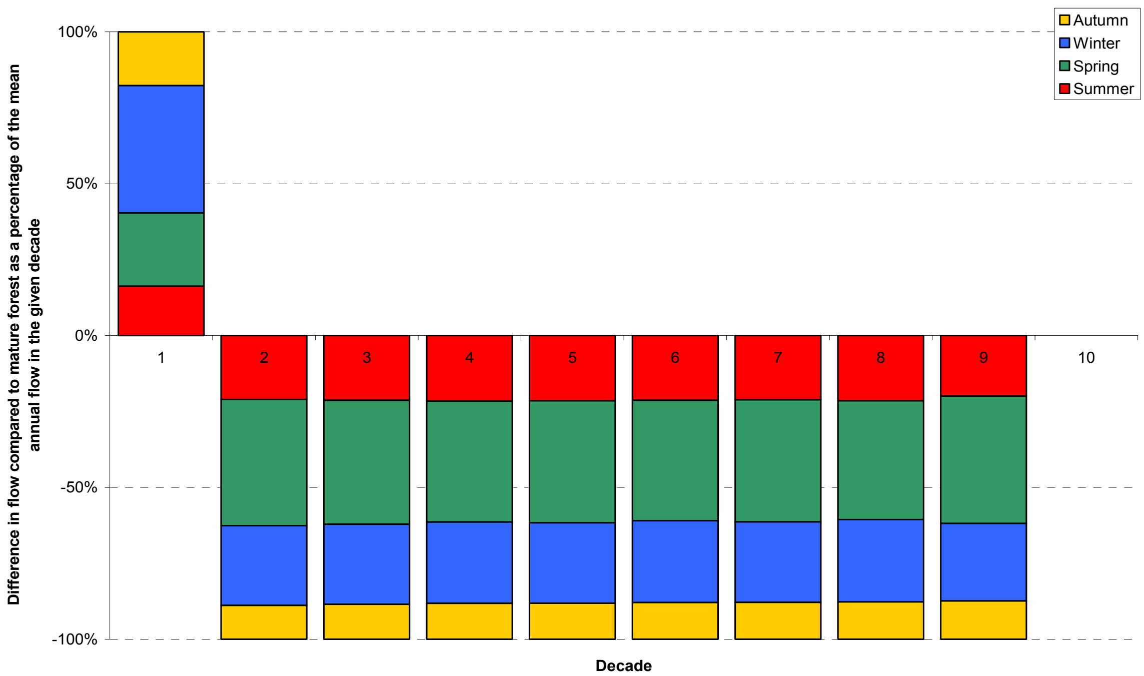
- **Table D-11 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 6**

Decade	Summer	Autumn	Winter	Spring
1	22%	15%	37%	26%
2	-25%	-12%	-23%	-40%
3	-26%	-12%	-22%	-40%
4	-26%	-13%	-23%	-39%
5	-26%	-13%	-22%	-39%
6	-27%	-13%	-22%	-38%
7	-27%	-13%	-21%	-38%
8	-29%	-13%	-21%	-37%
9	-25%	-13%	-21%	-41%
10	-	-	-	-
AVERAGE decades 2-9	**-26%**	**-13%**	**-22%**	**-39%**

D.2.7 Simulation Run 7: Livingstone Creek Lowered and Stretched Elevation, Big River Rainfall Series



- **Figure D-8-23 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 7**

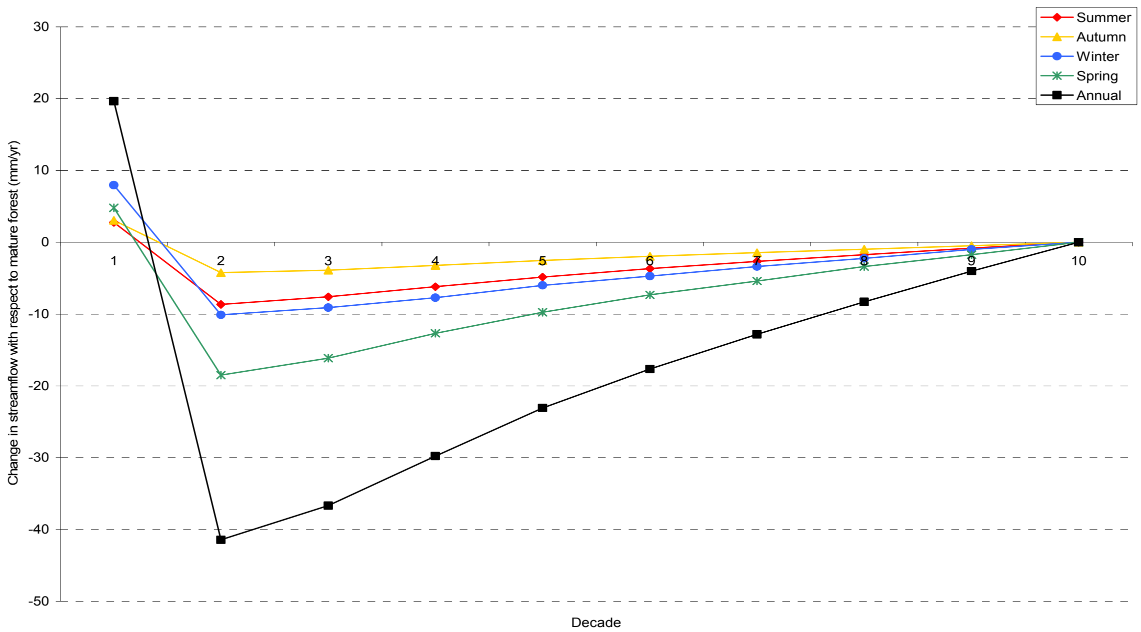


- **Figure D-8-24 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 7**

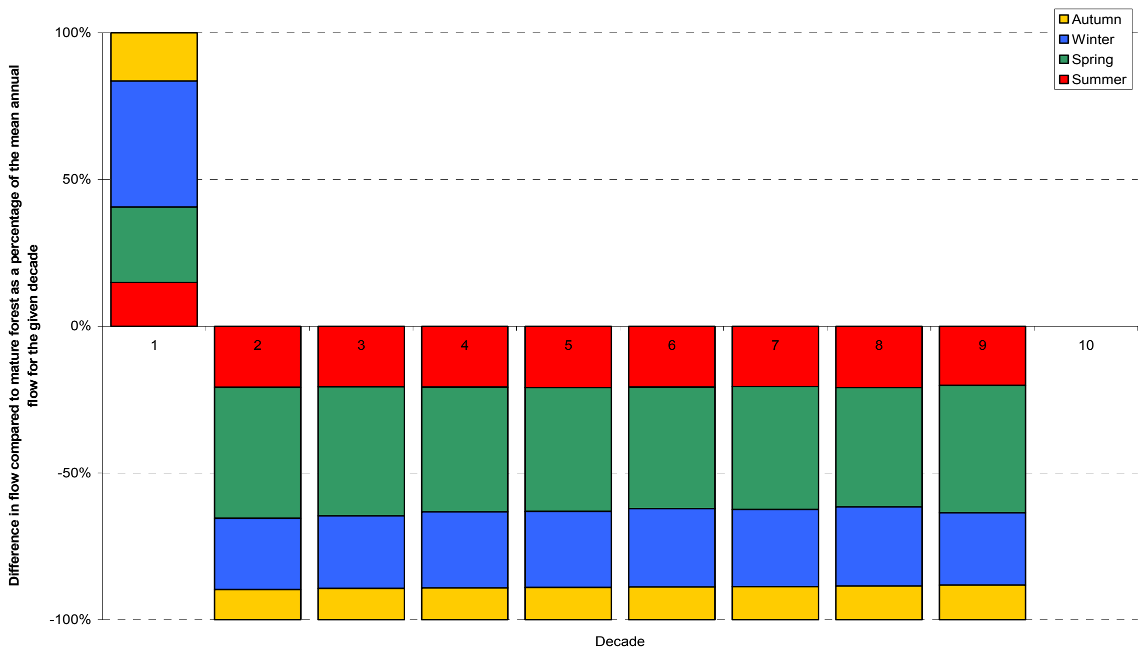
- **Table D-12 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 7**

Decade	Summer	Autumn	Winter	Spring
1	16%	18%	42%	24%
2	-21%	-11%	-26%	-42%
3	-21%	-12%	-26%	-41%
4	-22%	-12%	-27%	-40%
5	-22%	-12%	-26%	-40%
6	-21%	-12%	-27%	-40%
7	-21%	-12%	-27%	-40%
8	-21%	-12%	-27%	-39%
9	-20%	-13%	-26%	-42%
10	-	-	-	-
AVERAGE decades 2-9	**-21%**	**-12%**	**-26%**	**-40%**

D.2.8 Simulation Run 8: Livingstone Creek Lowered and Stretched Elevation, Big River Rainfall Series, Mixed Species Forest Cover



- **Figure D-8-25 Change in streamflow in the Livingstone Creek catchment with respect to mature forest (decade 10) for Simulation 8**



- **Figure D-8-26 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 8**

- **Table D-13 Difference in flow in the Livingstone Creek catchment compared to a mature forest as a percentage of the mean annual flow for Simulation 8**

Decade	Summer	Autumn	Winter	Spring
1	15%	16%	43%	26%
2	-21%	-10%	-24%	-45%
3	-21%	-11%	-25%	-44%
4	-21%	-11%	-26%	-43%
5	-21%	-11%	-26%	-42%
6	-21%	-11%	-27%	-41%
7	-21%	-11%	-26%	-42%
8	-21%	-11%	-27%	-41%
9	-20%	-12%	-25%	-43%
10	-	-	-	-
AVERAGE decades 2-9	**-21%**	**-11%**	**-26%**	**-43%**