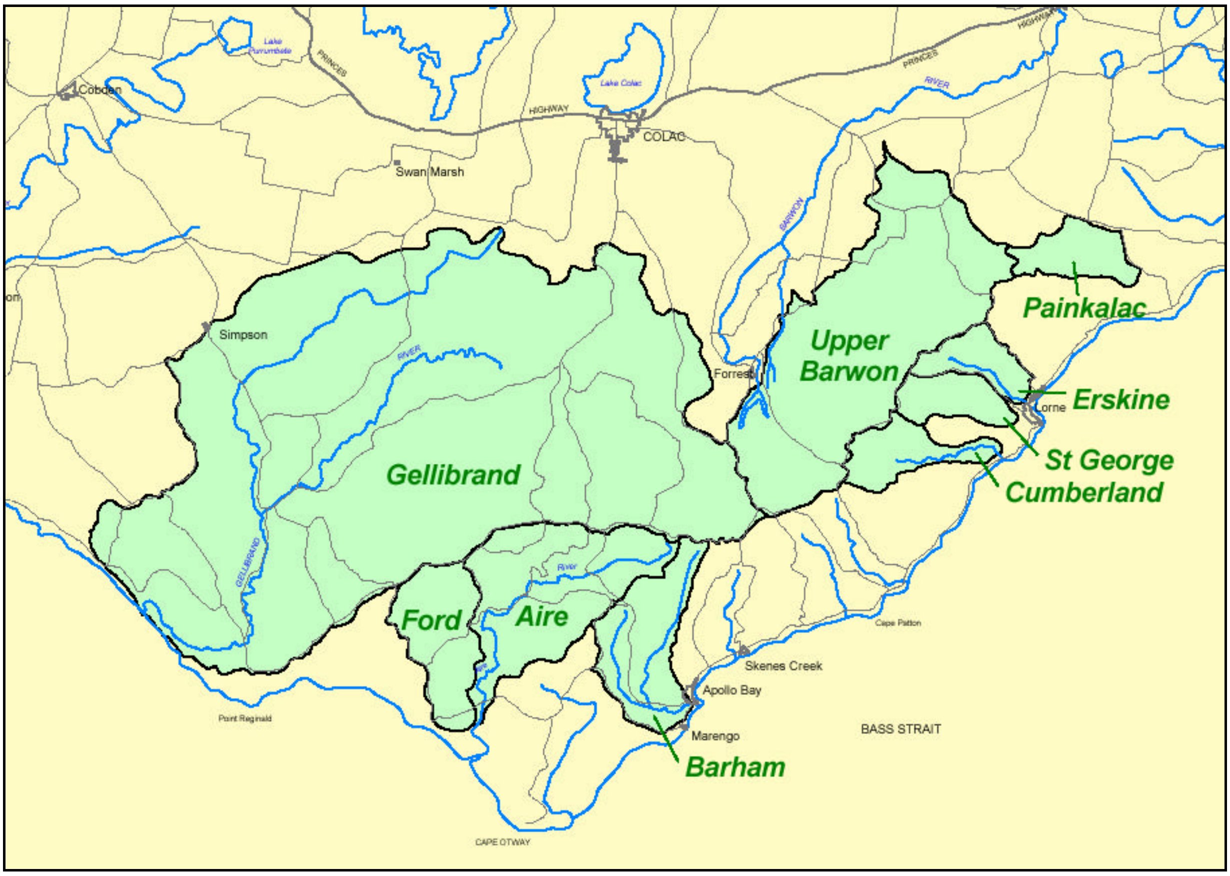
4. Water Resource Assessment

4.1 Introduction

This chapter describes an assessment of the availability of water resources of the Otway and Upper Barwon catchments. The assessment of water resources is undertaken in order to provide a context to Section 7 which describes the estimation of the potential changes in streamflow yield resulting from changes to the forest age.

The catchments assessed are the Painkalac, Cumberland, St George, Erskine, West Barham, Aire, Ford, Gellibrand and Upper Barwon. There are also a number of other smaller catchments within the Otway region which were not assessed because there is no streamflow data available and they are not affected by any significant extractions. The assessed catchments are shown in the figure below.



■ **Figure 4-1 Selected Catchments for water resource assessment**

4.2 Summary of Current Infrastructure

The water supply reservoirs in the Otway and Upper Barwon basins are summarised in Table 4-1.

- **Table 4-1 Water Supply Reservoirs**

Reservoir	Catchment	Volume (ML)[1]	Catchment Area (km²)	Date Constructed	Date Enlarged[1]
West Barwon	Barwon	20,900	51.0	1965	n/a
Wurdee Boluc*	Barwon	38,000	0.0	1929	1955,1991
Marengo	Barham	125	32.5	1979	n/a
West Gellibrand	Gellibrand	2,000	13.9	1972	n/a
Olangolah	Gellibrand	136	10.9	1910	1962
Allen	St George	220	15.4	1959	1984
Painkalac	Painkalac	514	35.7	1979	n/a

*Note: Wurdee Boluc storage is included for completeness but is an offstream storage and hence has no catchment area

4.3 Overview of Method

For the purposes of this project, streamflow yield was defined as the mean annual flow with the affect of historic diversions removed. No attempt has been made to remove the effect of other factors such as land use changes, bushfire and greenhouse on catchment yield.

Yield was calculated both at key offtake points, for example where urban extractions took place, and for the whole basin. Allowance was made for historic extractions where necessary, and adjustments were made to data sets to give results over a concurrent (and therefore comparable) period. Estimation was also made of the minimum annual flow at key locations, and the level of current demand was represented as a percentage of both the minimum annual flow and the yield figure. This was meant to give an indication of the level of usage in each catchment both in an average year and a dry year.

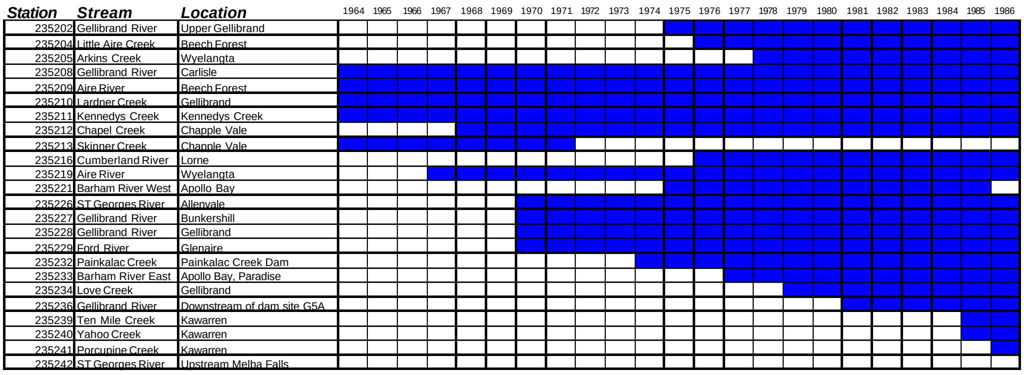
For each system a schematic was created to highlight where flows are gauged, where significant extraction points were located, and reaches where private diverters existed. Each of these schematics has been included in this report. The schematics assisted in establishing the method of calculation of yield for each basin. The adopted approach to estimation of streamflow yield was:

- determine mean annual flow at the key gauge over its full period of record;
- if necessary, add an estimate of historic upstream demands to the gauged flow to give an estimate of "natural" flow;
- factor the flow to the basin outlet on the basis of a derived relationship between catchment area specific to the basin;
- factor flow to create mean annual flow over a concurrent period by linking all flows to flow at a key gauge in the Otway and Upper Barwon catchments;
- calculate current demand as a percentage of yield;
- calculate current demand as a percentage of minimum annual flow.

Each of these steps is described in more detail in Appendix A, while a description of the methodology for specific catchments is given in Section 4.4.

4.3.1 Availability of Streamflow Data

Streamflow data was sourced from Thiess and from Barwon Water. The Thiess available streamflow data is shown in Figure 4-2, while the data available from Barwon Water is shown in Table 4-2.



■ **Figure 4-2 Available Flow Data**

■ **Table 4-2 Availability of Barwon Water Data**

Gauging Site	Period of Record Available
West Barwon Storage Volumes	01/01/96 - 31/07/00
20000100 - Wormbete Creek - Wormbete Siphon.	23/06/79 - 21/09/95
20000500 - Penny Royal Creek - Deans Marsh	01/06/79 - 21/09/95
20000600 - Penny Royal Creek - Birregurra	05/09/79 - 20/09/95
20000900 - Matthews Creek - Birregurra - Forrest Road	15/06/79 -10/12/98
20001000 - Matthews Creek - W.B.I.C Siphon Crossing	02/01/80 - 01/08/97
20001700 - West Barwon Comp Weir D/S Spillway	22/07/77 - 31/07/00
20001800 - West Barwon Spillway	17/06/77 - 31/07/00
20001900 - Dewings Creek at Barwon Downs	01/06/79 - 23/05/97
20002100 - Callahan Creek- Comp Weir	27/10/77 - 11/08/97
20010000 -W.B.I.C at Wurdee Boluc Reservoir	01/01/72 - 31/07/00
20010400 - W.B.I.C Penny Royal Creek Diversion	01/08/79 - 31/07/00
20010500 - W.B.I.C Matthews Creek Diversion	02/01/80 – 31/07/00
20010600 - W.B.I.C Dewings Creek Diversion	02/01/79 - 01/01/94
20010700 - W.B.I.C Callahan Creek Diversion	02/01/78 - 31/07/00
20020000 - W.B.I.C East Barwon Offtake	08/02/79 - 31/07/00

* Source – Barwon Water pers. Comm.

4.3.2 Availability of Historic Demands

Very little information existed on the nature of historic extractions in the study area (except for a few of the major systems). Given the potential errors involved in estimating historic demand trends, and the fact that annual data only was being assessed, historic demands were assumed equal to the level of current demand (1999/2000) for urban offtakes, and licensed volume for private diverters.

Historic demand data was supplied by South West Water and Barwon Water.

The distribution of urban and rural demands in the Otway and Upper Barwon River basins is shown in Table 4-3.

■ **Table 4-3 Summary of Demands in each Catchment**

Catchment	Urban Demands	Rural Demands
Painkalac Creek	Aireys Inlet	No
Erskine River	Lorne	No
St George River	Lorne	Yes
Cumberland River	None	Yes
Barham River	Apollo Bay and Skenes Creek	Yes
Aire River	None	Yes
Ford River	None	Yes
Gellibrand River	Colac, Gellibrand, North Otway Pipeline, South Otway Pipeline	Yes
Upper Barwon River	Geelong (part)	Yes

A full summary of private diverter licensed volumes and 1999/00 urban demands are given in Appendix B.

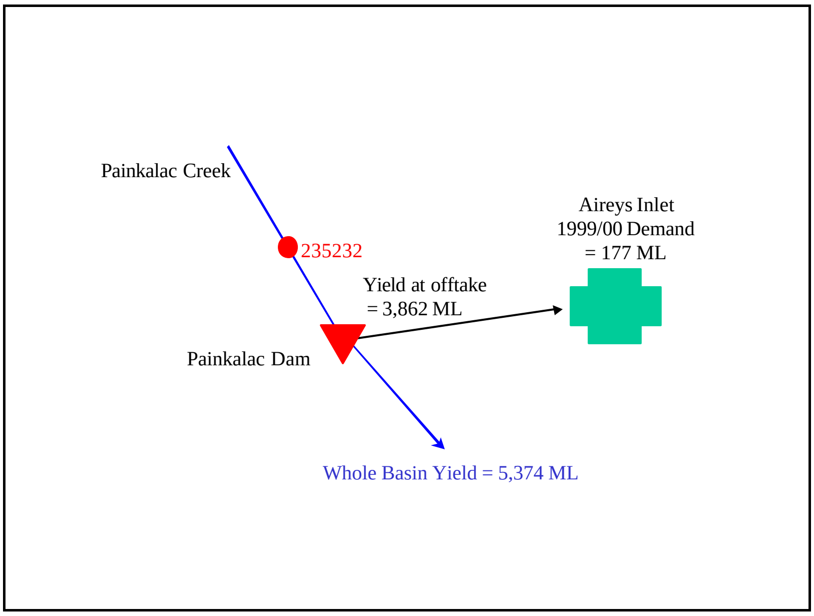
4.4 Assessments for Individual Catchments

The following sections give a brief description of the adopted methodology and estimated yield for each catchment.

4.4.1 Painkalac Creek

Yield in Painkalac Creek catchment was calculated using flow at 235232 and demand extracted at Painkalac Dam to supply Aireys Inlet. As the gauge is just upstream of the offtake, yield at the offtake was reported as the mean annual flow at the gauge, adjusted to be concurrent with the Gellibrand river gauge. To calculate whole basin yield the gauged flow was transposed to the basin outlet and the 1999/00 Aireys Inlet demand added back in. There are no private diverter demands in the catchment. The resulting yield figures are shown below. A more detailed summary of calculations is given in Appendix B.

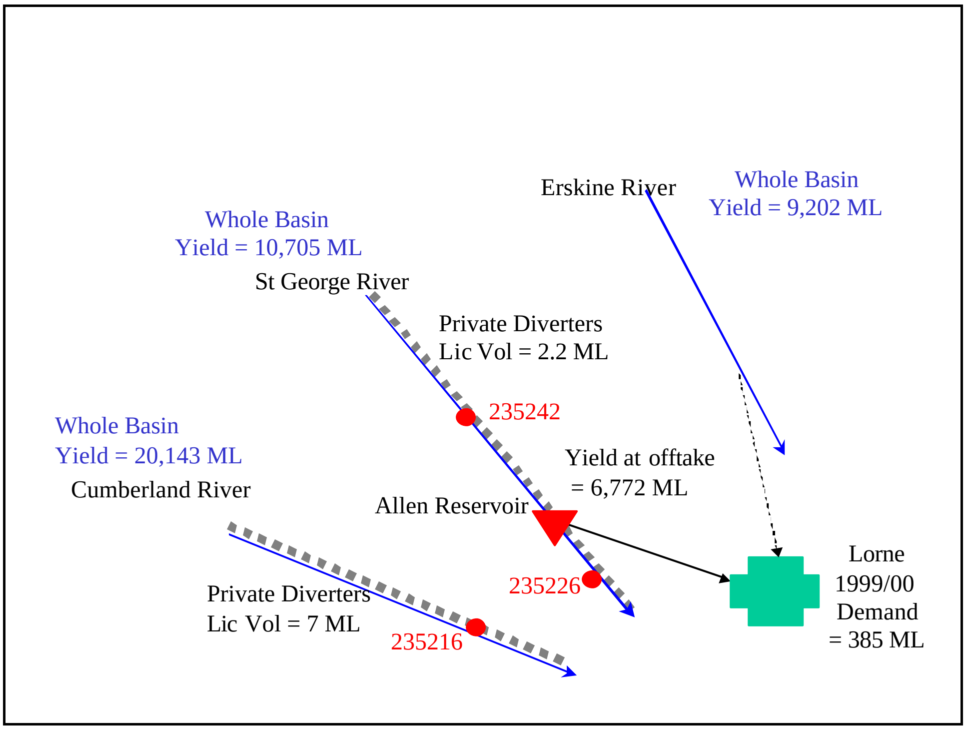
■ **Figure 4-3 Painkalac Creek Schematic**



4.4.2 Cumberland River

Yield in Cumberland River catchment was calculated using flow at 235216 and the licensed volume of private diverter demands. There is no urban extraction, so no "yield at offtake" figure was calculated. Whole basin yield was calculated by transposing gauged flow to the basin outlet and then adding back licensed private diverter demands. Finally, the yield was adjusted to be concurrent with the Gellibrand river gauge. A more detailed summary of calculations is given in Appendix B.

■ **Figure 4-4 Erskine, St George and Cumberland River Schematic**



4.4.3 St George River and Erskine River

The St George and Erskine Rivers supply the urban demand at Lorne. Currently the Erskine River offtake is not used but this is thought to be temporary. St George River is also utilised by private diverters.

Yield in St George River was calculated using data at the 235226 gauge. Flow at the gauge was transposed upstream to correspond with the offtake, and then 1999/2000 extraction for Lorne was added back to the gauged data and adjusted to be concurrent with the key Gellibrand gauge to estimate yield at the offtake. Yield at the basin outlet was derived by transposing yield at the offtake.

As the Erskine River is ungauged, data from the Cumberland River gauge 235216 was transposed based on catchment area to estimate yield at the offtake and for the whole basin.

A more detailed summary of calculations is given in Appendix B.

4.4.4 Barham River

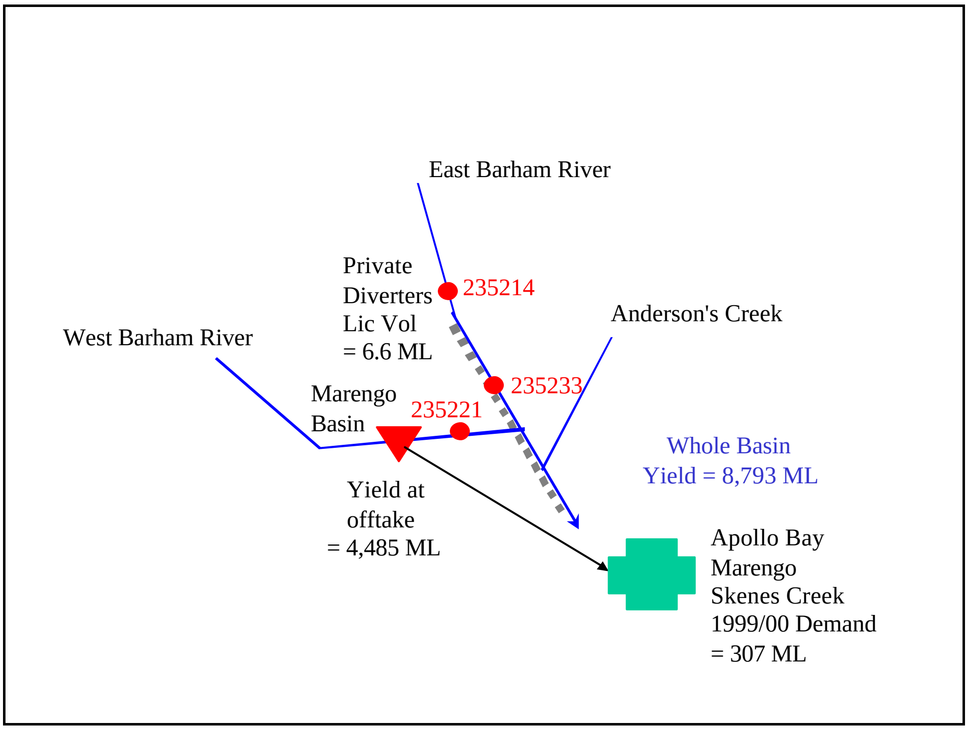
The Barham River system supplies the urban centres of Apollo Bay and Skenes Creek. The are also private diverter demands in the catchment. The offtake for Apollo Bay and Skenes Creek is in the West Barham River catchment.

Yield at the urban offtake was calculated using gauge 235221, transposed upstream with demands added back to the yield estimate. The yield value was then adjusted to be concurrent with the key Gellibrand gauge.

Whole catchment yield was calculated using the same gauged factored up to encompass the whole basin area. In addition, allowance was made for private diverter extractions by adding back their licensed volume.

A more detailed summary of calculations is given in Appendix B.

■ **Figure 4-5 Barham River Schematic**



4.4.5 Aire River and Ford River

There are no urban extractions from either the Aire or the Ford River, however both are effected by private diverter extractions.

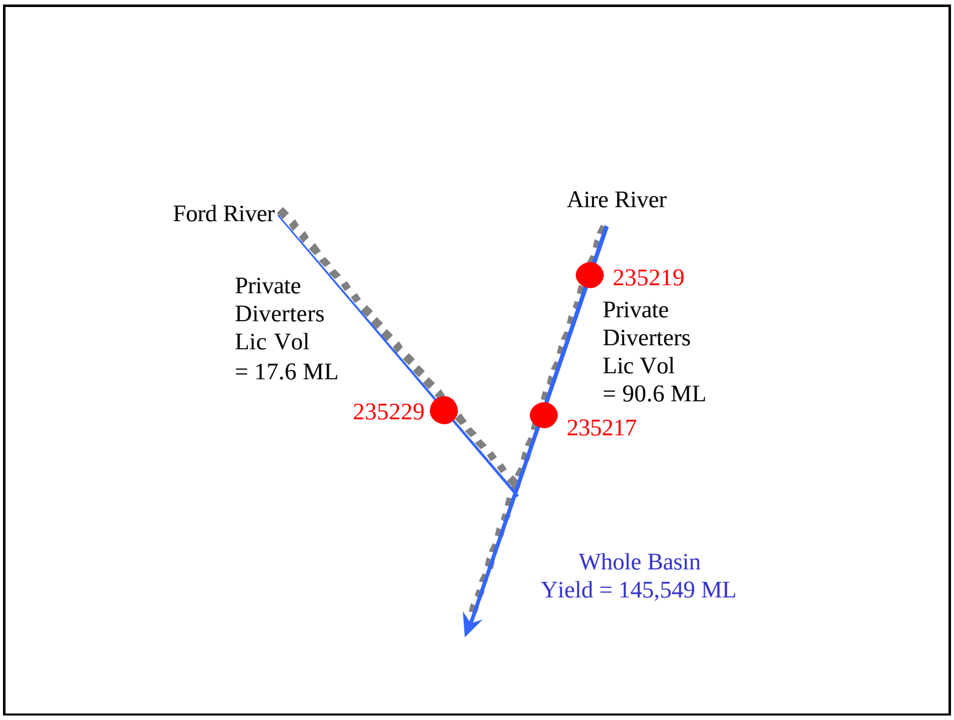
Yield in the Ford River was estimated using the 235229 gauge. Flow was transposed to the confluence with the Aire River and private diverter demands added back to the mean annual flow. Yield was then adjusted to correspond with the key Gellibrand gauge.

Yield in the Aire River was calculated by transposing 235219 to the catchment outlet and adding back private diverter demands. This yield figure was then adjusted t correspond with the key Gellibrand gauge.

Note that the whole basin yield shown on the figure below was reported as the sum of the Ford River and Aire River yields.

A more detailed summary of calculations is given in Appendix B.

■ **Figure 4-6 Aire and Ford River Schematic**



4.4.6 Gellibrand River

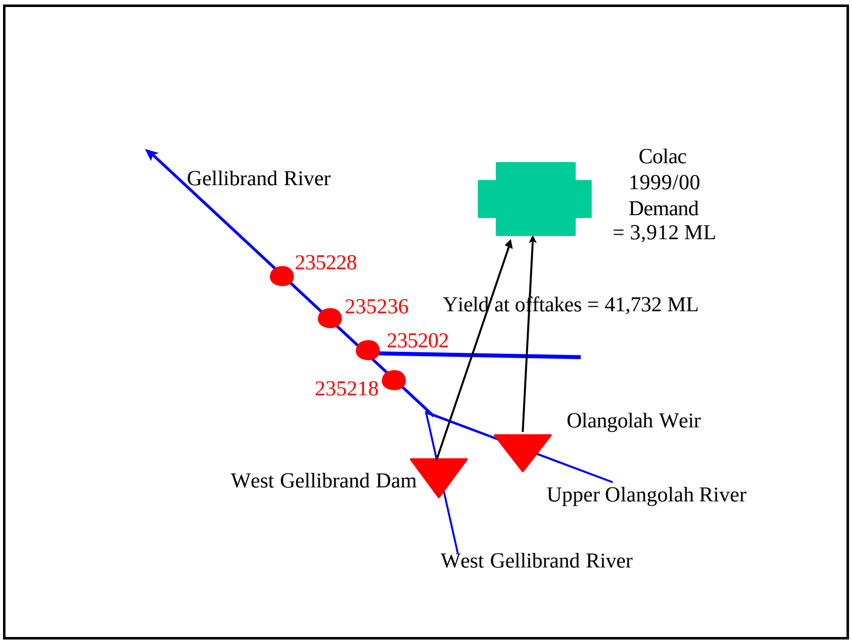
The Gellibrand Basin has offtakes for three major users, Colac, the North Otway Pipeline and the South Otway Pipeline. There is also extensive usage by private diverters in the catchment. Yield was calculated at each of the three offtake points as well as for the whole basin.

Upper Gellibrand River - Colac System

Colac is supplied from the Upper Gellibrand River from two offtake points. One is on the West Gellibrand River at West Gellibrand Dam, while the other is on the Upper Olangolah River at Olangolah Weir. A combined yield was derived at both these offtake points by transposing flow measured downstream at the 235202 gauge. Yield was then adjusted to be concurrent with the key Gellibrand gauge. Both urban and private diverter demands were added back to the flow. Given the relatively small size of the two storages, and the lack of flow data upstream of them, the effect of the storages on the annual flow (due to evaporation, seepage, etc) was ignored.

A more detailed summary of calculations is given in Appendix B.

■ **Figure 4-7 Upper Gellibrand River Schematic**

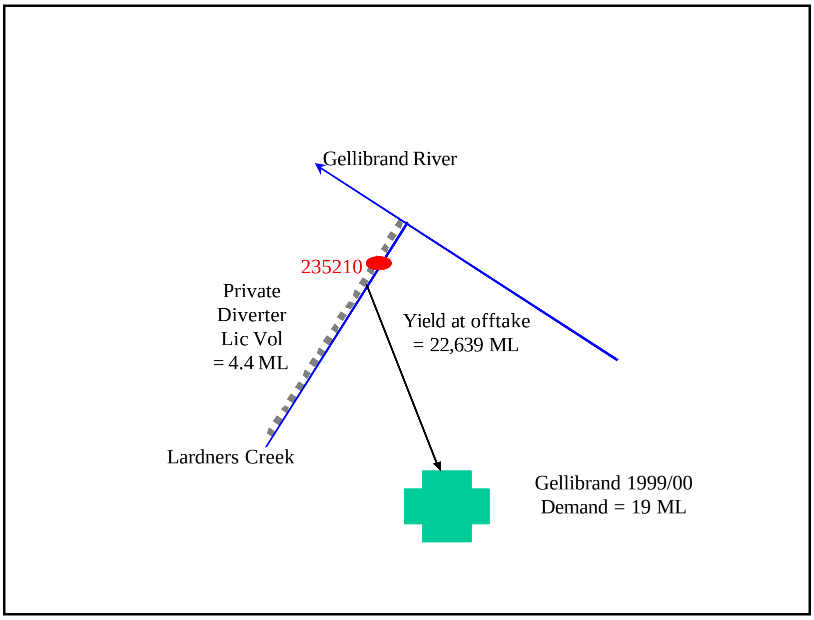


Lardners Creek

The town of Gellibrand is supplied off Lardners Creek in the Upper Gellibrand system. There are also private diverters on this stream. Yield at the offtake is estimated by transposition of flow at the downstream gauge 235210. These yield figures were then adjusted to be concurrent with the yield at the key Gellibrand gauge. A whole basin yield figure was not calculated.

A more detailed summary of calculations is given in Appendix B.

■ **Figure 4-8 Lardners Creek Schematic**



Mid Gellibrand River - North Otway Pipeline

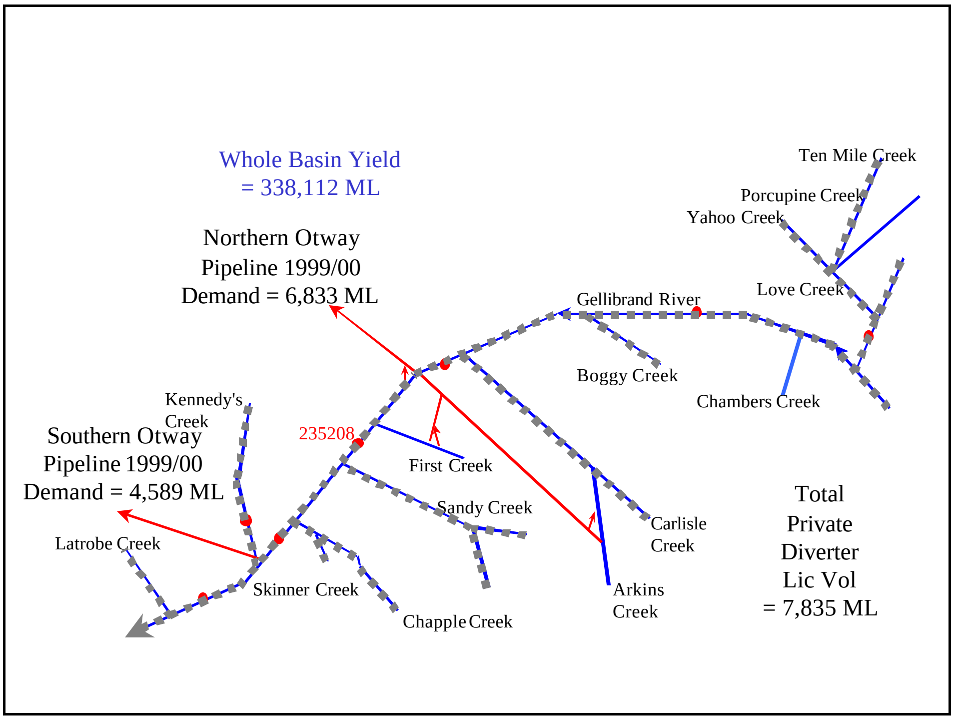
The North Otway Pipeline is supplied from three offtake points on Arkins Creek, First Creek and Gellibrand River. Yield was calculated at each of these three points.

Yield for Arkins Creek and First Creek was based on flow measured on Arkins Creek at 235205, upstream of the offtake. Yield was adjusted to be concurrent with the key Gellibrand gauge.

Yield on the Gellibrand River at the North Otway Pipeline offtake was calculated using the downstream gauge 235208 along with an estimate of upstream demands. Upstream demands included the volume of flow extracted at the pipeline offtake and the licensed volume of upstream private diverters excluding Lardners Creek. The yield estimate was then adjusted to be concurrent with the key Gellibrand gauge.

A more detailed summary of calculations is given in Appendix B.

- **Figure 4-9 Gellibrand River Schematic**



Lower Gellibrand River - South Otway Pipeline

The South Otway Pipeline is supplied from an offtake point on the Gellibrand River upstream of the confluence with Kennedys Creek. Yield at this point was estimated using flow at gauge 235208. The methodology use is similar to that applied for the northern pipeline offtake. It should be noted that the yield reported is in addition to the upstream yield, that is, it is the yield at the northern offtake plus the additional yield between offtakes.

To calculate whole catchment yield an additional 2400ML of private diverter demand was taken into account. This yield was calculated using the 235224 gauge, and as such is independent of the two yield calculations made upstream at the north and south pipeline offtakes. Yield was estimated by transposing flow to the basin outlet and adding back in all upstream demands.

A more detailed summary of calculations is given in Appendix B.

Gellibrand River Low Flows

It was recognised that since the North and South Otway Pipeline system has little carry over storage, flows on a lesser timestep than the annual figures examined here can be critical. Therefore a further analysis of flows available at the pipeline offtakes was carried out on a daily timestep.

This issue of low flow extractions is complicated by the Bulk Entitlement passing flow requirements at these locations. These are summarised as follows:

- **Table 4-4 North Otway Pipeline Passing Flow Rules**

Flow above the North Otway Pipeline	Maximum Extraction Allowed
≥ 54.9 ML/d	22.5 ML/d
between 44.9 and 54.9 ML/d	20.0 ML/d
between 22.5 and 44.9 ML/d	17.5 ML/d
Between 12 and 22.5 ML/d	12.0 ML/d
Less than 12 ML/d	All flow

- **Table 4-5 South Otway Pipeline Passing Flow Rules**

Flow above the South Otway Pipeline	Maximum Extraction Allowed
≥ 41.2 ML/d	21.5 ML/d
between 32.7 and 41.2 ML/d	19.0 ML/d
between 22.0 and 32.7 ML/d	17.0 ML/d
Between 12 and 22.0 ML/d	12.0 ML/d
Less than 12 ML/d	All flow

A flow exceedence analysis of daily data at the gauge 235208 transposed to the north and south pipeline offtake points offtake points was undertaken.

This shows that at the northern offtake the amount allowed to be extracted is likely to drop below 22.5ML/d around for 15% percent of days (on average 55 days per year). Extractions would be severely limited (less than or equal to 12 ML/d) around 6% of days (on average 22 days per year). The variability of this average is indicated by flow downstream of the northern offtake falling below 20ML/d for 90 days in 1968.

At the southern offtake, the situation is similar but less severe, the amount allowed to be extracted is likely to drop below 21.5ML/d for around 9% percent of days (on average 33 days per year). Extractions would be severely limited (less than or equal to 12 ML/d) around 6% of days (on average 22 days per year). The variability of this average is indicated by flow downstream of the southern offtake falling below 12ML/d for 66 days in 1974. Note however that since gauged flow has been transposed downstream in this case, no allowance has been made for the impact on flow of private diverters between 235208 and the southern offtake. It is estimated that at peak demand times, these diverters could reduce flows upstream of the offtake by up to 7ML/d.

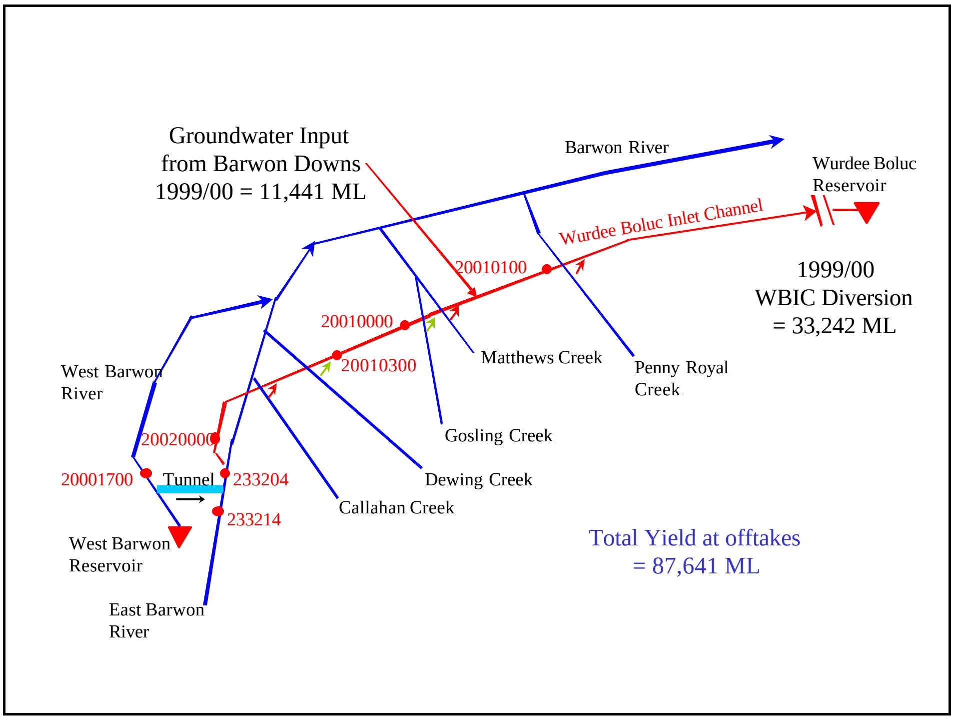
4.4.7 Upper Barwon River System

The Upper Barwon catchment is used to supply part of the Geelong urban demand. This supply is supplemented by the groundwater source at Barwon Downs Wellfield. Most of the flow is sourced from the West Barwon Reservoir and the East Barwon River. This flow is passed down the Wurdee Boluc Inlet Channel, which can pick up supplementary flows from a number of the tributaries it crosses on the way to Wurdee Boluc storage. A list of all flow sources follows:

- West Barwon Reservoir
- East Barwon River
- Callahan Creek
- Dewing Creek
- Gosling Creek
- Matthews Creek
- Penny Royal Creek

As this study only encompasses the upper reaches of the Barwon catchment, yield was only calculated at the offtake points, not for the whole basin.

Figure 4-10 Upper Barwon River Schematic



West Barwon Reservoir

Inflow into the West Barwon Reservoir had previously been estimated by Sinclair Knight Merz (then HydroTechnology) for Barwon Water (refer HydroTechnology, 1995). Inflow was estimated by a monthly water balance on the West Barwon storage. This data was used to estimate yield at the West Barwon Reservoir. As there were no upstream demands no adjustment was made to this flow except to correspond with the key Barwon gauge. It is assumed that the amount of flow calculated flowing into the reservoir is equivalent to the amount available for use from this source at the Wurdee Boluc Inlet Channel.

East Barwon River

Yield in the East Barwon River at the Wurdee Boluc Inlet Channel offtake was estimated by transposing flows at the 233214 gauge. It was assumed that there were no upstream extractions. Finally, the yield was adjusted to correspond to the key Barwon River gauge.

Callahan Creek

Some of the flow in Callahan Creek can be diverted into the Wurdee Boluc Inlet Channel. Therefore, yield in the creek was calculated where it crossed the channel. This was done by summing flow at two Barwon Water gauges, 20002100 and 20010700 and adding back upstream private diversions. Finally, the yield was adjusted to correspond with the key Barwon gauge.

Dewing Creek

As for Callahan Creek some of the flow in Dewing Creek can be diverted into the Wurdee Boluc Inlet Channel. Yield was calculated by summing flow at two Barwon Water gauges, 20001900 and 20010600. Finally, the yield was adjusted to correspond with the key Barwon gauge.

Gosling Creek

Similar to Callahan Creek and Dewing Creek, some of the flow in Gosling Creek can be diverted into the Wurdee Boluc Inlet Channel. This creek is not gauged so yield was calculated by transposing flow from Mathews Creek.

Matthews Creek

As for Callahan Creek, Dewing Creek and Gosling Creek, some of the flow in Matthews Creek can be diverted into the Wurdee Boluc Inlet Channel. Yield was calculated by summing flow at two Barwon Water gauges, 20001000 and 20010500. Finally, the yield was adjusted to correspond with the key Barwon gauge.

Penny Royal Creek

As above, some of the flow in Penny Royal Creek can be diverted into the Wurdee Boluc Inlet Channel. Therefore, yield in the creek was calculated where it crossed the channel. This was done by summing flow at two Barwon Water gauges, 20000600 and 20010400 and adding back upstream private diversions. Finally, the yield was adjusted to correspond with the key Barwon gauge.

Whole catchment yield was calculated by summing the yield at all the offtake points. The figure quoted excludes the additional flow passed to the Wurdee Boluc Inlet Channel from the Barwon Downs Wellfield. The amount of flow from the wellfield was supplied by SKM's groundwater group. Note that this estimate of flow was subtracted from the Geelong demand sourced from the Wurdee Boluc Inlet Channel when calculating demand as a percentage of yield and minimum flow.

A more detailed summary of calculations is given in Appendix B.

4.5 Summary of Results

The results shown in the following tables indicate that the level of usage across the study area varies widely. Current annual demand levels vary from as little as 0.04% for Cumberland River up to 25% of the whole catchment yield for Upper Barwon River.

The effect the current level of demand would have in a low flow year is illustrated by expressing 1999/2000 demand as a percentage of the minimum flow year. This impact varies from 0.4% in Lardners Creek up to 312% in the Upper Barwon. Of course, in the case of the Upper Barwon catchment this calculation assumes no carry-over storage in West Barwon Reservoir or Wurdee Boluc storage from the previous year. For the remaining catchments, the demand is less than 55 percent of the minimum annual flow.

The yield and demand values represent *annual* levels, and therefore the results should be carefully interpreted. The within year variation is likely to be important for those systems such as the Gellibrand which have very little storage. For the Gellibrand system, the current annual demand represents 6.9% of the annual basin yield. However, this percentage is likely to be much higher in summer (when flows are lower and demand is higher) and lower in the winter months.

- **Table 4-6 Summary of Results – Otway Catchment**

Catchment	Estimated Yield at Offtake (ML)	Demand as a % of Yield at offtake	Estimated Whole Basin Yield (ML)	Demand as a % of Whole Basin Yield	Demand as a % Min Annual at offtake
Painkalac	3,862	4.6	5,374	3.3	55.6
Cumberland	n/a		20,143	0.04	n/a
St George	6,772	5.7	10,705	3.6	39.1
Erskine	9,202	0.0	9,206	0.0	0.0
West Barham	4,485	7.0	8,793	3.6	11.6
Aire	n/a		106,139	0.09	n/a
Ford	n/a		39,410	0.05	n/a
Gellibrand					
West Gellibrand Reservoir / Olangolah Reservior	41,732	9.4			44.4
Lardner Ck	22,639	0.1			0.4
Arkins Ck	4,210				-
First Ck	4,210				-
Gellibrand River @ nth pipe	121,123	8.2			20.5
Gellibrand River @ sth pipe	150,475	11.2			31.7
Gellibrand River lower	n/a				n/a
TOTAL GELLIBRAND			338,112	6.9	

- **Table 4-7 Summary of Results – Upper Barwon Catchment**

Catchment	Estimated Yield at Offtake (ML)	Demand as a % of Yield at offtake	Estimated Whole Basin Yield (ML)	Demand as a % of Whole Basin Yield	Demand as a % Min Annual at offtake
West Barwon Res	28,112				
East Barwon River	10,092				
Callahan Creek	14,276				
Dewing Creek	7,806				
Gosling Creek	4,960				
Matthews Creek	5,264				
Penny Royal Creek	17,130				
TOTAL UPPER BARWON	87,641	25.0	87,641	25.0	312.7

5. Wildfire

5.1 Introduction

Fire is, and always has been, a natural feature of native forests in southern and eastern Australia. The forest environment has evolved with various degrees of tolerance to fire and a range of survival mechanisms. Fire, along with climatic and soil factors, strongly determines the ecology of plant communities in forest areas such as the Otways. Depending on severity and extent, individual fires can alter forest structure, composition and age, and reduce surface cover. Fire-induced changes are therefore capable of exerting major effects on the hydrology of forest areas, with consequent short- to long-term impacts on water quality and water yield (see Section 7).

The water quality effects of forest fire mostly result from increased soil erosion and sediment supply to streams, but short-term increases in the concentrations of dissolved ions and nutrients can occur in local streamwater. The latter impact is more likely where fires are hot and riparian areas are burnt. The removal of surface cover by fire is often accompanied by the (generally temporary) development of a water repellent layer at the soil surface. Both effects give rise to greater surface runoff volumes and velocities during storms, with an increased probability of erosion through rill development. Sediment delivery to streams is more likely if riparian areas, which normally perform a buffering and filtering role, are severely burnt. The potential for impact is greater after hot fires, but eucalypt ecosystems respond quickly to hot fire and revegetation can be rapid enough to ensure that any water quality impacts are no more than transient.

Major wildfire can have catastrophic effects on forest structure, composition and age. The current characteristics of many forests in southern Australia, including those in the Otways, are a direct consequence of past wildfires. Their age class distribution is frequently related to the occurrence of fire in earlier years, and it is therefore likely that the current water use of these forests may also be a direct consequence of fire history. Sudden changes in forest age (from old growth to regrowth) over large areas can have significant impacts on forest water use and catchment water yield (Langford, 1976). Extensive wildfire is therefore the most likely agent for major water yield change in these forests, and measures that reduce wildfire occurrence also reduce the likelihood of major water yield changes.

5.2 Fire History in the Otways

Fire records comparable to those of today were not kept for Otway forests until relatively recently, but very large fires were recorded in 1851, 1886, 1898, 1919, 1926, 1939, 1951 and 1983 (Harrison and Wouters, 1995). Many forests are a direct consequence of the very severe 1919, 1926 and 1939 fires, while the effects of the 1983 fires are still evident. Fires in the early years generally resulted from escaped clearing burns, but today wildfire is associated with deliberate lighting, with burning off operations, with lightning and with campfires. In general the forests have a low to medium level of fire activity punctuated by large fires that occur under severe fire weather conditions (Harrison and Wouters, 1995). Very few ignitions become large fires because of suppression strategies and the relatively low frequency of severe fire weather. Nevertheless the coincidence of high temperatures, strong winds, low humidity and high forest fuel loads leave the forest very vulnerable to any ignition.

Public plans and strategies are in place to minimize wildfire occurrence, as detailed below.

5.3 Fire Management in the Otways

Fire management in Victoria is a State responsibility and the Code of Practice for Fire Management on Public Land (CNR, 1995) provides a framework for fire management on public land. The Department of Natural Resources and Environment is responsible for the prevention and suppression of fires in State forests, National parks and other protected public lands (CRA, 1999). The above Code requires that Regional Fire Protection Plans be prepared, and the Otway Fire Protection Plan (Harrison and Wouters, 1995) details the objectives and strategies for the Otway forests. The **Fire Protection Objectives** of this Plan are:-

- Protect life, property and other assets from wildfire.
- Protect areas of identified natural and cultural value from the adverse effects of wildfire.
- Restrict the spread of wildfire.
- Decrease the severity of wildfire.
- Reduce the incidence of wildfire.

These Objectives are achieved through the implementation a number of **Fire Protection Strategies.**

- Fire prevention strategy. This includes public education, supervision and enforcement of legislation, enforcing a prohibited fire period on Protected Public Land and closing forests during periods of extreme fire danger.
- Fire pre-suppression strategy. Includes a number of activities undertaken in advance of wildfire occurrence such as liaison with other emergency services, early detection of fires and training and fuel reduction burning. The fuel management strategy includes fuel management burning in five zones. These zones prioritise fuel reduction from a target of 8t/ha of fuel in Zone 1 (very high priority) to the exclusion of prescribed burning in Zone 5. 58% of the Otway forests are subject to some fuel reduction burning (Harrison and Wouters, 1995).

Fire suppression strategy. This includes all activities associated with extinguishing a wildfire following its detection.

5.4 Conclusions

Although infrequent severe wildfires have been a feature of the Otway forests, the present fire management plans and strategies are professional, thorough and appropriate. However the probability of an extensive wildfire, although low, will always be present, as will the probability of widespread impacts. Very large areas of future fire-induced forest regeneration cannot be ruled out absolutely. Such an eventuality would have significant short-term impacts on water quality and long-term impacts on water yield.

6. Best Management Practices

6.1 Introduction

Best Management Practices (BMPs) designed to minimize the impacts of forest management on soil and water values have been implemented by State forest agencies in Australia since the 1970's. Initially these BMPs consisted of measures found successful in North America, and adapted for local conditions. Over time it became apparent that site-specific BMPs were required, and that an assessment of pertinent local factors were essential in achieving this. A satisfactory assessment system needs to be scientifically robust, transportable and practical, and the various State forest agencies in Australia have approached the task in slightly different ways, as reviewed by Ryan *et al* (1998). As soil erosion control is the primary aim of most soil/water BMPs, this assessment process is designed to assign an erosion hazard rating to forest land at the coupe (or finer) scale. Appropriate site-specific BMPs are then implemented based on the hazard rating. In summary the process is as follows:-

a). The formulation of goals (desired outcomes), guidelines (guidance on achieving goals) and prescriptions (operational instructions) by the forest agency. In Victoria this process is detailed in the Code of Forest Practices for Timber Production (NRE, 1996). Prescriptions are developed regionally in Victoria (eg Otway Forest Management Plan, DCE, 1992; Otway FMA Forest Management Prescriptions, NRE, 1997a), and allow local formulation and implementation.

b). The assessment of soil erosion hazard, which in Victoria has two components – a broadscale categorization of inherent erosion hazard and an assessment of soil erosion hazard at the coupe scale. The first component is limited by the quality and broad nature of Land System information, but this is expected to improve over time. The second assessment has recently been standardized (NRE, 1999), and considers soil properties at the coupe scale (soil erodibility, infiltration and drainage), and determines soil erosion site factors (rainfall erosivity index, slope gradient, slope length and revegetation capacity). These properties and factors yield scores that are combined to provide a low, medium or high hazard assessment for the coupe.

c). Final site-specific prescriptions will depend on the coupe hazard assessment derived above. In Victoria these prescriptions are formulated according to procedures outlined in the regional Forest Management Plan (here the Otway Forest Management Plan, DCE, 1992) and detailed in the Otway FMA Forest Management Prescriptions, (NRE, 1997a). These site-specific prescriptions form part of the Forest Coupe Plan and compliance with prescriptions and Plan is a condition of forest produce licences issued by the Secretary of NRE.

6.2 Essential BMPs

Research and experience in Australia and other countries point to a number of BMPs that are essential to the preservation of soil and water values in managed forests. In many cases their efficacy is highly dependent on the formulation and implementation of appropriate site-specific conditions. These essential BMPs are discussed in this section, together with their implementation in Victorian forests.

6.2.1 Protection of riparian vegetation around streams and drainage lines

This measure has a dual function; provided machinery is excluded from the vicinity of the stream, the bed and banks are protected from disturbance, and the undisturbed strip of forest intercepts overland flow and sediment before they reach the stream. Referred to as buffer strips (around permanent streams) and filter strips (around drainage lines and intermittent streams) in Victoria, slightly different definitions are employed by other forest agencies. The activities allowed within the strips also vary from State to State, as does the strip width. In Victoria the width of buffers and filters are described in the Code of Forest Practices for Timber Production (NRE, 1996), are prescribed locally in the Otway FMA Forest Management Prescriptions (NRE, 1997a), and depend on local erosion hazard, slope and on the potential of the soil to generate overland flow. This potential is determined from coupe-scale soil information (infiltration, drainage). Minimum strip widths vary between 10m and 40m. In Victoria trees may not be felled within buffers, nor may machinery enter (except at designated stream crossings). Trees may be felled within filter strips but machinery is still excluded.

6.2.2 Slope limitations to harvesting

In Victoria harvesting operations are generally restricted to slopes below 30^{o}. Actual maximum slopes allowed for logging are prescribed in the Otway Forest Management Plan (DCE, 1992), and Forest Coupe Plan and depend on erosion hazard, but other factors such as type of machinery, intensity of harvesting and seasonal soil moisture conditions are also taken into account. Other State agencies limit logging to certain slopes in a somewhat similar fashion.

6.2.3 Location, use and drainage of snig tracks

Snig (and forwarding) tracks represent areas of maximum disturbance and compaction within the coupe, and experience and research (eg Croke *et al.*, 1997) indicate that snig tracks can be major sources of sediment. They can also be preferential flow paths unless satisfactorily drained onto undisturbed areas. 10 metre buffers of undisturbed forest were sufficient to remove over 95% of sediment produced on well-drained snig tracks in eastern NSW (Lacey, 2000). In Victoria, the Code of Forest Practices for Timber Production goals recommend that tracks be located, used and drained in ways that minimise adverse impacts on soil and water quality. Prescriptions for the spacing of cross-drains on tracks (to divert runoff onto undisturbed areas) are provided in Forest Coupe Plans according to the local soil erodibility and slope (Otway FMA Forest Management Prescriptions, NRE, 1997a). Uphill snigging patterns are preferred, with tracks kept away from drainage lines and streams except at approved crossings. Track use during wet weather should be avoided. Victoria has adopted similar snig track BMPs to those operating in other States.

6.2.4 Location, construction and rehabilitation of log landings

Log landings can become highly disturbed and compacted with use and are therefore a potential sediment source. They should be located well away from drainage lines and streams, and should be rehabilitated (eg ripped, topsoil replaced, planted) after use. Goals and guidelines in the Victorian Code of Forest Practices for Timber Production, and prescriptions in the Otway FMA Forest Management Prescriptions (NRE, 1997a) detail these measures, including minimum distances of landings from drainage lines and streams.

6.2.5 Wet weather restrictions to forest operations

Various operations, when carried out under wet conditions, including the use of machinery on roads, tracks, landings and in the general harvest area (GHA) can significantly increase the potential for sediment delivery to streams. To achieve satisfactory outcomes temporary or seasonal restrictions to vehicular and machinery movement may be required. Such restrictions are specified in the guidelines within the Victorian Code of Forest Practices for Timber Production, and employed following a local assessment of current or seasonal conditions. The Otway FMA Forest Management Prescriptions (NRE, 1997a) list catchments subject to seasonal closure, and provide a range of prescriptions related to temporary restrictions. Similar restrictions are employed in other States.

6.2.6 Rehabilitation of the harvested area

Rapid rehabilitation (through revegetation) of all areas disturbed during the harvesting process will lessen the period when these areas are subject to higher potential erosion. While areas of greater disturbance (temporary roads, snig tracks and landings) should be targeted, rapid revegetation of the GHA is also beneficial (Cornish, in press). Victorian guidelines recognize the need for disturbed site rehabilitation following the completion of harvesting operations.

6.2.7 Careful planning, design, location, construction, drainage and maintenance of roads

The permanent forest roading network is a continuing source of sediment to drainages, while temporary roads (even if closed and rehabilitated) are sources for some years. Impacts can be minimized by the inclusion of appropriate soil/water stabilization measures at every stage of the road design, construction and maintenance process. The Victorian Code of Forest Practices for Timber Production (NRE, 1996) details numerous guidelines which are intended to minimize soil/water impacts from roads. Guidelines cover the planning, design, location, drainage and maintenance of roads, and include the requirement that roads avoid streams, buffer strips and areas prone to landslips. General prescriptions for roads are included in the Otway FMA Forest Management Prescriptions (NRE, 1997a), while detailed prescriptions for permanent roads are contained in Wood Utilisation Plans. Forest Coupe Plans contain local prescriptions for temporary roads. Prescriptions vary with road class and soil erodibility. Maintenance schedules for permanent roads are detailed in the Otway FMA Forest Management Plan (DCE, 1992), which also lists roads subject to temporary or seasonal wet weather closure. This Plan directs that temporary roads be rehabilitated when no longer required. These measures (with some exceptions) parallel those implemented in other States.

Croke (1999) concludes that road-to-stream connectivity is a major factor in the supply of road sediment to drainage lines and streams. This review highlighted gully erosion at road drainage outlets as the most persistent outcome from an inadequate spacing of road drainage structures. Of equal importance was the location of road drainage features in the vicinity of streams or major drainage lines; if drainage features are located with insufficient opportunity to discharge runoff onto undisturbed, infiltrating forest floor then sediment will not be deposited but transported directly into drainages. The Otway FMA Forest Management Prescriptions (NRE, 1997a) prescribe road drainage spacings based on road grade and soil erodibility, and stipulate that road drainage must discharge onto at least 20m of undisturbed vegetation, and not directly into streams or drainage lines. Correctly implemented, these prescriptions should minimize sediment delivery from Otway forest roads to the drainage network.

6.2.8 Design and construction of stream and drainage line crossings

Bridges, culverts and fords should be designed for stability in high flows, and be constructed so as to deny road runoff (and associated sediment) easy entry to the stream. Various measures in the Otway FMA Forest Management Prescriptions (NRE, 1997a) detail design and drainage requirements. Roads must be gravel-surfaced approaching bridges, with surfacing distances determined by the grade of the bridge approach. Temporary culverts may be permitted, but must be removed following use. Victorian prescriptions in this area are in line with those implemented elsewhere.

6.3 Protection of Catchments from Water Yield Changes

Two approaches can be taken to protect catchments from water yield reductions that may result from higher water use in a regenerating eucalypt forest. Catchments can be quarantined from harvesting, thereby allowing the forest to continue to age with a consequently declining water use. Alternatively harvesting can be restricted to a small percentage of the catchment in any year, rotations can be increased and more frequent thinning regimes can be introduced. Both approaches are endorsed in Victoria, with the Otway FMA Forest Management Plan (DCE, 1992) prescribing harvesting levels allowed in proclaimed water supply catchments in the Otways. Harvesting is not permitted in Arkins Creek catchment, which is the most sensitive to changes in yield.

6.4 Audit of Compliance with Victorian Code of Forest Practices for Timber Production

Victorias' NRE has conducted an annual Audit of Compliance with the Code of Forest Practices for Timber Production since 1994, and the results of the 1996/97, 1997/98 and 1998/99 Audits have been published (NRE, 1997b; NRE, 1998; NRE, 2000). Each of these Audits targets 3-4 individual FMA's annually. The Otway FMA was audited as part of the 1996/97 Audit, and again it has been audited this year (the audit report has not yet been published). In addition it is understood that audits are also undertaken by Forests Victoria, but no audit reports have been obtained or sighted at time of writing. These Audits report compliance with a number of soil/water prescriptions imposed under the Code, and outcomes for the three published years are summarized in Table 6-1. Audit reports contain recommendations to address certain findings which are consolidated into an Audit Recommendation Management System.

■ **Table 6-1 Summary of Code compliance with soil and water prescriptions**

Principle	Measure	Audit Report		
		1996/97	1997/98	1998/99
1 - protection of streamside buffers	% of boundary edge intact	99.1	97.8	97.1
2 - protection of filter strips	% of boundary edge intact	98.5	96.8	94.7
3 - rehab. and location of landings	% fully rehabilitated	58.0	75.0	64.7
4 - rehab. of snig tracks	% fully rehabilitated	94.5	96.0	91.6
5 - rehab. of temporary roads	% fully rehabilitated	92.4	100.0	96.5
6 - rehab. of boundary tracks	% fully rehabilitated	89.1	81.0	95.4
12 - construct. and maint. of temp. roads	% of full compliance	88.2	90.0	63.5
13 - construct. and maint. of perm. roads	% of full compliance	n/a[1]	32.0	n/a[1]

[1] Not assessed

The 1998/99 Audit (NRE, 2000) concluded (in part) that:-

- "Streamside buffers and filter strips were very well protected during harvesting operations."
- "Rehabilitation of snig tracks, temporary roads and boundary tracks was very good. Rehabilitation was satisfactory for two thirds of all landings."
- "Construction and maintenance of temporary roads generally complied with prescriptions. However, significant lengths of road were affected by inappropriate road batters and inadequate drainage."

Somewhat similar conclusions could be drawn from the other Audits, but there has been some variation from year-to-year and FMA to FMA. Overall buffers and filters have been well protected, but the rehabilitation of landings and boundary tracks could be improved, as could the construction and maintenance of temporary roads.

The Audit procedure for permanent roads only applies to roads constructed since the introduction of the Code, and only to roads under the jurisdiction of NRE and not to the other permanent roads in the region. This has resulted in the Audit of only one permanent road in the three years, with an unsatisfactory audit outcome.

There exists no provision in the Code to bring the drainage of existing permanent roads constructed before Code implementation into line with current requirements, though it should be noted that when any "pre-Code" road is upgraded that the full standards of the Code are then applied. It is understood that at present NRE are prioritising a Statewide works program to upgrade all old roads to meet the Code standards. It is recognised that any upgrade works itself presents a sediment load hazard, and thus upgrading works should only be undertaken in cases where the sediment load under current conditions presents more of a hazard than the works required to upgrade it.

The 1996/97 Audit (NRE, 1997b) lists some issues specific to the Otway FMA, as follows:-

- There was some confusion surrounding the marking of stream buffer/filter boundaries. Staff were subsequently instructed to mark coupe features in the field so that marking was clear and unambiguous.

- Landing rehabilitation was found to be excellent and staff were informed of the high level of compliance.

- Construction and rehabilitation of temporary roads on erodible soils required attention. Staff were instructed to be aware of roading problems on highly erodible soils, but the availability of complete soils information was identified as a concern. The subsequent introduction of field assessment guides in connection with soil erosion hazard determination presumably provides better soils information now.

Given the role of forest roads in both the supply and delivery of sediment to streams, any shortfalls in the construction and rehabilitation of temporary roads assume considerable importance. Adequate drainage of all roads in the vicinity of drainage features is essential to the preservation of good water quality in managed forests.

6.5 Comparison of VIC and NSW soil/water BMPs

This section briefly compares the Victorian and NSW prescriptions backing the more essential soil/water BMPs, and examines the administrative framework behind the two sets of prescriptions. Victoria is compared with NSW as it could be argued that these two States both have similar objectives of achieving high standards and they have the longest history of forest BMP implementation in Australia. Major differences between the two approaches will be highlighted, particularly where BMP performance shortfalls appear possible.

6.5.1 BMP administrative framework – Victoria

The Code of Forest Practices for Timber Production (NRE, 1996) sets goals for soil/water (and other) objectives in all commercial timber production activities in Victoria, and provides guidelines for the achievement of these goals. Some key guidelines are also Statewide minimum prescriptions, but the bulk of the prescriptions are formulated locally (see Section 3.1) as site-specific BMPs. These site-specific BMPs are detailed in Forest Management Plans and Forest Coupe Plans.

Activities of the Victorian Department of Natural Resources and Environment (NRE) are not regulated, monitored or audited by any external authority. NRE does conduct an annual audit of compliance with the Code of Forest Practices for Timber Production, as discussed in Section 3.3 above. Compliance with the Code is a requirement of forest produce licences issued to Licensed Forest Operators, and compliance is monitored by authorized NRE officers. Non-compliance can result in the suspension, withdrawal or cancellation of licences.

Although there are two major (and numerous minor) water quality monitoring programs in Victoria, none appear to target forest streams or to be designed to provide feedback on the effectiveness of current forest soil/water BMPs. Local water supply authorities such as Barwon Water monitor water quality in streams in the Otway area, but sampling sites are generally well outside State forest and do not target forest operations.

6.5.2 BMP administrative framework – New South Wales

Most forestry activities carried out by, or on behalf of, State Forests of NSW (SFNSW) are regulated by external agencies. All activities in coastal native forests require an Environment Protection Licence from the NSW Environment Protection Authority (NSWEPA), as legislated in the Protection of the Environment Operations Act 1997. The licence states that:-

> "The objects of this licence are to require practical measures to be taken to protect the aquatic environment from water pollution caused by forestry activities and to ensure monitoring of the effectiveness of the licence conditions in achieving the relevant environmental goals. In formulating this licence, the environmental goals that have been adopted by the EPA for all forests in NSW are the *protection of aquatic ecosystems* and *primary contact recreation*."

The licence contains a large number of soil/water conditions and minimum prescriptions. These conditions and prescriptions have been listed in easier-to-read Forest Practices Codes for Native Forest Harvesting (SFNSW, 1998), and for Roads and Fire Trails (SFNSW, 1999) by State Forests NSW. Many conditions require local assessments to be made so that prescriptions become site-specific, as outlined below.

The licence requires that SFNSW carry out four separate assessments before assigning an overall erosion hazard to a compartment or section of road, as summarized below:-

"Three site and soil assessment protocols and one seasonality assessment are required, and have been developed for assessing the inherent sensitivity of a compartment or roading area to soil erosion and water pollution processes. The four assessments are:

1) inherent soil erosion and water pollution assessment;
2) mass movement assessment
3) dispersibility assessment; and
4) seasonality.

State Forests must apply all four assessments during the pre-operational planning phase which precedes the commencement of forestry activities."

Procedures detailed in the licence allow the formulation of site-specific conditions (BMPs) once these assessments have been completed. These BMPs are then included in a Harvesting Plan which is produced for each compartment.

The licence includes provision for a mandatory water monitoring program, which is essentially a paired-catchment quasi-research program. The original program (sampling over every storm with laboratory analysis for a number of parameters) proved to be ineffective and expensive. Many storms were not sampled because of equipment malfunction. At present the program is being modified by the inclusion of in-situ probes to measure turbidity and specific conductivity, and the generation and use of suspended sediment/turbidity relationships to estimate suspended sediment concentrations from turbidity. No sampled catchments have been harvested to date – all data from native forest streams is either pre-treatment or reference data at present.

All data must be regularly supplied to the NSWEPA, and an annual monitoring report must be compiled and submitted to the NSWEPA.

The monitoring report forms part of the reporting obligations of SFNSW under the licence. The obligations are:-

“State Forests must complete and supply to the EPA an Annual Return in the approved form comprising:

- Statement of Compliance;
- Operational & Complaints Summary; and
- Monitoring & Compliance Summary.”

The licence requires SFNSW to continue developing a soil and water training program for operators, supervisors and planners, and all persons verifying the soil regolith and detecting dispersible soils must be trained in those areas.

Compliance with the conditions of the licence is audited internally by SFNSW and externally by the NSWEPA. Non-compliance can result in the issue of a Pollution Infringement Notice by the NSWEPA, with an attached fine. Disputation over Notices may result in a court challenge.

6.5.3 BMP Comparison

This section attempts to make an objective comparison between the formulation by Victoria and NSW of certain essential BMPs. Differences, especially those occurring under identical site and harvesting conditions, will be highlighted and relevant comments made.

Table 6-2 Comparison of Victorian and NSW soil/water BMPs

BMP or Methodology	Victoria	NSW	Comment
Slope limitations to harvesting	Maximum 20^{o} – 30^{o} depending on hazard class and season.	Maximum 10^{o} – 30^{o} depending on inherent hazard. (For comparable erosivities 20^{o} -30^{o}).	NSW has a max. slope of 10^{o} for the highest rainfall erosivities. These erosivities do not occur in Vic.
Riparian protection	Buffer/filter strips vary from 10m to 40m either side of stream/water body and depend on stream class, slope and soil permeability.	Buffer/filter strips vary from 10m to 40m either side of stream/water body and depend on stream order and inherent hazard.	Terminology is reversed in NSW (NSW filter=Vic. buffer). No trees may be felled in or into filter strips in NSW, so strips are effectively wider with loss of resource.
Snig track drainage	Cross drain spacings vary with slope and soil erodibility. Minimum 5m for 25^{o}-30^{o} slope. Temporary crossing of drainage features permitted. Uphill snigging preferred.	Cross drain spacings vary with slope. Minimum 15m for 30^{o} slope. Temporary crossing of drainage features permitted. Uphill snigging preferred.	In NSW temporary crossings must be removed, and sediment control measures taken during construction. Soil stabilization is required near crossings.
Log landing location and use	Located >40m from permanent streams and >20m from temporary streams and drainage lines.	Located a minimum of 10m – 20m from a filter (Vic buffer) strip depending on inherent hazard.	Vic and NSW impose wet weather restrictions. Vic imposes seasonal closures. Both States rehabilitate landings.
Wet weather restrictions	Temporary suspensions in wet weather and seasonal closures in proclaimed water supply catchments.	Temporary suspensions in wet weather and seasonal closures depending on inherent hazard and rainfall erosivity.	Harvesting may be permitted in Vic during seasonal closures following an assessment of soil moisture.

Rehabilitation of disturbed areas	Various measures to rehabilitate tracks, landings and temporary roads.	Various measures to rehabilitate tracks, landings and temporary roads.	Rehabilitation outcomes are highlighted in Vic audits.
Road grades	Maximum grade depends on soil erodibility. Ruling grade max. of 7.5^o, short length grade max. of 10^o.	Maximum ruling grade 10^o, with short lengths up to 15^o.	NSW does not permit new roads to be built where side-slopes exceed 30^o, and the practice is avoided in Vic.
Road drainage	Spacing of drains etc depends on road grade and soil erodibility. Only applies to new roads.	Spacing of drains etc depends on road grade. Applies to all roads.	Vic and NSW spacing similar for low soil erodibility, otherwise Vic spacing less.
Road batters	Batter slopes vary according to soil type and rock stability. Batter stabilization and catch-drains may be required.	Batter stabilization and batter drainage (drop down structure and dissipater) may be required.	Batter rehabilitation (revegetation) may be required in both States.
Road crossings of streams and drainage lines	Crossings constructed for 1:20 yr storm (bridges) and 1:10 yr storm (culverts).	All crossings constructed to contain a 1:5 yr storm and withstand a 1:10 yr storm.	Vic requires road surfacing in the vicinity of bridges, and the diversion of road runoff in the vicinity of streams is normal practice. NSW requires roads be drained 5m-30m from crossings, and 20m of road surfacing around all crossings in dispersible soil types.
Road closures	Roads are to be closed when no longer required, drained and rehabilitated.	Roads are to be closed when no longer required, drained and rehabilitated.	Both States have a policy of closing roads and reducing the native forest road network.
Assessment of soil erosion hazard	Site-specific soil erosion hazard and soil permeability assessments are determined from rainfall erosivity, slope, soil properties and the capacity for revegetation (NRE, 1999).	A site-specific soil erosion and water pollution hazard is determined from rainfall erosivity, slope and soil regolith stability, with an overlay of harvesting intensity and extraction method.	Although based on accepted methodology, the NSW assessment system is somewhat subjective and very precautionary. The Vic system may give better site-specific information. NSW has much higher rainfall erosivities.
Assessment of mass movement hazard	No published procedure but Code requires that roads avoid landslip-prone areas.	Procedure involves using available information, field assessment and air photo interpretation.	Mass movement is an important consideration in steep country, and a standardized assessment would benefit Vic.
Practices to minimise water yield changes	Quarantines some catchments from harvesting, and restricts harvesting and changes rotation lengths and thinning schedules in others. Estimates yield changes using models.	Restricts harvesting and changes rotation lengths and thinning schedules in certain catchments. Estimates yield changes using models.	The long-term effects of ongoing harvesting and regeneration on water yields in mixed-species mixed-age eucalypt forests remain largely unquantified. Models that estimate long-term yield change with tree age can only be verified by further data from long-term catchment research.

6.6 Conclusions

6.6.1 BMPs Implemented in the Otways

- The suite of BMPs implemented in the Otways as measures prescribed under the Code of Forest Practices for Timber Production (NRE, 1996) are generally in line with equivalent soil/water BMPs implemented elsewhere in Australian forests.

- While the Code of Forest Practices for Timber Production (NRE, 1996) covers a raft of measures required in relation to the construction, drainage and maintenance of new permanent roads, the measures are not applicable to roads existing before the imposition of the Code unless they are upgraded. The decision whether or not to upgrade a road should balance the risks between the environmental hazards imposed by the upgrading works and the ongoing risks associated with leaving the road in its current condition.

- Mass movement and landslips are common soil erosion processes in steep, moist forests. The Otways have been recognised as landslip-prone and the Code of Forest Practices for Timber Production (NRE, 1996) and the regional prescriptions contain measures to minimize soil erosion and the potential for mass movement. However, there is no standardized procedure for identifying, or responding to, mass movement hazard. Prescribed use of a standardized procedure may result in better road and track location and construction, with reduced landslip risk, particularly near streams.

6.6.2 BMP Administrative Framework in Victoria

- The various tiers of soil/water BMP development, and implementation, in Victorian State forests (Code Goals and Guidelines, FMA Forest Management Prescriptions, Forest Coupe and Road Plan Prescriptions) deliver scientifically based site-specific BMPs without external regulation or cumbersome administration.

6.6.3 BMP Audit and Monitoring in Victoria

- The internal Audit of Compliance with the Code of Forest Practices for Timber Production (NRE, 1996) covers the principal soil/water BMPs. While cost is an obvious consideration for the Audit program, a case could be put for more frequent audits of all FMA’s to better measure trends and track the outcomes of recommendations.

- The current Audit procedure only tests for compliance with the Code. This results in the erosion status of pre-existing permanent roads (see 3.5.1 above) being excluded from audit.

- Experience elsewhere has shown that the detection of statistically valid trends in water quality or yield, that have been wholly the result of forest management, is impossible without expensive, long-term research. The present water quality monitoring programs in the Otways are unlikely to provide much information on the effectiveness of current BMPs. Detailed demonstration/observation studies of the effectiveness of BMPs such as the Sayers Track study in the Otways (Sheridan and Lane, 2000a) are likely to be more cost-effective.

6.6.4 Research into BMP Effectiveness in Victoria

- There has been no coordinated research program to assess the effectiveness of forest BMPs in Victoria. Such programs tend to be expensive because of logistic, replication or climatic factors. Nevertheless some program to assess whether BMPs are effective, ineffective or over-precautionary should be part of forest management. Demonstration/observation studies such as that on Sayers Track in the Otways (Sheridan and Lane, 2000a) can be very useful in this regard.

- Changes in water yield with forest age may have important implications for water supplies sourced from some forested catchments. Research, which underpins the present modeling of these changes, is limited to a small number of forest types and is of necessity long-term. A better understanding of important processes and more accurate modeling will result from future data from the current forest hydrology research catchments in Victoria, NSW and WA.

7. Impacts of Logging on Water Yield

7.1 Context of modelling

The effect of logging on stream flow volume was a primary concern of the Otway Forest Hydrology project. The SKM team adapted an approach already used in NSW State Forests (SKM, 1998) to address this concern. The initial intention was to provide indications of the possible effects of logging on stream flow and to highlight where the input data sets were weakest.

Five catchments were selected for analysis and these are shown in Figure 7-1. Two catchments (East Barwon, Arkins) were used to test development of forest stream flow models, the approach was applied to the remaining three catchments (West Barwon, St George, Greater Arkins). These three catchments represent the Barwon River basin, coastal river systems and the Gellibrand River basin respectively, thus addressing the concerns of the Otway Forest Hydrology Reference Group.

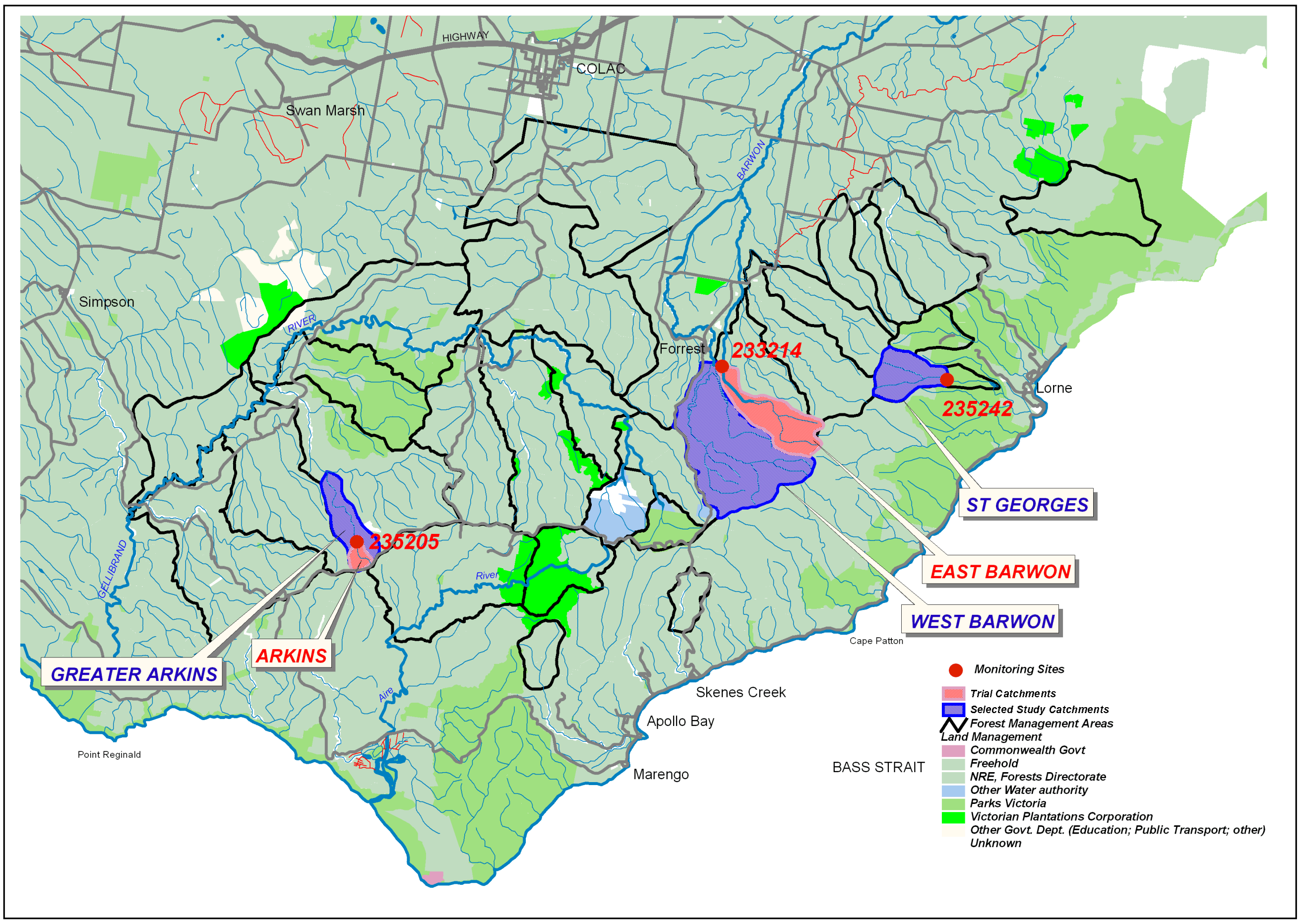


Figure 7-1 Map of the area showing the catchments studied.

The primary inputs for land use identification came from a version of the State-wide Forest Resource Inventory (SFRI) provided by the Forest Information group (M. Sutton) of the Dept. for Natural Resources and Environment (DNRE). The interpretation of these data sets was aided by a number of DNRE staff and is explained in the following section.

Rainfall for the catchments was calculated using a GIS layer provided by Colac-Otway Shire (Dalhaus et al, 2000). Unfortunately this rainfall information did not extend to the St. George catchment and therefore it was necessary to use a much coarser resolution rainfall layer (Bureau of Meteorology, 1998) for this catchment.

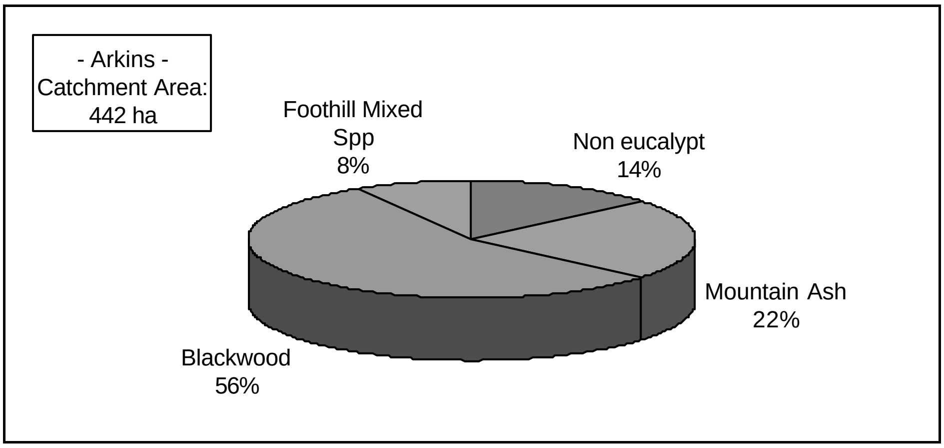
Other important inputs included stream flow and rainfall records from a number of gauges across the Otway Ranges. A full list of data sources provided to this study is listed in Appendix C.

7.2 Interpretation of SFRI data

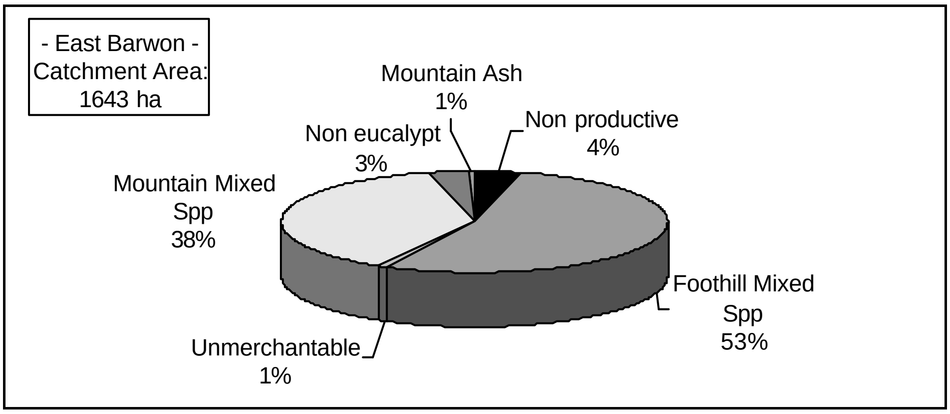
The interpretation of State-wide Forest Resource Inventory (SFRI) data used in this study is summarised in Tables 6-1 and 6-2. Figures 6-2 to 6-6 show the distribution of forest types listed in Table 7-1 for the five catchments.

■ **Table 7-1 Forest types in the Otways (from SFRI).**

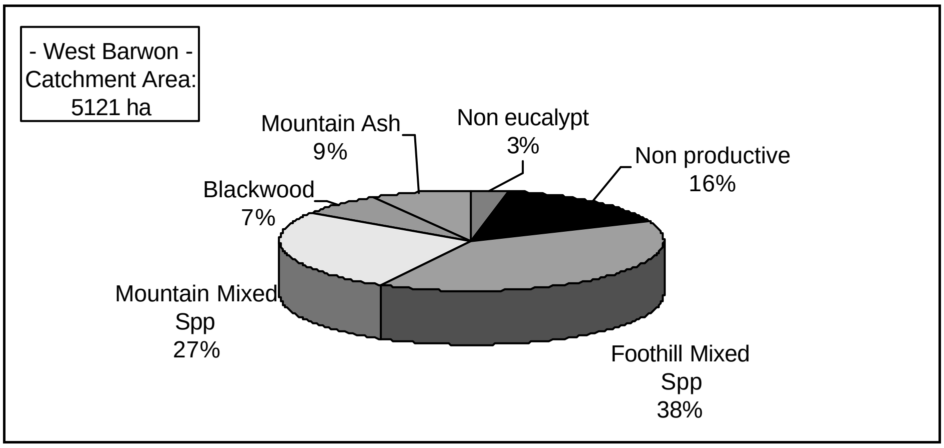
Type	Description
Mountain Ash	Forest predominantly of mountain ash species
Mountain Mixed Species	Mixed species forest including mountain ash and messmate
Foothill Mixed Species	Mixed species forest in lower altitude (and rainfall) zones
Unmerchantable	Non-productive eucalypt forest that may be improved with silvicultural treatment
Unproductive	Non-productive eucalypt forest that can not be improved with silvicultural treatment (short, stunted forest in low rainfall zones and on grey sandy loams)
Blackwood	Wattle – acacia species – often appears as regrowth on abandoned farm land (reaches maturity at about the same age as mountain ash) High value timber – logging licences issued for Blackwood.
Non-Eucalypt	Anything other than eucalypt species, could include farm land, softwood plantation



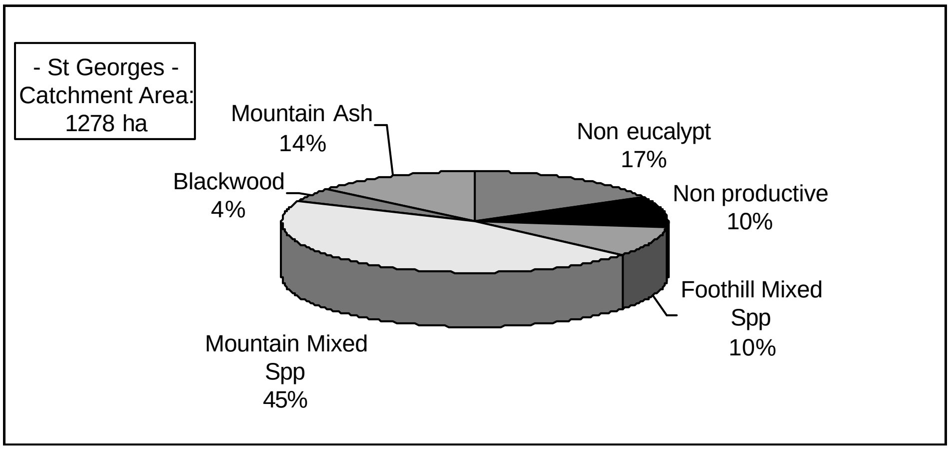
■ **Figure 7-2 Species composition for Arkins catchment**



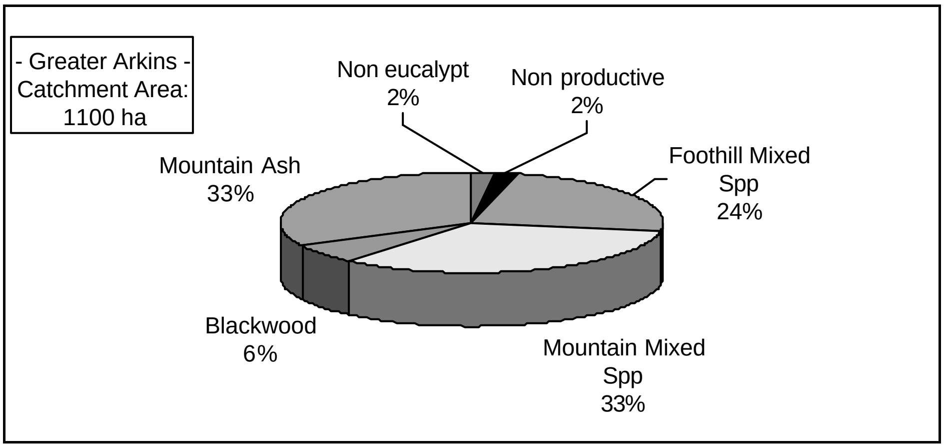
■ **Figure 7-3 Species composition for East Barwon catchment**



■ **Figure 7-4 Species composition of West Barwon catchment**



■ **Figure 7-5 Species composition St George catchment**



■ **Figure 7-6 Species composition Greater Arkins catchment**

It should be noted that the Arkins catchment is a sub-catchment of the Greater Arkins, however all modelling done on the Greater Arkins excluded the Arkins catchment. For example the percentage areas shown in Figure 7-6 refer to the Greater Arkins catchment excluding Arkins (shown in Figure 7-2).

Tree age information is not available for areas considered to be non-eucalypt, blackwood, unproductive or unmerchantable. It is assumed that stream flow from these areas does not change with time.

■ **Table 7-2 Forest age classifications used in the SFRI and forest age in years used in this study for three forest types (Mountain Ash, Mountain Mixed Species, Foothill Mixed Species):**

Classification	Age in year 2000 (years)	Description
1890s regrowth	110	
1920s regrowth	80	
1940s regrowth	60	
1950s regrowth	50	
1960s regrowth	40	
1970s regrowth	30	
1980s regrowth	20	
1990s regrowth	10	
Regrowth (age unknown)	60	Anywhere from 20 to 60 years old, may be as old as 80 years. Regrowth crown shape
Early Mature	100	
Mature	150	Could range from 80 years to 250 years
Late Mature	200	
Overmature-Mature	300	250-350 years old
Overmature-Other	300	250-350 years old
Scenescent	300	>= 250 years old
Uneven Aged	50% at 60 years 50% at 150 years	Partial mortality due to fire in mixed species forests, we assume that this classification was generated by the 1939 fires
Unstocked	- No attributed age	Eucalypt area unstocked with eucalypt (usually as a result of successive fires over a short period e.g. 1919 and 1926 or 1939), may have blackwood, may have other scrub. This area would be eucalypt if re-seeded. This age classification is a very small fraction of the studied catchments and this area has been ignored. In future, development of unstocked areas could be considered to be reafforestation and this might have an important effect on yield changes where unstocked areas are significant.

7.3 Stream Flow Response Curves

7.3.1 Summary of the modelling approach

Two forest types in the Otways are characterised below in terms of their stream flow response to forest logging or wildfire. These two are the mountain ash forest and the mixed species forest (including both mountain and foothill mixed species forest).

The modelling approach considers one forest type at a time. A forest is divided into 10000 units each of the same area but of independent forest age. The contribution to stream flow from a forest unit is assigned on the basis of forest age using a stream flow response curve. Logging and fire affect the distribution of forest ages and hence stream flow. Thus a forest is represented as a mosaic of units each with its own age and associated streamflow.

Streamflow response curves represent the change in catchment streamflow expected in the years following logging or wildfire, assuming complete forest clearance and then subsequent regeneration of a mature forested catchment. The method also assumes that annual rainfall is constant throughout the modelling period. Thus a streamflow response curve has an associated rainfall. The procedure used to apply the streamflow response curve to another catchment with a different rainfall is described below in Section 7.3.2.

It was assumed that both Mountain Ash and Mixed Species forests reach maturity at an age of 150 years in terms of their stream flow response.

7.3.2 Adjustment of Stream Flow Response Curve for Rainfall

In past forest hydrology projects conducted by Sinclair Knight Merz, adjustments for differences in rainfall between catchments have been made using the ratio of the mean annual rainfall for the catchment being modelled divided by the mean annual rainfall associated with the streamflow response curve.

In the Otway Forest Hydrology project a possible improvement to this former approach was considered using a relationship between mature forest water use (E_{forest}) and rainfall (R) developed by Zhang et al. (1999) that built on earlier work by Holmes & Sinclair (1986). This generalised relationship is given in Equation 6.1 and is assumed to be applicable to all forest types.

$$E_{forest} = \frac{R + 2800}{1 + \frac{2800}{R} + \frac{R}{1400}} \qquad (6.1)$$

To apply this information a direct relationship is assumed between forest water use and streamflow (S), that is when the forest water use increases the stream flow decreases by the same amount (Equation 6.2).

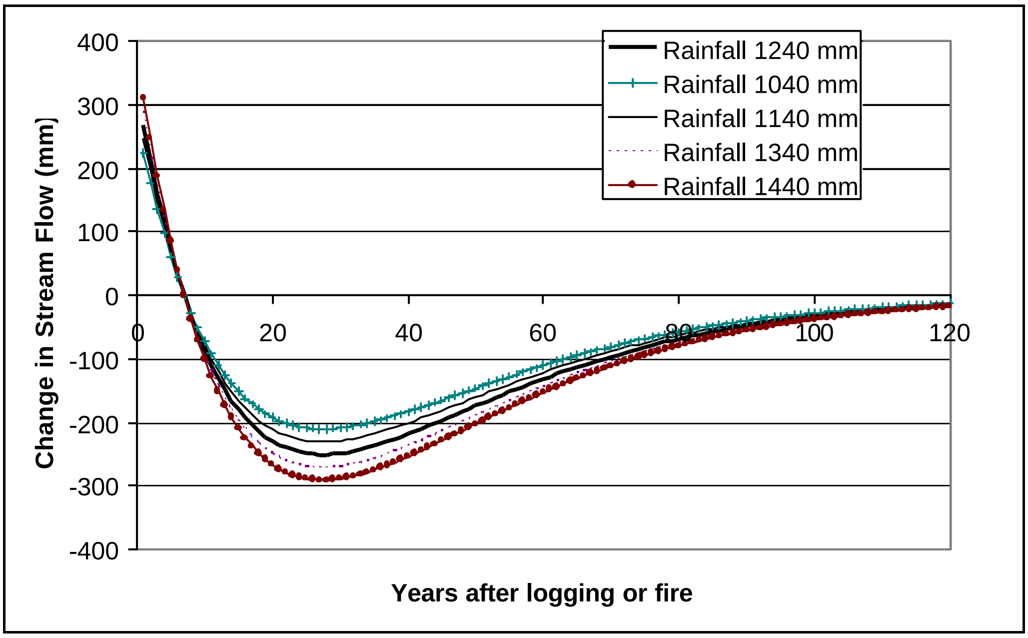
$$S = R - E_{forest} \qquad (6.2)$$

Using Equations 6.1 and 6.2 the ratio used to adjust stream flow response for rainfall is therefore: (S at catchment rainfall) / (S at the rainfall associated with the curve).

This adjustment ratio was tried and subsequently rejected for use in the Otway Forest Hydrology project for the following reasons:

- The increases and decreases in streamflow during the first 50 years after logging were found to be greater for Mixed Species forest than for Mountain Ash forest when both were adjusted to the same rainfall. (For example with a rainfall of 1426 mm the maximum decrease in stream flow relative to mature forest yield would be 343 mm for Mixed Species forest and 259 mm for Mountain Ash forest using Equations 6.1 and 6.2.) This did not agree with current understanding of forest hydrology in the Otway Ranges.
- There were theoretical inconsistencies in the modelling approach when this ratio was used. The non-linearity in the adjustment for rainfall could cause different streamflow estimates for a forest depending if it was modelled as two independent halves or modelled as a whole catchment.

Because of these issues, the adjustment to streamflow response curves was undertaken using the ratio of the mean annual rainfalls rather than using Equations 6.1 and 6.2. Using this ratio a streamflow response curve can be adjusted for forests of different mean annual rainfalls. This is demonstrated in Figure 7-7 where the family of curves has been adjusted from the curve drawn with the bold line (representing a mean annual rainfall of 1,240 mm). Each curve would be appropriate for a forest of a given type with an areal average rainfall equal to that shown.



■ **Figure 7-7 Adjustment of streamflow response curves for mean rainfall**

7.3.3 Mixed Species Forest

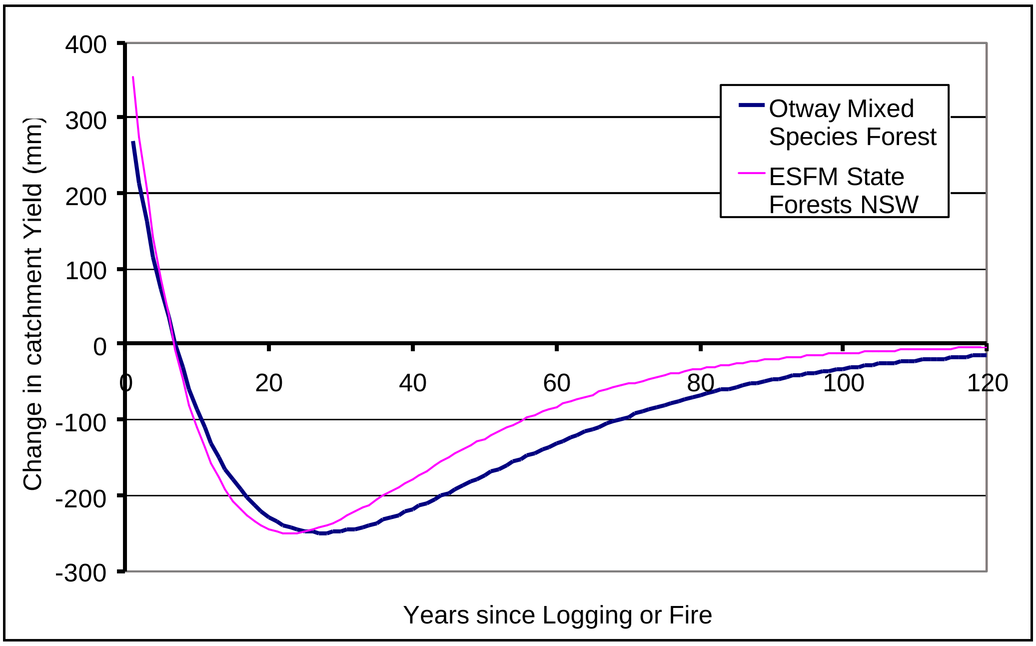
For mixed species forest the primary inputs were:

(i.) work undertaken for the NSW Ecologically Sustainable Forest Management Group (SKM, 1998);

(ii.) streamflow measurements from the East Barwon catchment.

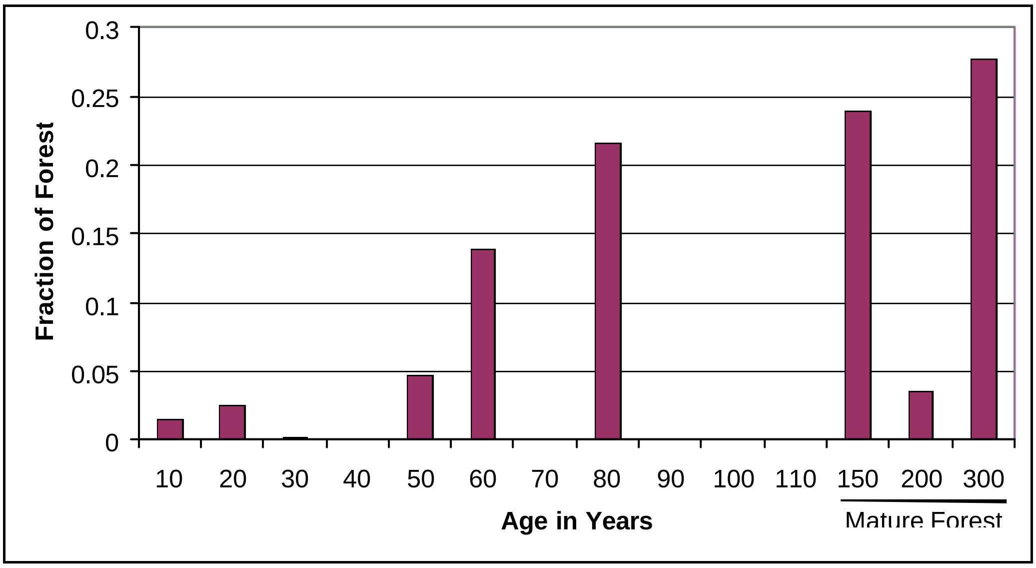
The East Barwon catchment is 91% mixed species forest (including both mountain and foothill types, see Figure 7-3). It has a long annual stream flow record and therefore provides an opportunity to test the application of the response curve for this forest type. The mixed species forest within the East Barwon catchment has a mean annual rainfall of 1240 mm.

The starting point for estimating the streamflow response curve was the curve used for mixed eucalypt State Forest in southern NSW at an annual rainfall of 1000 mm (SKM, 1998). Although the annual rainfall is higher in the East Barwon catchment it is expected that the shallow soil depths seen in the Otways would result in similar magnitude responses to logging. Thus the maximum yield decrease relative to mature forest is unchanged at 250 mm. The time taken to reach the maximum decrease was changed from 23 to 27.4 years to bring it in closer agreement with mountain ash forest. Differences in climate between NSW and the Otways, particularly temperature, support this change. It is also expected that smaller magnitude changes in stream flow are expected for mixed species forest than for mountain ash forest (presented in Section 7.3.4). The stream flow response curve for Mixed Species Forest in the Otway Ranges is shown in Figure 7-8.



■ **Figure 7-8 Stream flow response curve for mixed species forest in the East Barwon catchment (rainfall = 1240 mm). Also shown is the response curve used for eucalypt State Forest in Southern NSW (SKM, 1998).**

Other inputs required to estimate stream flow in the East Barwon catchment between 1956 and 1998 are the initial forest age distribution and when and where logging occurs. These inputs were calculated from the forest age distribution in 2000 shown in Figure 7-9.



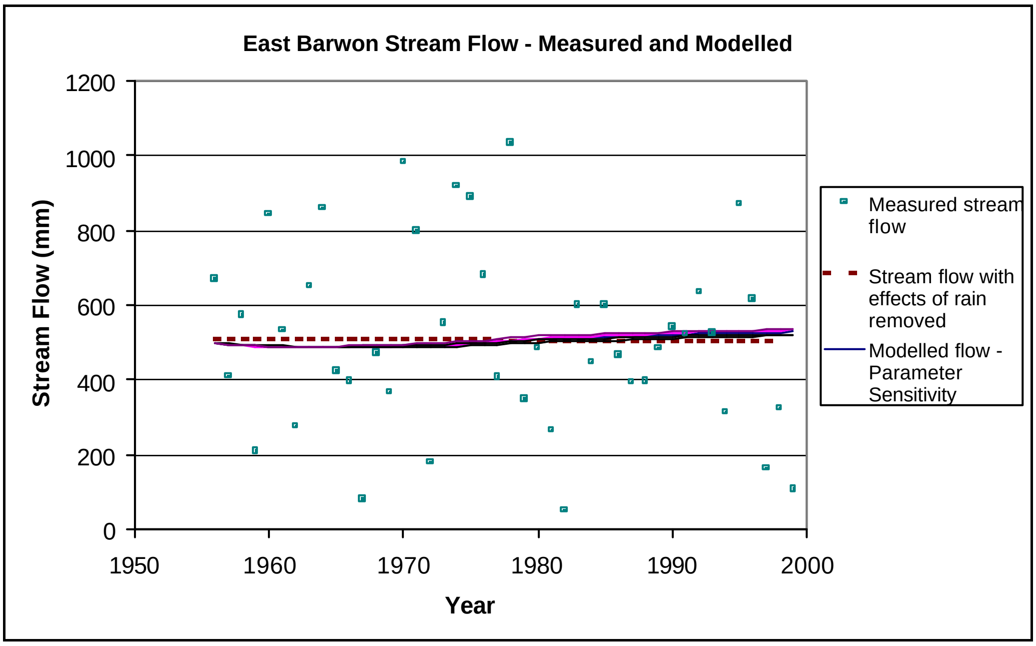
■ **Figure 7-9 Mixed Species forest age distribution for the East Barwon catchment in 2000.**

To investigate how sensitive the yield response in the East Barwon catchment is to parameter values of the stream flow response curve we evaluated the effects of both an increase and decrease of 20% in:

- the maximum yield decrease and;
- the time taken to reach the maximum decrease.

This family of curves and the measured stream flow data for the East Barwon catchment are plotted as a time series in Figure 7-10. Also shown in Figure 7-10 is an estimate of changes in stream flow with annual variation in rainfall removed, this estimate showed no statistically significant trends with time. In other words if the variations in stream flow due to rainfall are removed, the stream flow can be considered to be constant over the measurement period (1956 to 1998).

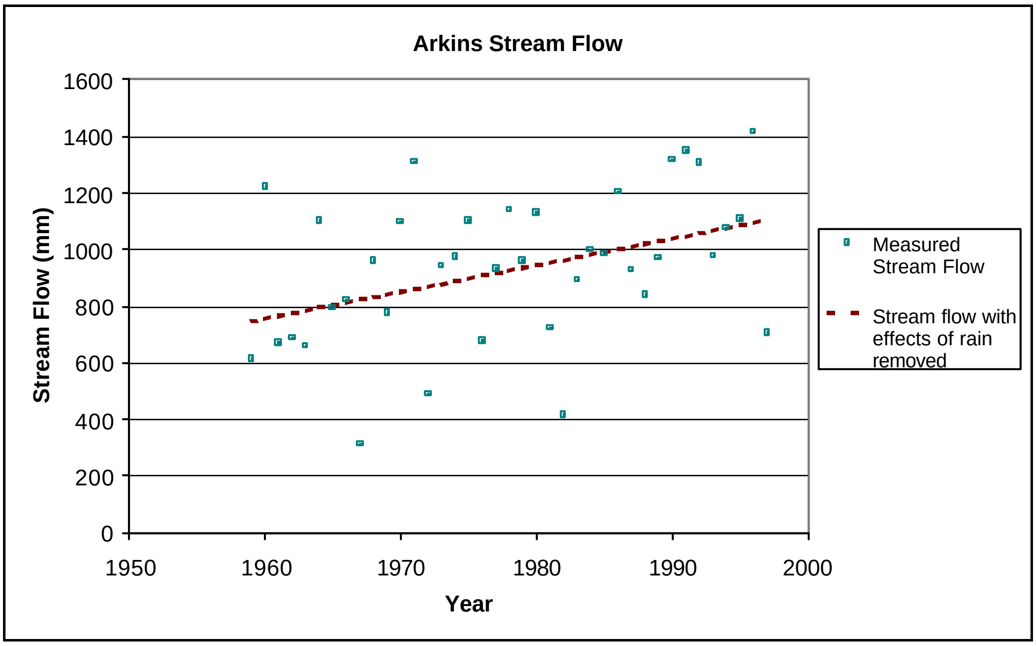
The stream flow response generated by the modelling approach is in good agreement with a prediction of little stream flow change over the measurement period. It is also apparent that the stream flow response is not greatly sensitive to 20 % changes in the parameters (as described above). The result supports use of the curve shown in Figure 7-8 for Mixed Species forest in the Otway Ranges although some uncertainty of parameter values remains.



■ **Figure 7-10 Measured and modelled stream flow in the East Barwon catchment. Annual stream flow is shown as points; the dotted line shows the linear trend in stream flow with variation in annual rainfall removed (not significant); and the family of curves plotted as thin lines shows the sensitivity of the modelled stream to variation of salient parameters by 20 %.**

7.3.4 Mountain Ash Forest

It was intended to test our stream flow response curve for Mountain Ash forest against flow measurements in the Arkins catchment. Originally it was believed this catchment had a high proportion of Mountain Ash forest but once detailed information was available it became evident that this was not the case. An accurate interpretation of the information revealed that the catchment was more than half Blackwood (Figure 7-2) and therefore little use for testing the stream flow response curve for Mountain Ash. However the stream flow showed a significant increase of about 350 mm between 1959 and 1997 when the effects of rainfall variability had been removed (Figure 7-11). This is consistent with a maturing forest (of Mountain Ash and Blackwood) that would have regenerated after the 1939 fires or following abandonment of farm land prior to 1939. The increase in stream flow is unlikely to continue beyond the 1100 mm in 1998 because catchment rainfall is estimated at 1780 mm and annual forest water use would be expected to be 700 mm or greater (see Zhang et al., 1999).



■ **Figure 7-11 Stream flow in the Arkins catchment**

The sources of information available to develop a stream flow response curve for mountain ash forest in the Otways were:

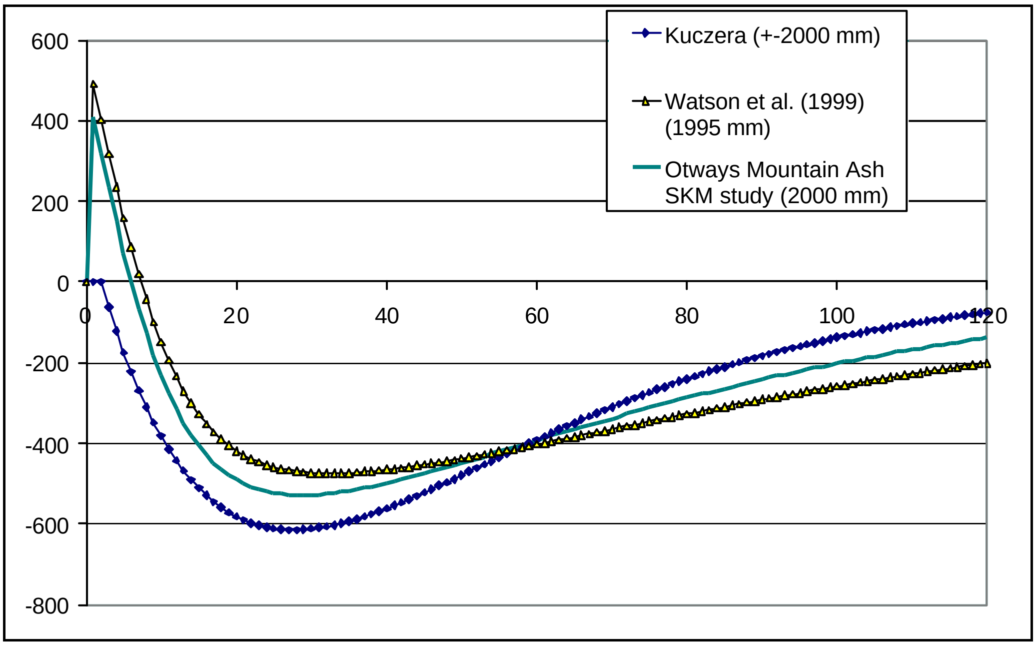
(i) Kuczera's original study of Mountain Ash forest in the Maroondah catchments (Victorian Central Highlands);

(ii) Watson et al. (1999) study of Mountain Ash in the Maroondah catchments;

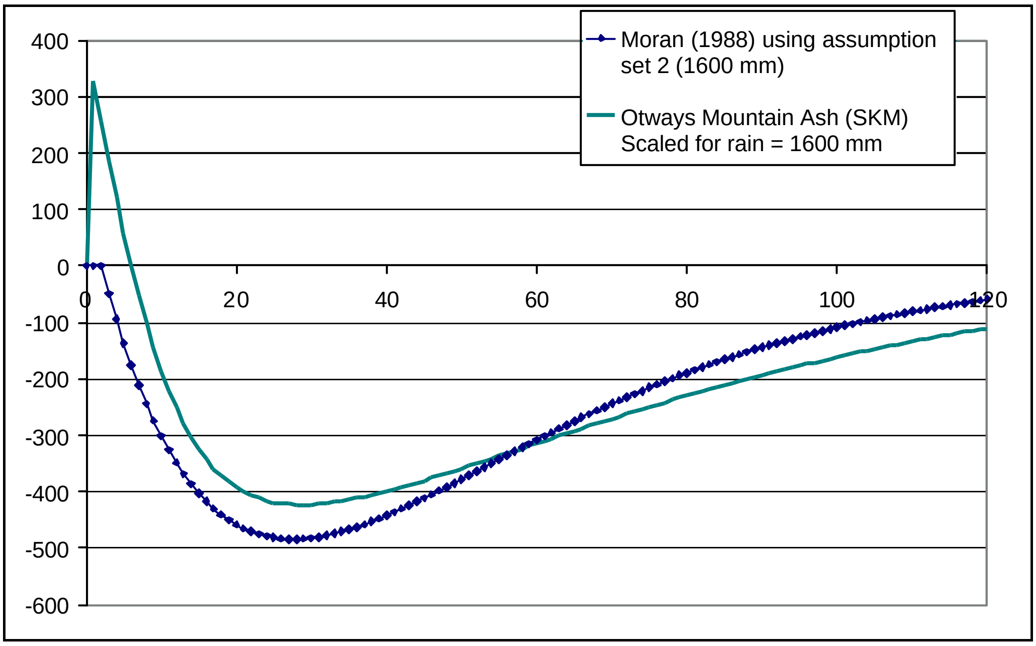
(iii) Moran (1988) study of Mountain Ash in the Otways.

A stream flow response curve was fitted by eye to information sources 1) and 2) (Figure 7-12) and then checked against source 3) (Figure 7-13). There is considerable uncertainty about the annual rainfall attributable to the Maroondah catchments studied in sources 1) and 2), a value of 2000 mm was used here (see Watson et al., 1999 and Moran, 1988). In Figure 7-13 the fitted curve from Figure 7-12 was adjusted for a catchment rainfall of 1600 mm as described in Section 7.3.2.

In addition to Figures 6-12 and 6-13, the stream flow record from the Arkins catchment (Figure 7-11) is not inconsistent with our stream flow response curve for Mountain Ash. In the absence of further information, the curve in Figures 6-12 and 6-13 is adopted for Mountain Ash in the Otways.



■ **Figure 7-12 The stream flow response curve for Mountain Ash forest was fitted by eye to the two other curves shown in this Figure.**



■ **Figure 7-13 Comparison of the stream flow response curve for Mountain Ash forest used by Moran (1988) and used in this study. The curve shown in Fig. 2-4 has been scaled for a rainfall of 1600 mm.**

7.4 Yield Response Results

In Section 7.3, stream flow response curves were developed for Mountain Ash Forest and Mixed Species Forest in the Otways using information from the East Barwon and Arkins catchments. Below, we use these curves to model the effects of logging and wildfire on catchment water yield for the West Barwon, St. George and the Greater Arkins catchments (Figure 7-1).

7.4.1 Use of Mean Annual Rainfall

The Otway Forest Hydrology project aims to consider the effects of logging on stream flow. The mean annual rainfall for a catchment is assumed to occur every year and the results of this study show the stream flow response to this rainfall as influenced by the forest age distribution. The forest age distribution is affected by logging operations and fire. The assumption of a constant mean annual rainfall will reveal the effects of logging most clearly.

However, the most important factor affecting stream flow is annual rainfall as seen clearly in Figure 7-10. Annual variations in rainfall are likely to mask the effects of logging if logging occurs in less than 15% of catchment area per decade (as it does in this study). A comprehensive study of the combined effects of annual rainfall and logging is beyond the scope of this project. For example, the effects of logging on stream flow in a very dry year are not estimated. An indication of the range of possible effects of logging on low flows (and high flows) is given in the literature review.

7.4.2 Scenario Modelling

Catchment stream flow was simulated for 100 years under the following three scenarios:

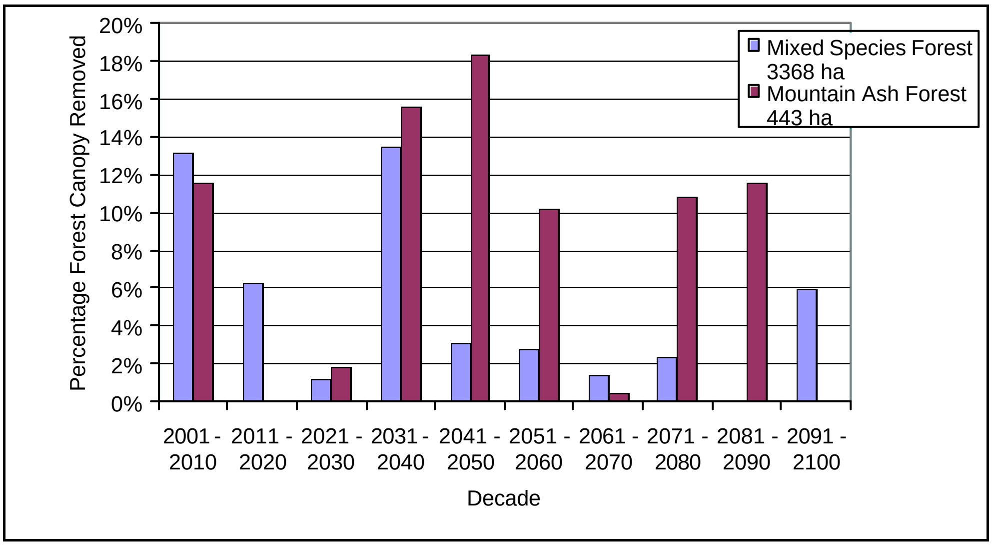
(i) *No disturbance*. In this scenario no logging, fire or other disturbance occurs and the forest is allowed to age from the age distribution in the year 2000;

(ii) *Logging only*. The forest area logged in a particular forest type and age class was provided by DNRE. These areas were calculated using the constraints of: (a) consistent with RFA outcomes; (b) the logging rotations specified in the Otway Forest Management Plan; and (c) the need to maintain a timber yield that varies as little as possible over the period for both Ash and Mixed Species.;

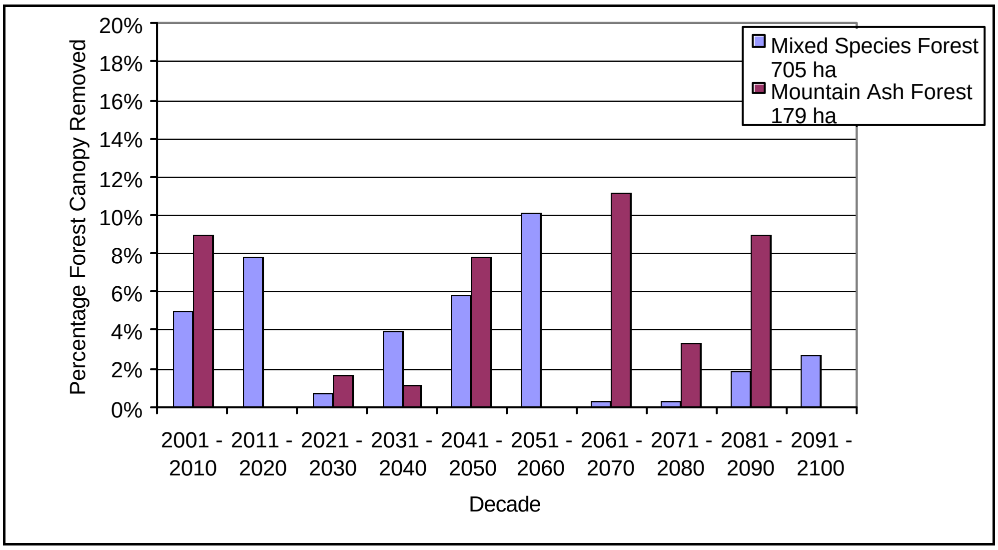
(iii) *Wildfire only*. Complete mortality of 50 % of the catchment by fire at the beginning of the 100 years, with no logging or other disturbance.

The 'logging only' scenario is summarised for the three catchments in Figures 6-14, 6-15 and 6-16 that show the percentage area of a particular forest type logged by decade over the 100 year period. In the case of Greater Arkins, the logging scenarios were provided for the 'Carlisle River' forest management catchment of DNRE. Carlisle River is a larger area including the Greater Arkins catchment. Logging scenarios were developed on the basis of percentage of Carlisle River forest within the Greater Arkins catchment. Both forest type and age were used to calculated these percentages.

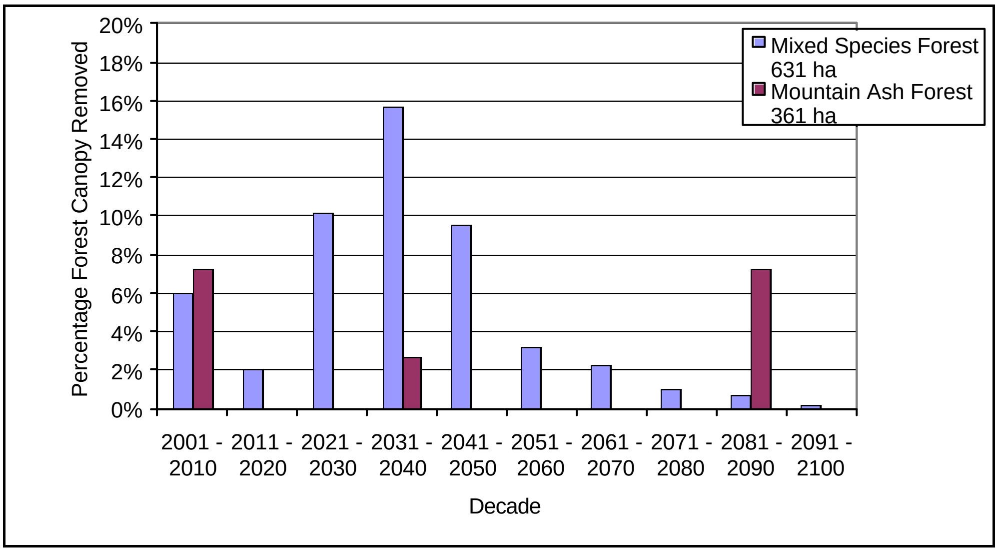
To model the effects of wildfire and tree mortality in half of the catchment, more than half of the Mountain Ash and Mixed Species forest area was modelled as destroyed by fire (see Figures 6-4, 6-5 and 6-6). It was assumed that equal percentages of forest type and forest age were destroyed. As in all simulations, the other 'forest types' listed in Table 7-1 were assumed to have a constant and unchanging stream flow yield. While it is recognised that Mountain Ash forest and Mixed Species forest may be affected in different ways by fire these differences are not considered explicitly in this study. The approach to estimating stream flow would not distinguish between a fire that caused 100 % mortality in half of the catchment and another fire that caused 50 % mortality across the whole catchment.



■ **Figure 7-14 Percentage forest canopy removed by logging in 'Logging Only' Scenario for West Barwon**



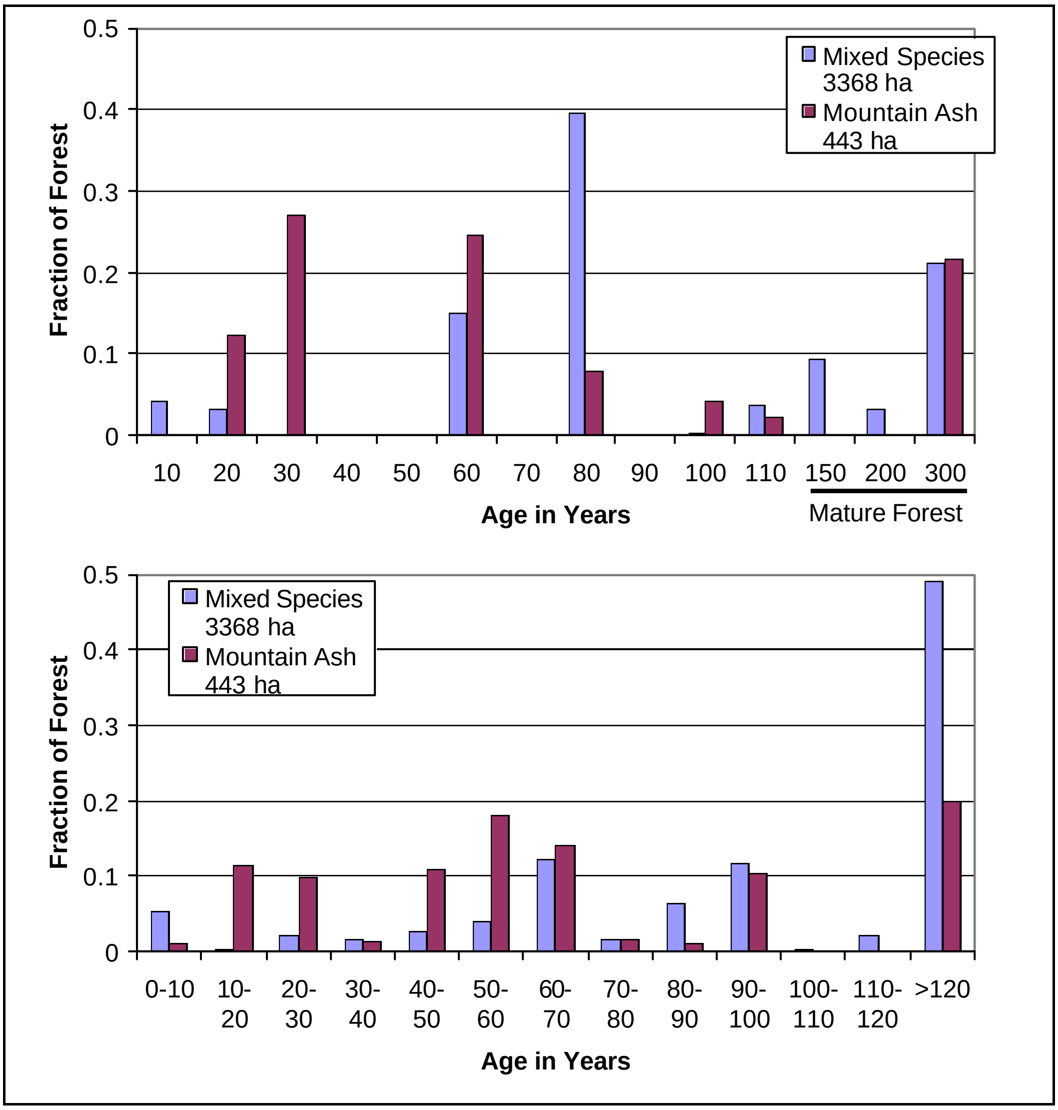
■ **Figure 7-15 Percentage forest canopy removed by logging in 'Logging Only' Scenario for St George**



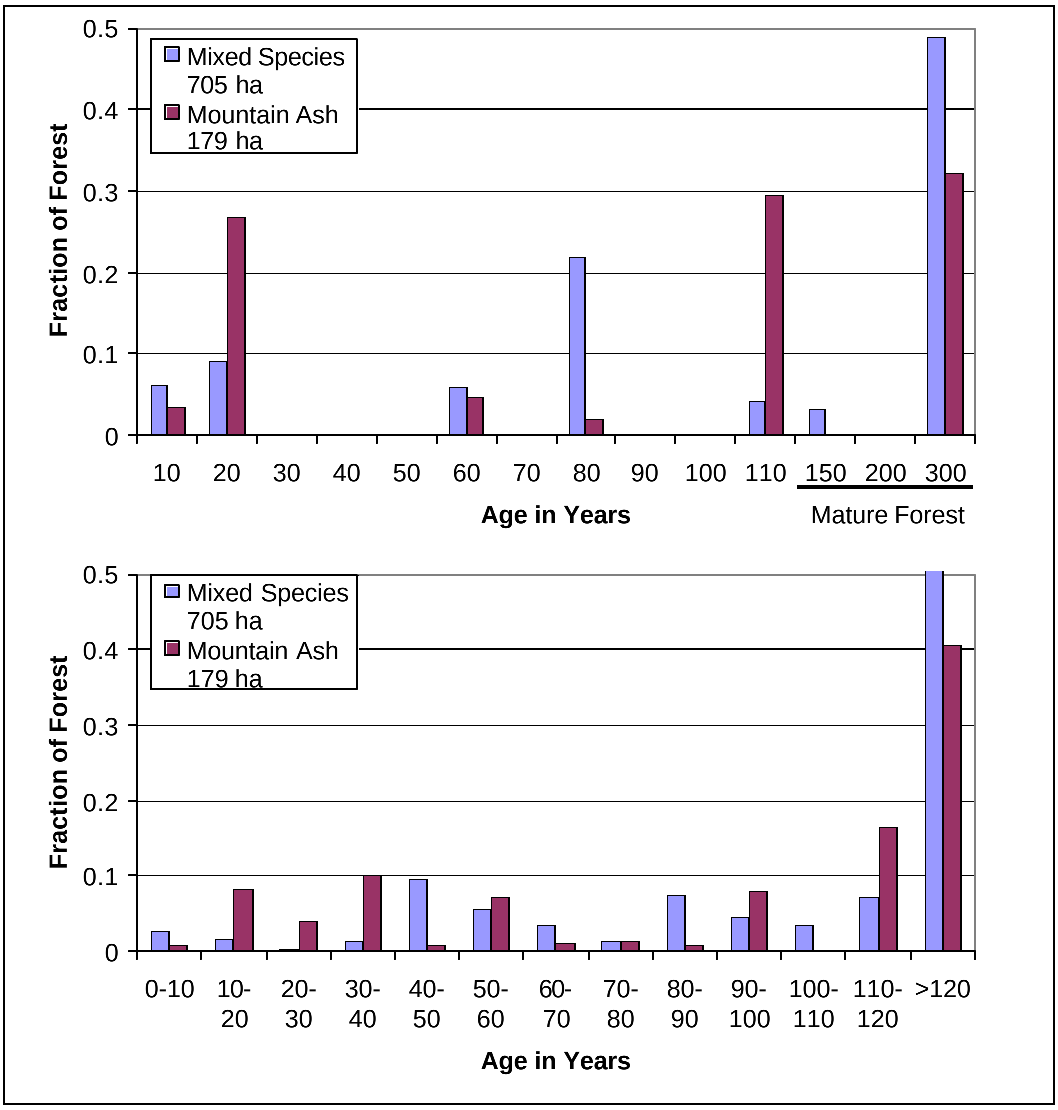
■ **Figure 7-16 Percentage forest canopy removed by logging in 'Logging Only' Scenario for Greater Arkins**

An important input to the forecast modelling is the current forest age distribution in the year 2000. Forest ages were estimated from the SFRI data as summarised in Table 7-2. The forest age distributions in the year 2000 and after 100 years of the 'logging only' scenario are given in Figures 6-17, 6-18 and 6-19.

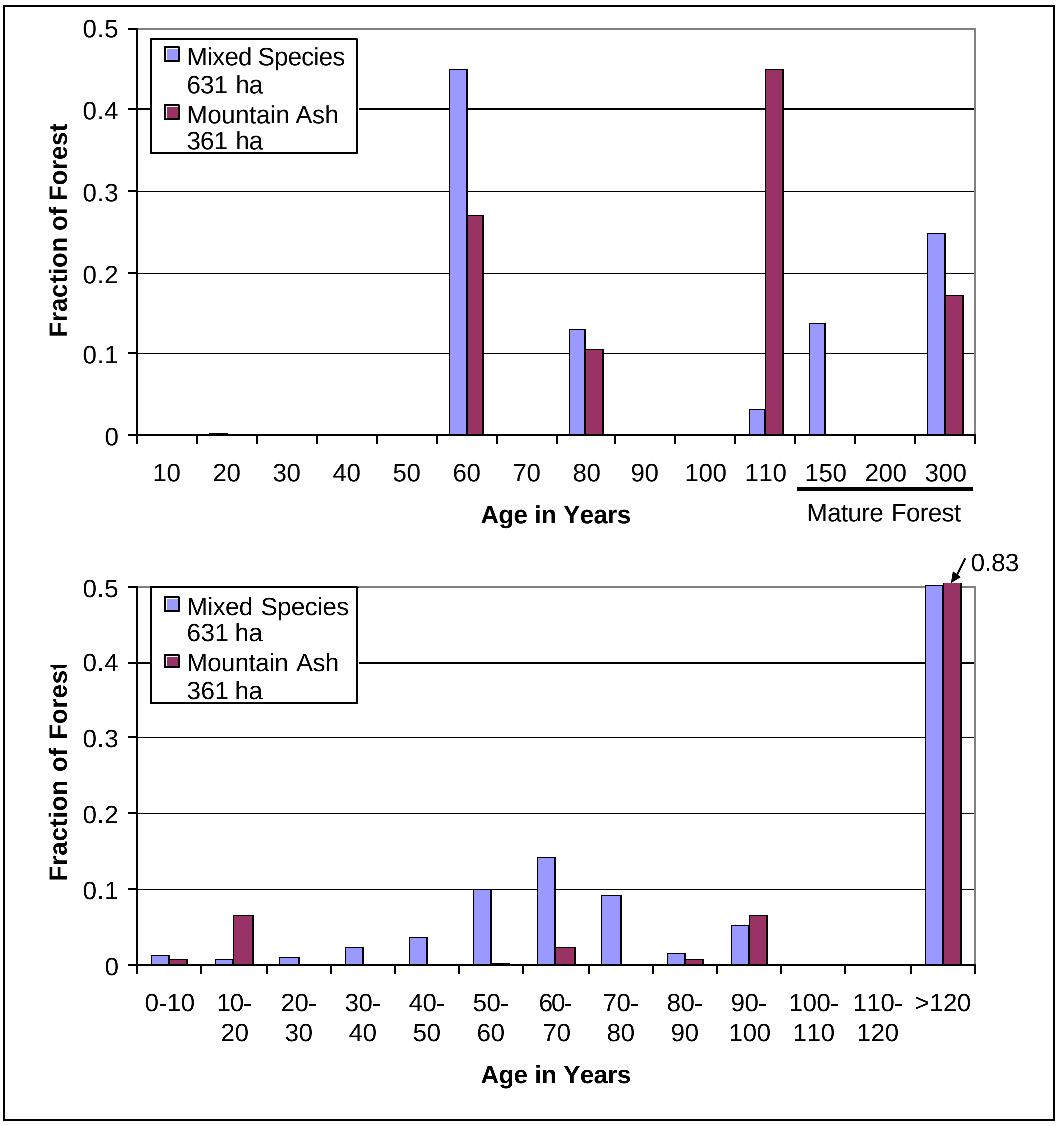
The stream flow results for the three catchments are given in Figures 6-20 to 6-22. The top panels of these figures show the changes in stream flow over the next 100 years relative to stream flow in the year 2000 (assuming mean annual rainfall). Each figure shows the results of all 3 scenarios (no disturbance, logging only and wildfire only) for one of the catchments. The lower panels in Figures 6-20 to 6-22 are similar to the top panels but show the difference in stream flow resulting from scenarios 2 and 3 relative to scenario 1 on a year by year basis.



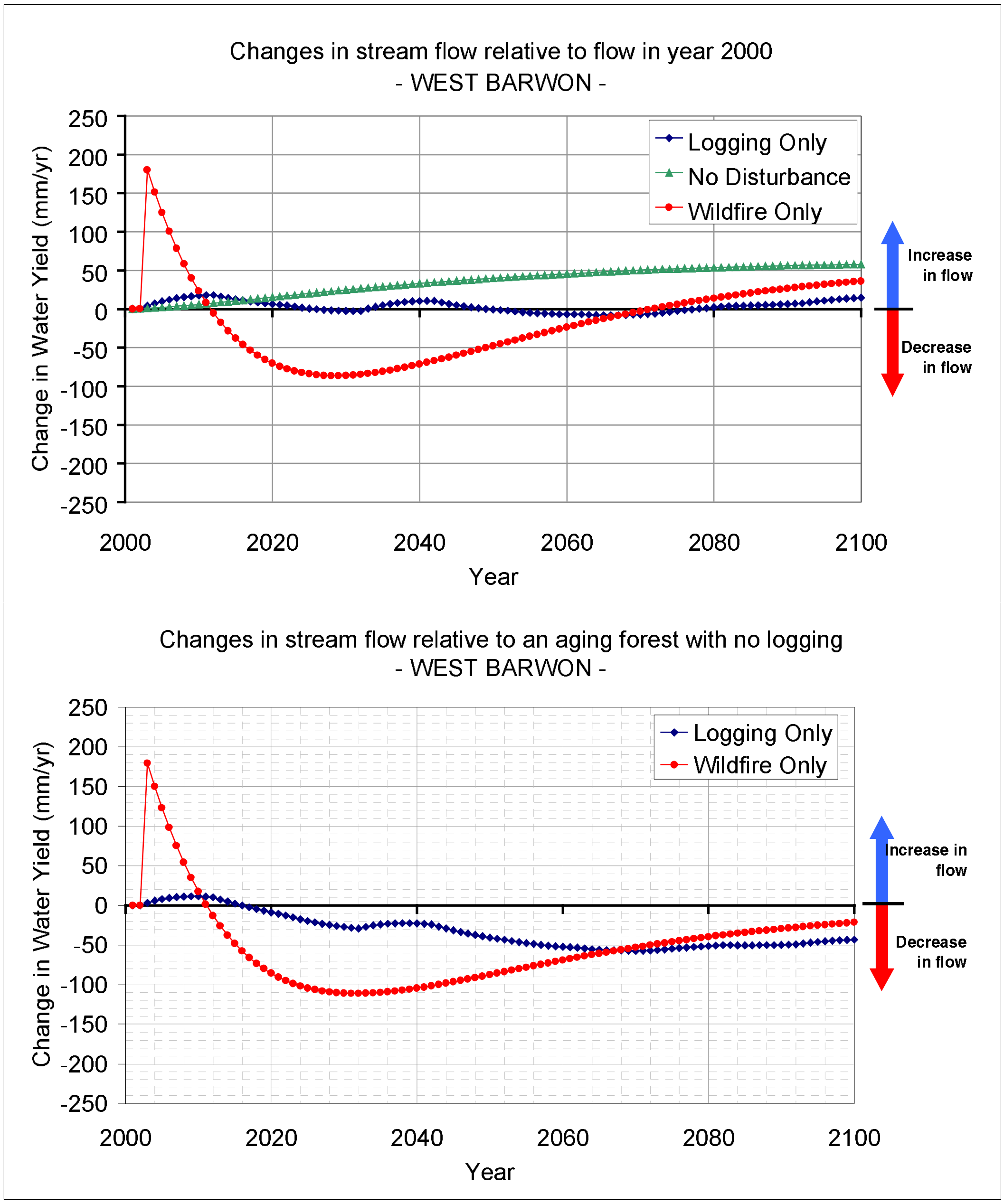
- **Figure 7-17 West Barwon forest age distribution before (upper panel) and after 100 years of the 'logging only' scenario (lower panel).**



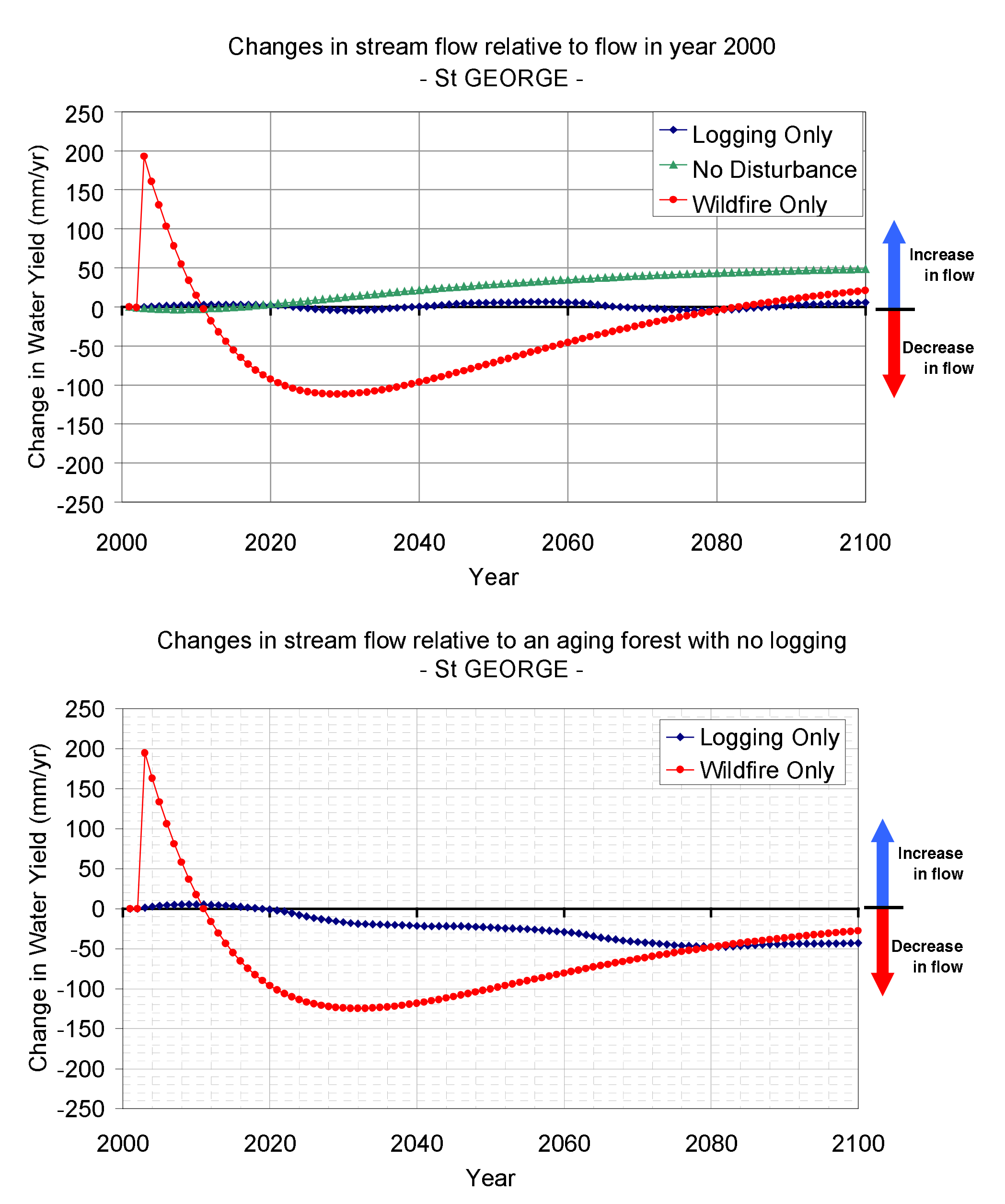
■ **Figure 7-18 St. George forest age distribution before (upper panel) and after 100 years of the 'logging only' scenario (lower panel).**



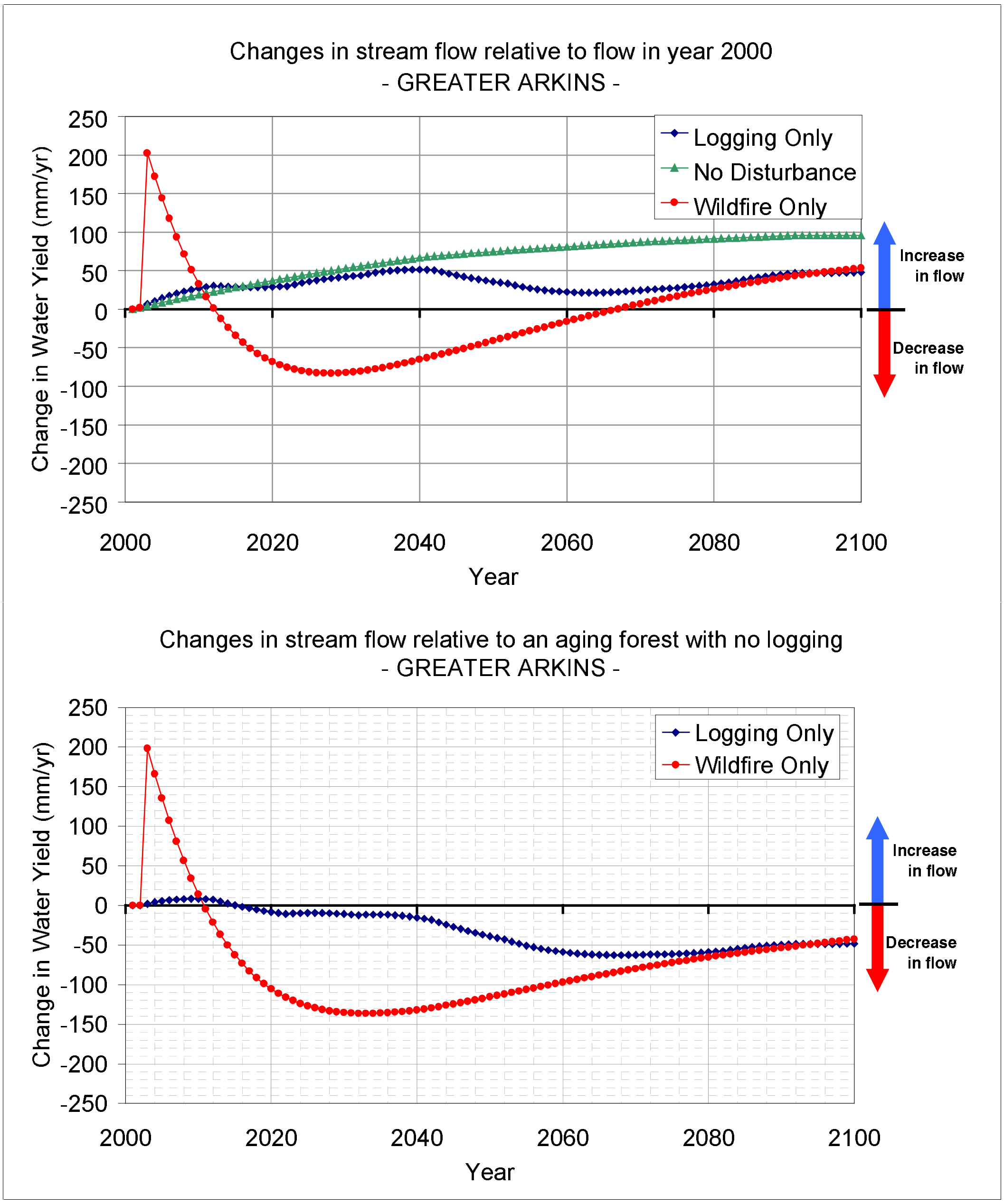
- **Figure 7-19 Greater Arkins forest age distribution before (upper panel) and after 100 years of the 'logging only' scenario (lower panel).**



- **Figure 7-20 Stream flow forecasts for West Barwon catchment**



■ **Figure 7-21 Stream flow forecasts for St. George catchment**



- **Figure 7-22 Stream flow forecasts for Greater Arkins catchment**

7.5 Interpretation of Streamflow Results

7.5.1 Comparison with mean annual flow

Mean annual flow was estimated for the three study catchments using the results of the water resource assessment reported upon earlier. This is described in Table 7-3 below.

■ **Table 7-3 Mean annual flow estimates for study catchments (1955-1996)**

Catchment	Mean Annual Flow (ML/yr)	Source
West Barwon	28,110	Derived from water balance analysis of West Barwon Dam.
Greater Arkins	3,830	Derived by transposition of gauged data at 235205 using a log-log relationship established between mean annual flow and catchment area. Adjusted to be concurrent with a key gauge in the Gellibrand (55-96). This estimate excludes yield from the Arkins sub-catchment.
St George	8,720	Derived from gauged data (235242) spanning 1988 to 1996. This estimate was subsequently adjusted to correspond to the 1955 to 1996 period.

Mean annual demand (1980 to 1999) from the West Barwon dam is estimated to be approximately 23,300 ML/yr, based on recorded data at gauge 20020000. It should be noted that this estimate includes water demand from the East Barwon, however it is assumed that this catchment only supplies a small fraction of the total demand.

Percentage changes in mean annual flow are tabulated for each catchment below using the changes in stream flow shown in Figures 6-20 to 6-22. The following tables present the results every 20 years to show how the changes vary with time. The maximum and minimum changes are therefore likely to be understated in the numbers summarised below and are therefore best inferred from Figures 6-20 to 6-22. Also shown are the net changes over the 100 year simulation period expressed as an average impact.

■ **Table 7-4 West Barwon - changes with respect to Mean Annual Flow**

Year	No Disturbance	Logging only	50 % Fire only
2020	2.8 %	1.2 %	-12.8 %
2040	6.0 %	1.9 %	-13.0 %
2060	8.3 %	-1.2 %	-4.3 %
2080	9.8 %	0.4 %	2.5 %
2100	10.5 %	2.7 %	6.6 %
Average impact	6.8 %	0.8 %	-2.9 %

- **Table 7-5 St. George - changes with respect to Mean Annual Flow**

Year	No Disturbance	Logging only	50 % Fire only
2020	0.5 %	0.3 %	-13.6 %
2040	3.2 %	0.1 %	-14.2 %
2060	5.1 %	0.8 %	-6.7 %
2080	6.4 %	-0.6 %	-0.7 %
2100	7.1 %	0.8 %	3.0 %
Average impact	3.8 %	0.3 %	-5.2 %

- **Table 7-6 Greater Arkins - changes with respect to Mean Annual Flow**

Year	No Disturbance	Logging only	50 % Fire only
2020	10.7 %	8.3 %	-19.6 %
2040	19.2 %	14.8 %	-18.8 %
2060	23.4 %	6.4 %	-4.6 %
2080	26.3 %	9.3 %	7.5 %
2100	27.6 %	13.7 %	15.4 %
Average impact	19.0 %	9.7 %	-2.3 %

In the case of the Greater Arkins (Table 7-6) the percentage effects of logging appear to be considerably greater than in West Barwon and St George. To give these figures further context it should be noted that the estimate of mean annual flow in the Greater Arkins is 3830 ML/y and the mean annual flow from the Arkins (not included in Greater Arkins) is 4230 ML/y. (Furthermore mean annual flow from the Arkins was increasing from 1958 to 1998 (Figure 7-11) with annual flow in 1998 estimated as 4840 ML/y after adjustment for annual rainfall.) Therefore, the actual stream flow at the outlet of the Greater Arkins catchment will be considerably larger than 3830 ML/y and the actual percentage effects will be considerably less than shown in Table 7-6. This study only considers the fraction of stream flow attributable to the Greater Arkins catchment as shown in Figure 7-1.

In addition, for the West Barwon catchment, changes can also be related to mean annual demand. These percentages are given in Table 7-7.

- **Table 7-7 West Barwon - change with respect to Mean Annual Demand**

Year	No Disturbance	Logging only	50 % Fire only
2020	3.4 %	1.4 %	-15.4 %
2040	7.3 %	2.3 %	-15.7 %
2060	10.0 %	-1.5 %	-5.2 %
2080	11.8 %	0.5 %	3.1 %
2100	12.7 %	3.2 %	8.0 %
Average impact	8.3 %	0.9 %	-3.6 %

7.6 Conclusions

Application of the modelling approach and its assumptions indicates the following conclusions:

(i) Allowing the forest to age with no logging, fire or other disturbance results in an increase in stream flow relative to conditions in the year 2000 for all studied catchments.

(ii) The 'logging only' scenario results in little change in stream flow over 100 years from the year 2000. This is certainly the case for the West Barwon and St George catchments however the Greater Arkins catchment indicates a small increase in stream flow suggesting that logging is less intense than past forest disturbances in the Greater Arkins catchment.

(iii) From Figures 6.20 to 6.22 it is evident that a wildfire destroying 50% of the forest cover is estimated to result in changes of streamflow (increases and decreases) that are more than double (at some point in time) than the changes caused by the other scenarios.