TECHNICAL NOTE 2006/06

Department of Water, Land and Biodiversity Conservation

ADDITIONAL HYDROLOGICAL INVESTIGATIONS FOR THE DIVERSION OF FLOW FROM THE LOWER TO THE UPPER SOUTH EAST: POTENTIAL IMPACT OF FORESTRY AND CLIMATE CHANGE ON WATER RESOURCE AVAILIABLITY

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PURPOSE

A preliminary hydrological investigation of the potential volume and frequency of flows available for diversion from the Lower South East into the Upper South East was undertaken for the Upper South East Dryland Salinity and Flood Management Program as reported in DWLBC Technical Note 2004/06 (Heneker, 2006). The purpose of this technical note is to document the methodology and results of an extension of that assessment during which potential reductions in available flows due to plantation forestry and climate change were evaluated.

INTRODUCTION

Streamflow in the South East of South Australia has historically moved from south to north. However, the construction of a drainage network in the Lower South East has broken the connectivity of this flow and hence altered the regional flow paths. As a result, the ecological systems in the Upper South East have suffered from reduced water availability.

Figure 1 shows the drains, watercourses, wetlands and regulators that form the system examined in both the preliminary hydrological investigation and in the assessment to follow. Heneker (2006) used available data from 1972 to 2004 to assess the potential volume and frequency of flows available that could potentially be re-diverted from the Lower South East into the Upper South East from:

1. Bool Lagoon to Drain E and the Marcollat Watercourse.
2. Drain M at Callendale along the Bakers Range Watercourse.

It was shown that diversions to both Drain E and Bakers Range could provide valuable environmental flows to the wetlands and swamps throughout these systems.

In recent years, plantation forestry and climate change have been recognised as potential risks to water resources in many areas of Australia, particularly where rainfall and hence runoff are low. This assessment attempts to quantify reductions in available flows due to these risks, the objectives of which were to:

1. Calculate the potential reduction in inflows reaching Bool Lagoon and Callendale due to plantation forestry and climate change.
2. Calculate the resulting reduction in the volume and frequency of flows available for diversion.
3. Evaluate the reduced hydrological benefit that the diversion of these flows may have on the wetlands along these northern systems.
4. Evaluate the additional reductions in flow to Lake George resulting from possible diversions.

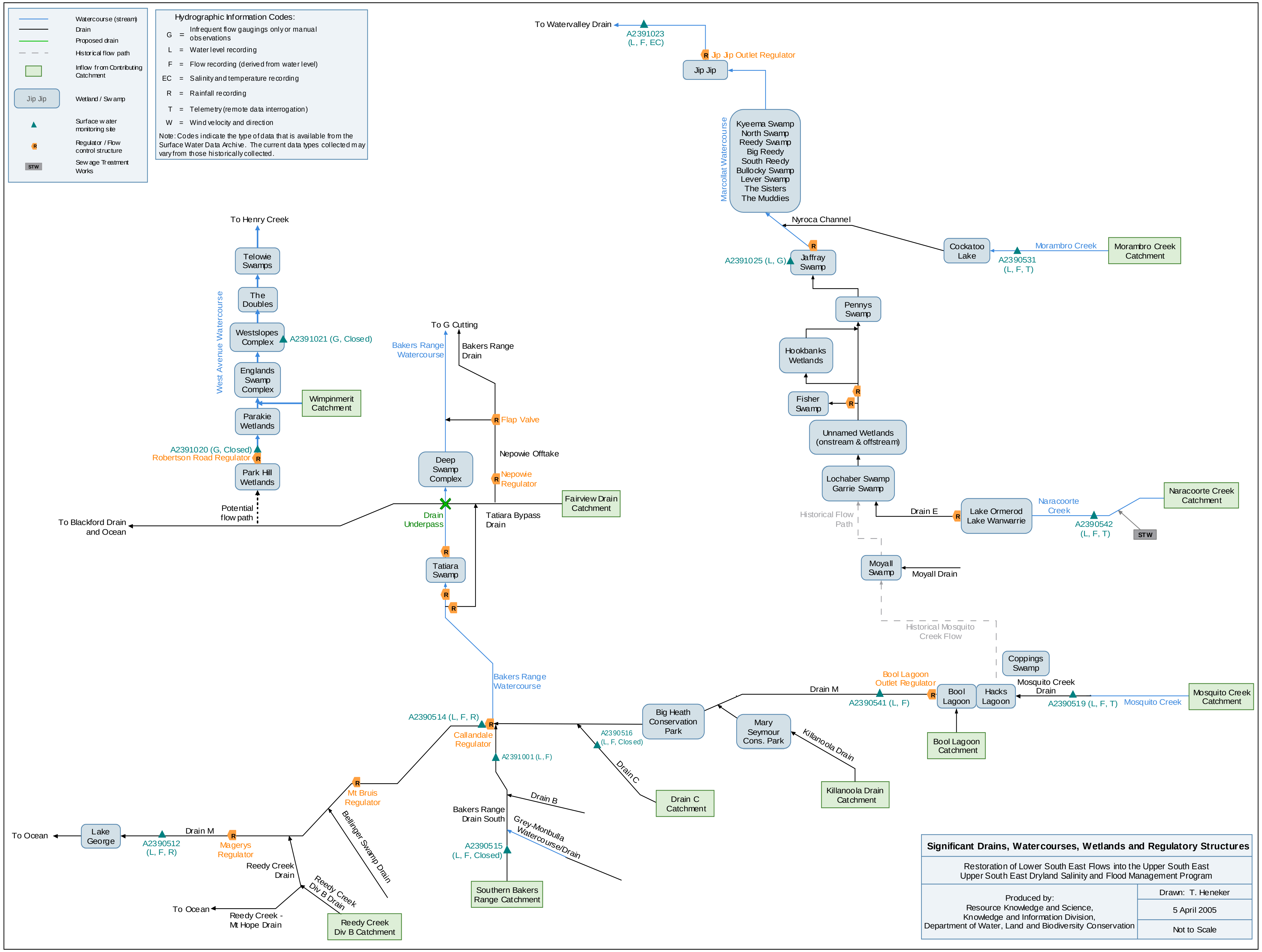

Figure 1 Significant Drains, Watercourses, Wetlands and Regulatory Structures.

RISKS TO DIVERTIBLE FLOWS

Plantation forestry and climate change have both been recognised as potential risks to water resources. Plantation forests may directly reduce runoff while climate change projections indicate decreasing rainfall and increasing temperature, which may result in reduced runoff and increased evaporation. Therefore, both have the potential to reduce future inflows to the drainage network and hence available water that could be diverted to the Upper South East.

It is difficult to determine the critical levels of plantation forestry within contributing catchment areas or the critical reductions in rainfall due to climate change that are likely to reduce the effectiveness of the diverting water to the Upper South East. It is preferable to evaluate percentage reductions in current flows, irrespective of the source of these reductions. However, the following sections describe the potential reductions in runoff due to plantation forestry and climate change and relate these to reductions in total flows from the Lower South East catchments.

PLANTATION FORESTRY

Plantation pine forestry is well established in areas within the Mosquito Creek, Bool Lagoon, Killanoola Drain, Drain C and Southern Bakers Range Catchments, and recorded data over the last 30 years accounts for reductions in runoff due to these plantations. However, in recent years additional areas of plantation forestry have been established, mainly hardwood trees such as blue gums. It is generally accepted that plantation forests reduce runoff and hence water resource availability, although there is currently little guidance as to the volume of flow reduction from a given area once planted.

The impact of forestry on runoff in the Mount Lofty Ranges (MLR) has been quantified by Cresswell (2001), through comparison between the average runoff over the MLR Watershed, and a combination of the Dashwood Gully and Burnt Out Creek Catchments, which are forested. The results show that the reduction in runoff ranges from 50 to 100 mm depending on rainfall within the catchment in question. Based on typical winter rainfall of 650 mm, a runoff reduction of 80 mm (0.8 ML/ha) was predicted for the MLR Watershed. The background data from Burnt Out Creek (a forested catchment that was cleared by fire but which then regrew) showed continuous baseflow during the first five years after the fire during which the forest was becoming more established. Following this period, the baseflow ceased for three to four months each year.

An annual runoff coefficient (annual rainfall divided by the annual runoff) indicates the proportion of rainfall that becomes runoff in a given year. Using topographically defined contributing catchment areas, this coefficient is very low in the South East and is in the order of 0.03 to 0.07. This equates to 3 to 7 mm of runoff for every 100 mm of rainfall and, in part due to the low relief, is less than half that which generally occurs in the MLR. Given the already low runoff coefficient and the potential reductions in runoff due to plantation forests observed in other areas, runoff from increased plantation areas is likely to be negligible.

Vertessy et al. (1998) indicated that the rise or fall in water yield is proportional to the percentage area of forest added or removed, and that water yield changes are difficult to detect if less than 20% of the catchment is covered with forest. This may be in part due to the non-uniform generation of runoff across a catchment. Without an understanding of the spatial generation of runoff within the Mosquito Creek, Southern Bakers Range and Drain C Catchments, it has been necessary to assume that runoff occurs uniformly in order to relate increases in plantation forestry to reduced flows. Therefore, it has been assumed that reductions in runoff would be directly proportional to the area of forest planted (for example, if 5% of a catchment is forested, there will be a 5% reduction in flow leaving that catchment).

Based on the above assumptions, Figures 2 and 3 were generated for the Mosquito Creek, Southern Bakers Range and Drain C Catchments respectively. These allow the total area of forest to be easily equated to a percentage of catchment area and hence a percentage reduction in contributing catchment runoff. As the area of forest increases, these figures provide a guide to the decreasing percentage of catchment runoff and the potential impact can then be linked to the flow scenario corresponding to that reduction. This approach is preferable when there is little information on what areas future plantations may cover.

The area of Mosquito Creek Catchment was estimated at 114,000 Ha from a Digital Elevation Model (Victorian area) provided by the Wimmera Catchment Management Area and contours (South Australian area). It is estimated that almost 4,000 Ha (J. Lawson, DWLBC and D. Schunke, SERIC, *pers. comm.*, 2006) are currently planted with blue gums, equating to just over 3% of the total catchment area. The majority of these plantings have occurred since 2000. Land-use data indicate that most, if not all, plantation development has taken place in the southern arm of the Mosquito Creek Catchment. It is estimated that 70% of the total catchment flow is generated in this southern arm (B. Puddy, SEWCDB, *pers. comm.*, 2006). Hence, the reduction of catchment flows based on the percentage of the catchment that is forested may underestimate the impact.

It is estimated that there is in the order of 35,000 Ha (J. Lawson, DWLBC and D. Schunke, SERIC, *pers. comm.*, 2007) currently planted with blue gums in South Australia. Approximately 70% is located in the Southern Bakers Range and Drain C catchment, equating to between 15 and 20% of the total catchment area (area estimated from available contours). The remaining 30% of blue gum plantings are located immediately north of Drain M, along the Bakers Range Watercourse. Plantings north of Drain M are unlikely to significantly reduce flows directly into Drain M. However, if plantings have occurred close to or along the Bakers Range Watercourse, then there is likely to be a reduction in runoff into the watercourse as well as the potential for additional transmission losses in comparison to pre-forested conditions.

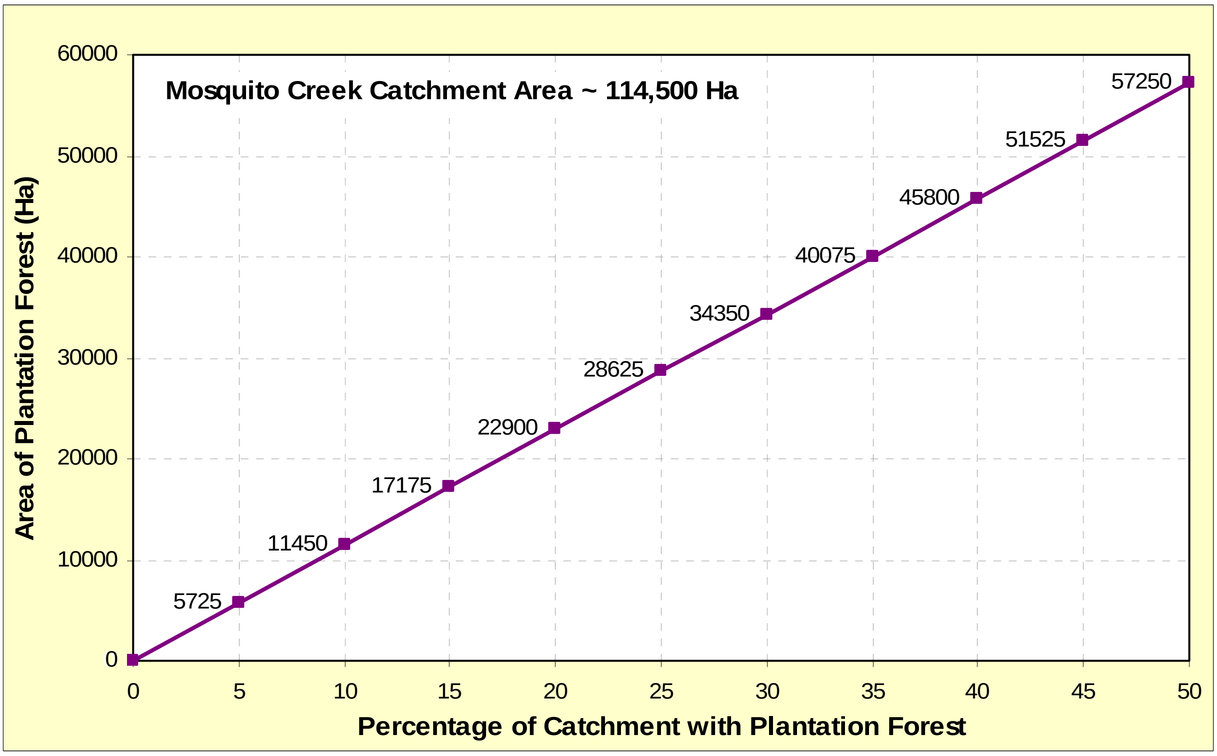

Figure 2 Mosquito Creek Catchment: Relationship between Total Area and Percentage of Catchment with Plantation Forest.

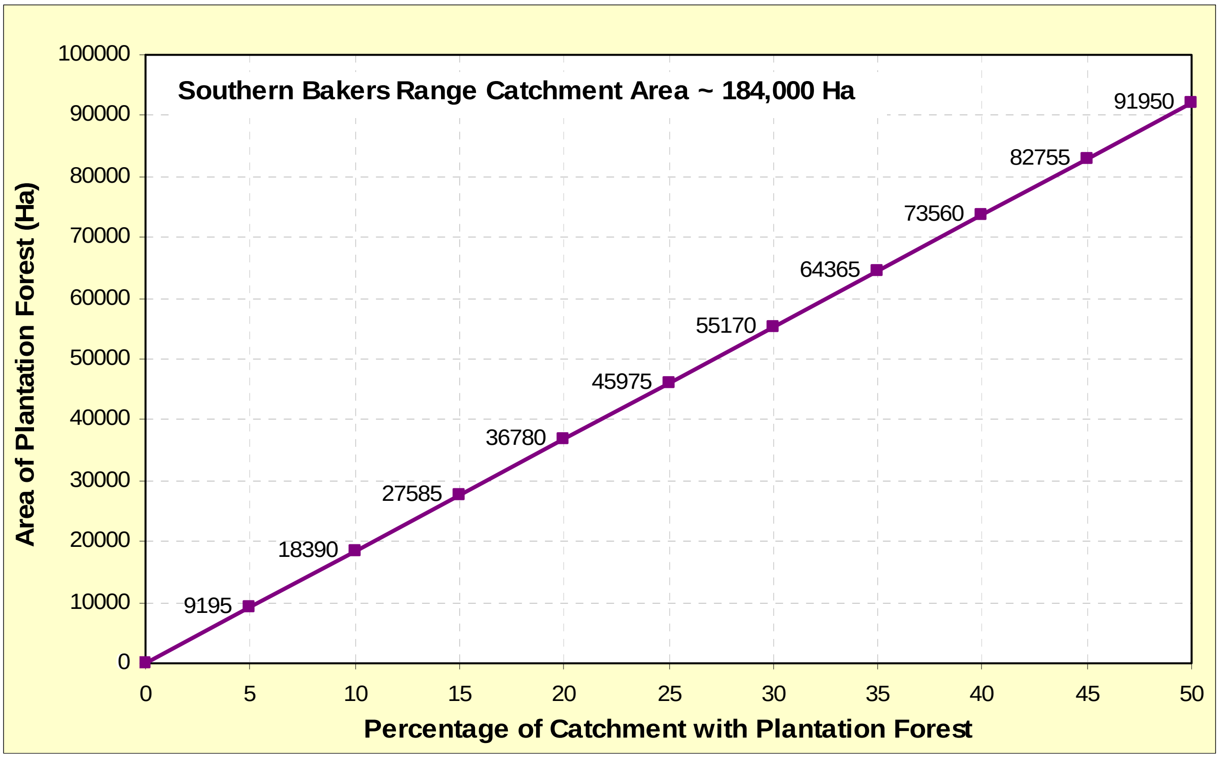

Figure 3 Southern Bakers Range and Drain C Catchment: Relationship between Total Area and Percentage of Catchment with Plantation Forest.

During the planting of plantation forests, banking and contouring of the catchment are common and this changes the way in which runoff moves across the landscape. It increases the potential for the trees to intercept flows moving along natural drainage lines, and the impact increases the closer the trees are planted to primary drains and watercourses. Many of the forests in the Southern Bakers Range and Drain C Catchments have been planted in this manner (R. England, USE Board Member, *pers. comm.*, 2006).

CLIMATE CHANGE

The study of climate variability and climate change has increased over the last twenty years. Drier than average periods, particularly over the last ten years, have increased general perceptions that the Earth is experiencing man-induced climate change that is impacting on climate variables such as rainfall. In respect to changes in rainfall across the South East of South Australia and western Victoria, Heneker (2004) examined stations throughout the region, many having over 100 years of rainfall data. It was shown that while generally decreasing annual rainfall trends have occurred over the last 50 years, similar extended dry periods have occurred before. Results of a decadal analysis reiterated observations by Latif *et al*. (1999) that natural climate variability at decadal time scales has the potential to interact with, and interfere in, an unambiguous detection of climate change. Whilst analyses undertaken do not discount the occurrence of climate change, it is important to thoroughly examine historical records to identify potential natural variability.

Charles *et al*. (2006) used statistical downscaling to determine the key relationships between observed regional rainfall trends and natural climate variability to understand how large-scale atmospheric drivers influence multi-site, daily rainfall at the rain gauge, that is, at the scale required for hydrological modelling. Charles and Bates (2006) then extended this analysis to produce projections of possible future (mid-21st century) rainfall by downscaling atmospheric conditions from climate change GCM (General Circulation Model) simulations. The projections suggest that there may be consistent decreases in seasonal totals, a reduction in very wet winters but only slight changes to the number of wet (rain) days.

Figures 4 and 5 show the projected reductions in monthly rainfall totals at the Edenhope (079011) and Penola (026025) rainfall stations. The reduction in annual rainfall is in the order of 75 mm (12%) at Edenhope and 85 mm (12%) at Penola. Due to the non-linearity of the rainfall-runoff response, a 10% decrease in rainfall may result in a 30 to 40% decrease in runoff.

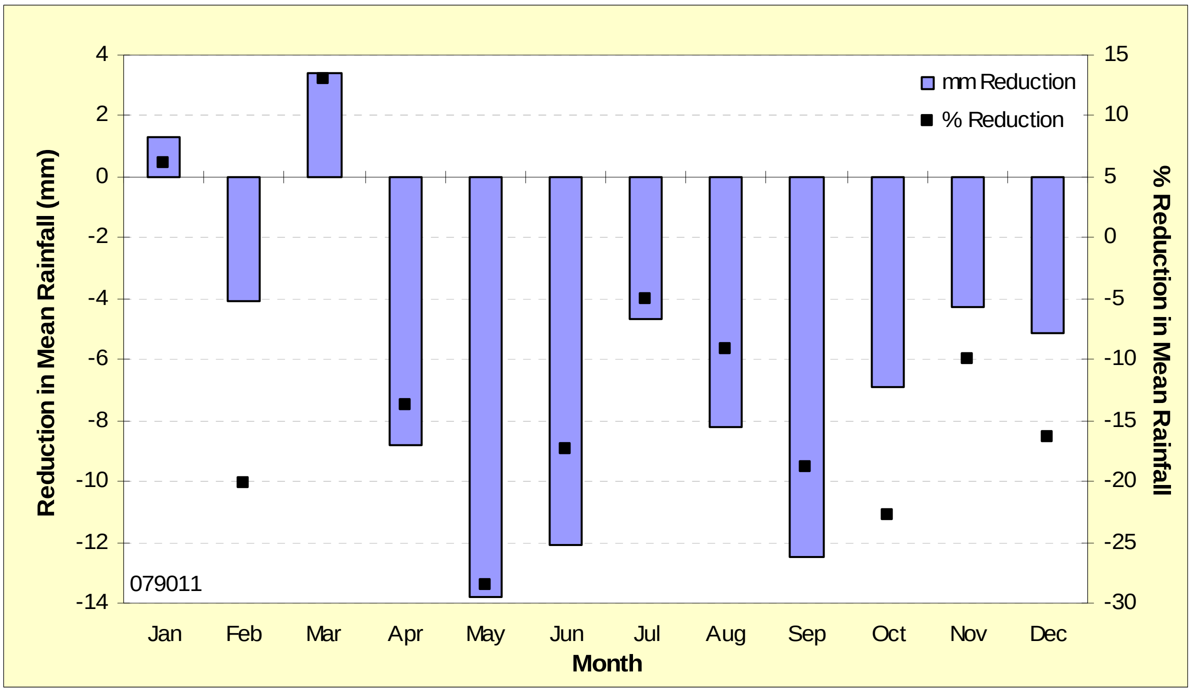

Figure 4 Potential Reduction in Monthly Rainfall at Edenhope Rainfall Station (079011).

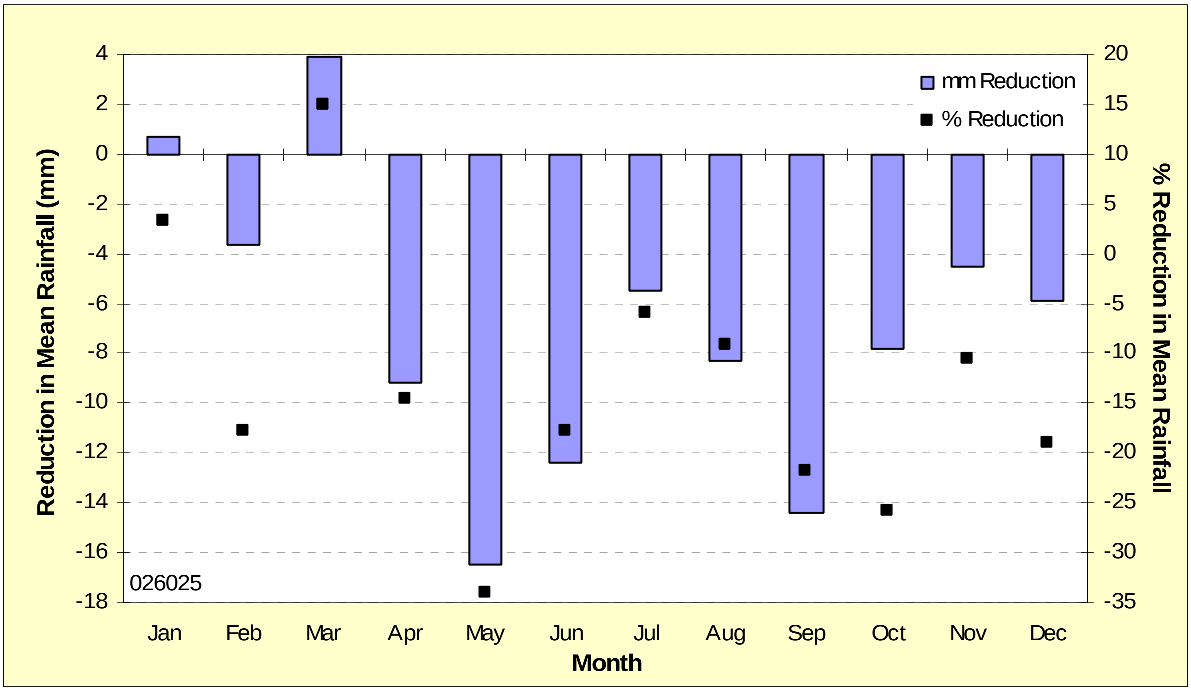

Figure 5 Potential Reduction in Monthly Rainfall at Penola Rainfall Station (026025).

DIVERSION FROM BOOL LAGOON

Mosquito Creek begins in Victoria and flows into South Australia before discharging into Hack's Lagoon and subsequently Bool Lagoon. Water historically flowed north from Hack's Lagoon, through Moyall Swamp and into Garrie Swamp and Drain E. Heneker (2006) assumed that the current drainage and conservation requirements for Bool Lagoon would need to be maintained and any water historically released from Bool Lagoon would give a good indication of excess water available water to push north into Drain E.

EXCESS FLOW AT BOOL LAGOON

Heneker (2006) examined the volumes of excess flow at an annual timescale without consideration to the intra-annual timing of water availability. The majority of inflow into Bool Lagoon occurs over a short period in winter and spring, and the lagoon is likely to fill and excess water become available primarily during this period. Consequently, diversions northwards would most likely occur for one period during each year. Channel capacity to move the available water north may be a constraint and will ultimately affect the total volume diverted. It was shown that an annual flow of least 20,000 ML from Mosquito Creek into Bool Lagoon occurred before water was historically released into Drain M. From this it was assumed that an annual inflow of 20,000 ML would generally satisfy the requirements of Bool Lagoon and that the remainder could be diverted north.

The flow measured upstream of Bool Lagoon (A2390519) was reduced by 10% increments to simulate reductions in contributing areas and hence runoff. Figure 6 shows the historical data together with reductions up to 30%. Total inflow to Bool Lagoon is significantly reduced during higher rainfall and hence runoff years. It is observed that in four years approximately 20,000 ML historically flowed into Bool Lagoon and hence a 10% reduction in inflow would likely lead to no excess flow being available during these years.

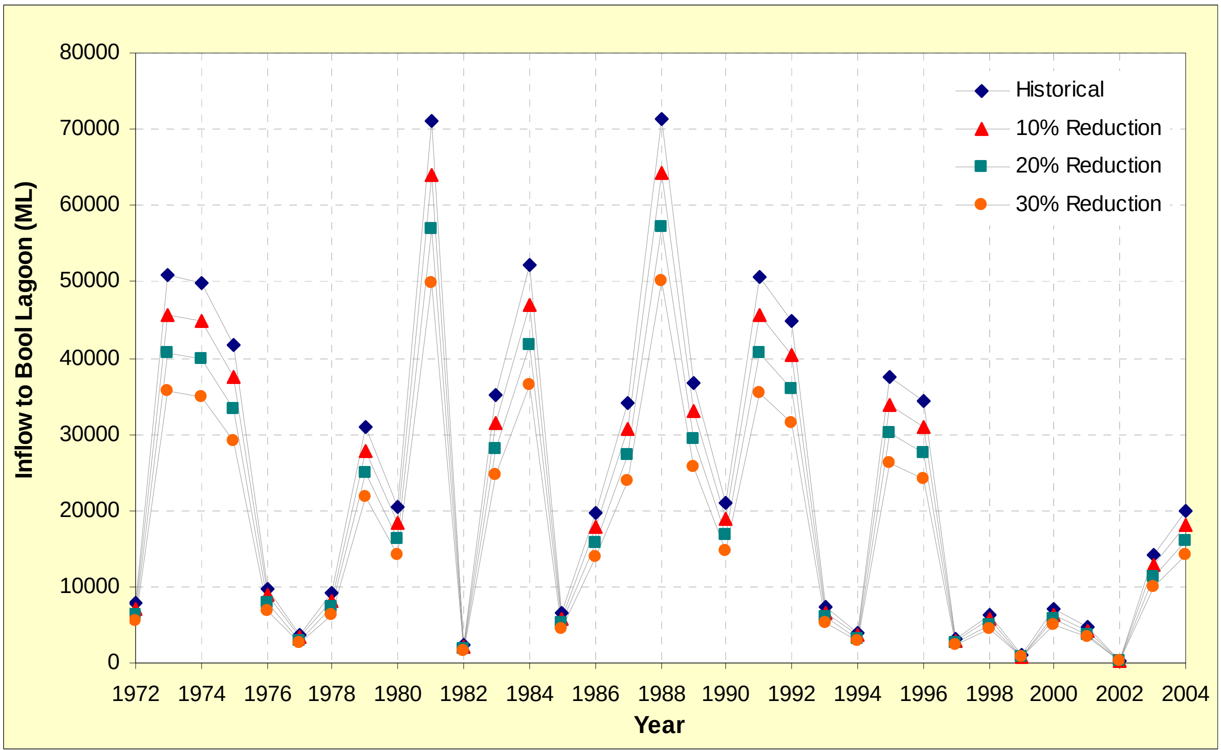

Figure 6 Reduction in Inflow to Bool Lagoon.

Heneker (2006) examined the relationship between annual rainfall and inflow to Bool Lagoon from which it was concluded that at least 590 mm of annual rainfall was required before the annual inflow exceeded 20,000 ML. For rainfalls above 590 mm, the magnitude increased quickly and varied significantly. This variation is caused by a number of factors including the spatial and temporal distribution of rainfall, particularly over such a large catchment.

Figure 7 shows the relationship between average catchment rainfall and flow from both the historical data and with reductions up to 30% from 1972 to 2004. These have been calculated using the recorded flow data downstream of Bool Lagoon from 1985 to 2004 and extrapolated to 1972 by assuming that all flow in excess of 20,000 ML entering Bool Lagoon is available for diversion. TanH curves have also been fitted to these data.

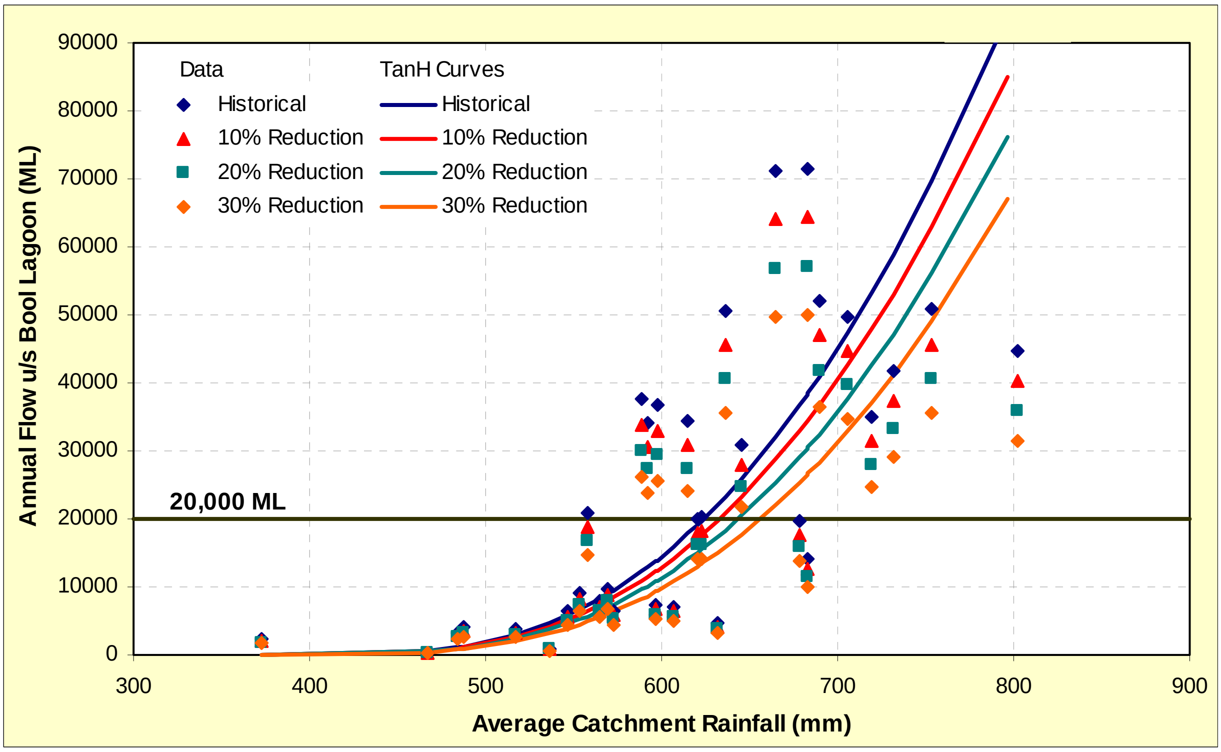

Figure 7 Relationship Between Catchment Rainfall and Inflow to Bool Lagoon.

The analysis above has assumed that runoff occurs uniformly across the Mosquito Creek Catchment but, as indicated previously, it is likely that 70% of the recorded flow comes from the southern arm of Mosquito Creek and the remaining 30% from the northern arm. Two streamflow gauges have recently been installed, one on each of the northern and southern arms. Given that the majority of hardwood plantation forestry has been established in the southern portions of the catchment, it will be important to conclusively establish these flow proportions after enough data have been collected.

The indicative inflow criteria for diversion of 20,000 ML only provides the point from which excess flow may be available. For any connection north to be successful in benefiting the environmental systems to which water is delivered, it is desirable for the inflows to be as high as possible. The historic data points in Figure 7 show that 590 mm of rainfall was sufficient to produce inflows in excess of 30,000 ML. If the contributing catchment area was reduced by 30%, 635 mm of annual rainfall would be required before the magnitude of annual inflow increased above 30,000 ML.

Table 1 shows the frequencies of inflows greater than 20,000 ML. With a reduced contributing catchment area, the frequency of these inflows would reduce from 1 in 2 years to 2 in 5 years. At each of the 10 to 30% reduction levels there is no difference in the frequencies of inflows greater than 20,000 ML. However, as the contributing catchment area and hence the inflows to Bool Lagoon reduce, the frequencies of diversion volumes change significantly.

Table 1 Potential Frequency of Inflows to Bool Lagoon.

Contributing Catchment	Inflow > 20,000 ML*	Frequency (years)
Historical	17	1 in 2
10% Reduction	14	2 in 5
20% Reduction	14	2 in 5
30% Reduction	14	2 in 5

*Period of analysis 1972 to 2004

Table 2 and Figure 8 show the frequencies of diversion volumes. Excess volumes between 10,000 and 20,000 ML would almost halve under the 30% reduction scenario while higher divertible volumes (those greater than 30,000 ML) would be very infrequent.

Table 2 Frequency of Diversion Volumes from Bool Lagoon.

Flow Available for Diversion (ML)	No. Years*	Frequency (years)
Historical		
>10,000	13	4 in 10
>20,000	9	3 in 10
>30,000	5	2 in 10
>40,000	3	1 in 10
>50,000	2	0.5 in 10
10% Reduction		
>10,000	12	3.5 in 10
>20,000	8	2.5 in 10
>30,000	3	1 in 10
>40,000	3	1 in 10
>50,000	1	0.5 in 10
20% Reduction		
>10,000	11	3 in 10
>20,000	5	1.5 in 10
>30,000	3	1 in 10
>40,000	1	0.5 in 10
>50,000	1	0.5 in 10
30% Reduction		
>10,000	8	2.5 in 10
>20,000	3	1 in 10
>30,000	1	0.5 in 10
>40,000	1	0.5 in 10
>50,000	0	-

*Period of analysis 1972 to 2004

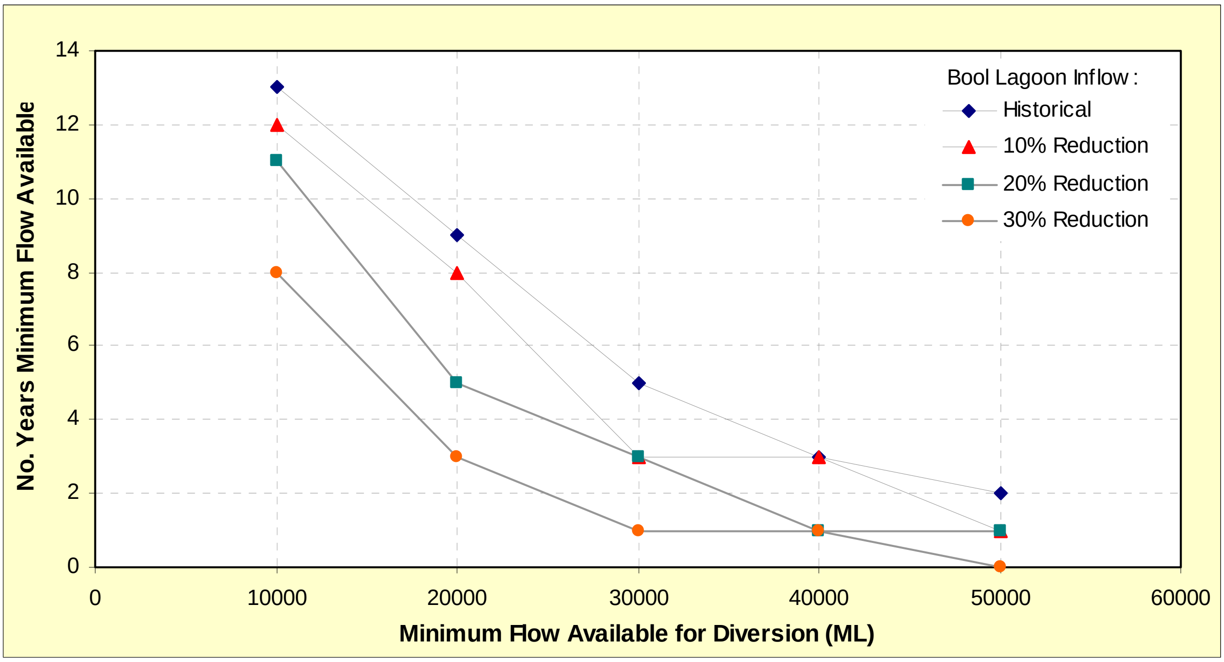

Figure 8 Frequency of Diversion Volumes from Bool Lagoon.

ADDITIONAL FLOW TO DRAIN E

The diversion northwards of all excess water currently released from Bool Lagoon would add significantly to current inflows from Naracoorte Creek into Drain E, and increase the turnover of water within the on-stream wetlands. The analysis conducted by Heneker (2006) used recorded Bool Lagoon release data (1985 to 2004) and assumed 500 ML of losses between Bool Lagoon and Garrie Swamp. It was also assumed that no water would be diverted northwards unless there was more than 1000 ML of excess water available. The model developed by Cresswell (2004) was used to determine inflow to Garrie Swamp from Naracoorte Creek and to model the spill from Jaffray Swamp from 1985 until recording began in 1994. The estimated increases in the quantity and movement of flow throughout Drain E and the on-stream wetlands was then determined. Losses between Garrie Swamp and Jaffray Swamp were assumed to be 500 ML.

The analysis conducted in Heneker (2006) is repeated here for the reduced diversion volumes calculated for 10 to 30% reductions in inflows to Bool Lagoon. The assumptions are identical (refer to Heneker (2006) for a detailed description).

Figure 9 shows the potential total annual inflows to Garrie Swamp if water was diverted from Bool Lagoon, identifying the Naracoorte Creek and Bool Lagoon components. The “Bool Lagoon - 30% Reduction” (maroon) flow component represents the inflow to Garrie Swamp if the inflows to Bool Lagoon were reduced by 30%. The “Bool Lagoon - Historical” (yellow) flow component represents the additional flow into Garrie Swamp under historical conditions. Hence, the sum of these components is the total diverted flow to Garrie Swamp under historical conditions.

Figure 9 clearly shows that diversions from Bool Lagoon have the potential to enhance existing inflows, irrespective of reductions to Bool Lagoon inflow of up to 30%. However, the magnitude of the benefit is reduced, particularly in a number of years when there was little or no spill from Lake Ormerod.

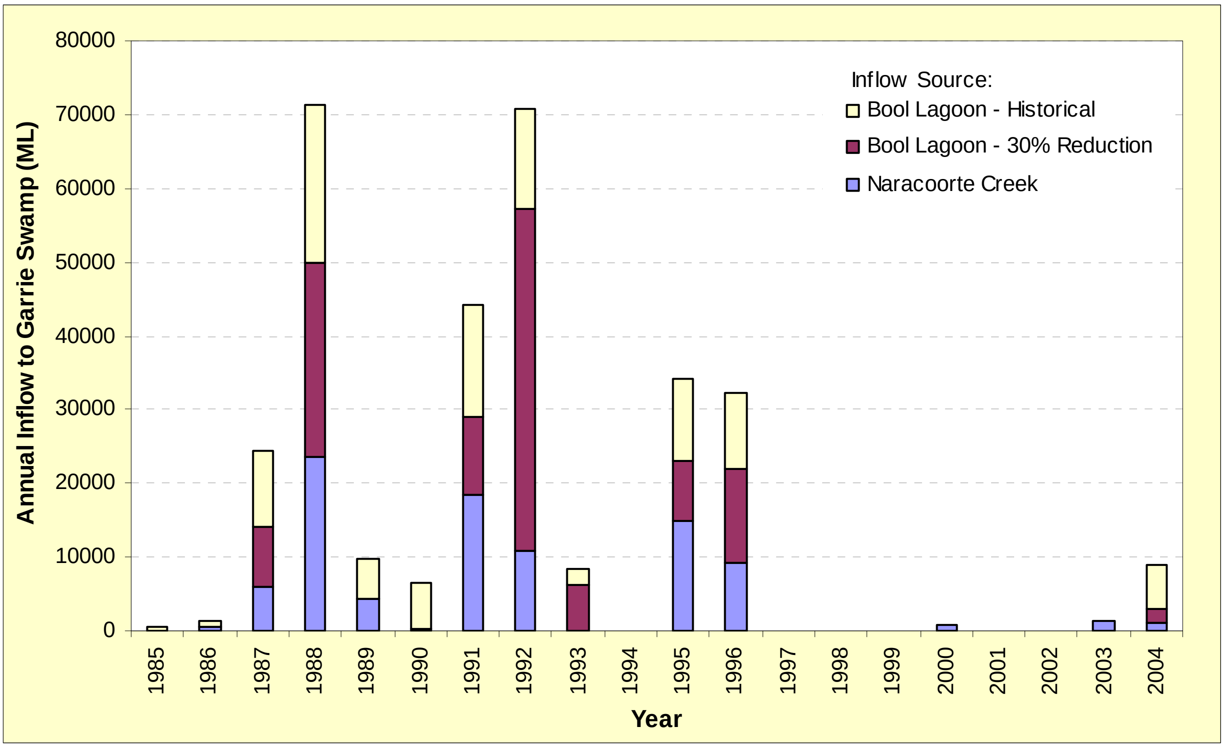

Figure 9 Potential Total Inflow into Drain E at Garrie Swamp.

Figure 10 shows the spill from Jaffray Swamp and Drain E wetland turnovers without diversions at Bool Lagoon, together with the potential spill and turnovers if historical and reduced inflows were diverted north.

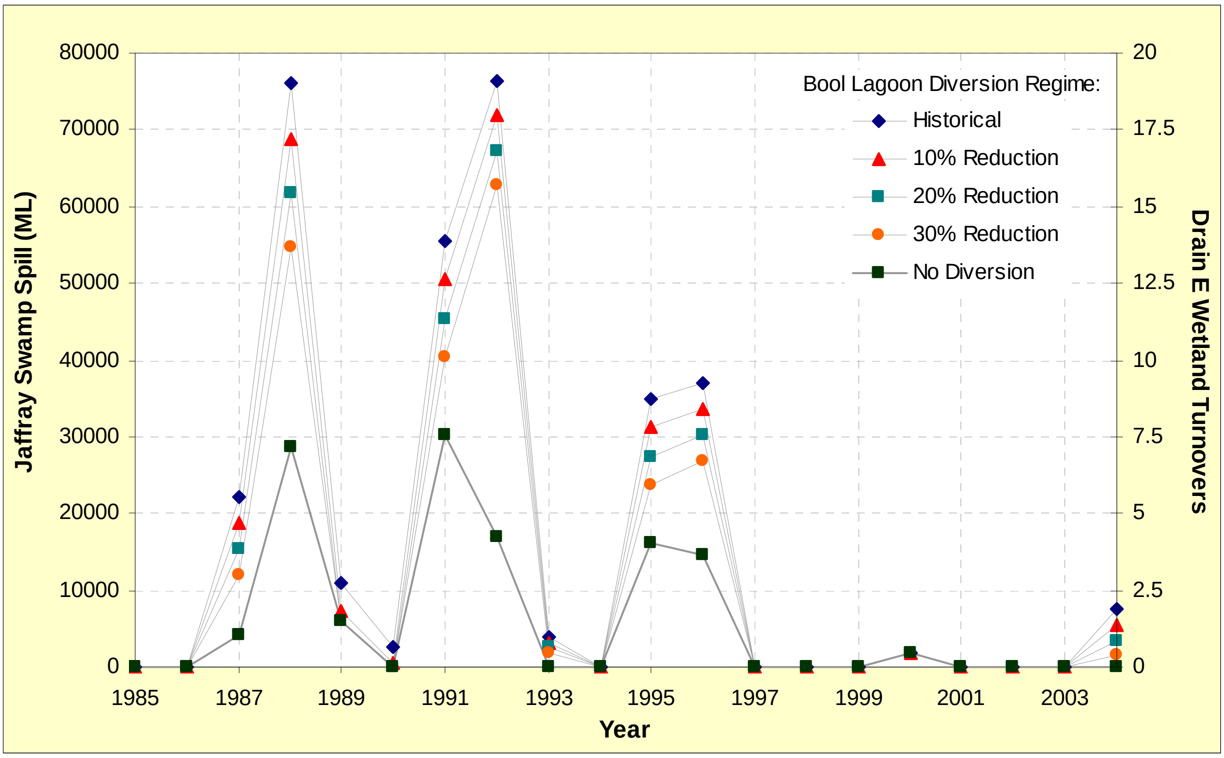

Figure 10 Jaffray Swamp Spill and Drain E Wetland Turnovers.

The spill at Jaffray Swamp and associated benefits to wetlands along Drain E were examined for the period from 1985 to 2004 for which there was Naracoorte Creek flow data and Bool Lagoon release data. Logically, the spill at Jaffray Swamp corresponds directly with the turnover of water within the wetlands. From this it can be seen that:

- Jaffray Swamp spilled during eight years between 1985 and 2004.
- Spill during an additional two years may have been possible with diversions from Bool Lagoon under historical inflow conditions and an additional one year given inflow reductions up to 30%.

The largest benefits, in terms of turnover of water within the wetlands, are achieved when there is 40,000 ML or more water available for diversion, although volumes greater than 20,000 ML would also provide significant benefits. As expected, the volume spilling reduces as the divertible volume decreases. However, the excess volumes at Jaffray Swamp and the Drain E wetland turnovers would still be significantly larger than those without the diversions.

It is clear from Figure 10 that diversions from Bool Lagoon have the potential to enhance existing inflows, irrespective of reductions to Bool Lagoon inflow of up to 30%. However, the magnitude of the benefit is reduced, and diversions would be unlikely during 1 of the 10 years when diversions may have occurred under historical inflows to Bool Lagoon.

ADDITIONAL FLOW TO MARCOLLAT WATERCOURSE

A similar analysis was conducted for the Marcollat Watercourse. The diversion of flow north from Bool Lagoon has the potential to increase the flows entering the Marcollat Watercourse at The Muddies. Heneker (2006) used the model developed by Cresswell (2004) to route the flow data from the Morambro Creek gauging station through Cockatoo Lake to determine the Morambro Creek component of the inflow into The Muddies. It was shown that diversions from Bool Lagoon had the potential to enhance the existing inflows and provide inflows in years when both Jaffray Swamp and Cockatoo Lake historically did not spill.

The analysis conducted in Heneker (2006) is repeated here for the reduced diversion volumes calculated for 10 to 30% reductions in inflows to Bool Lagoon. The assumptions are identical (refer to Heneker (2006) for a detailed description).

Figure 11 shows the potential total annual inflows to The Muddies if water was diverted from Bool Lagoon, identifying the Morambro Creek, Drain E and Bool Lagoon components. The “Bool Lagoon - 30% Reduction” (green) flow component represents the inflow to The Muddies if the inflows to Bool Lagoon were reduced by 30%. The “Bool Lagoon - Historical” (yellow) flow component represents the additional flow into The Muddies under historical conditions. Hence, the sum of these components is the total diverted flow to The Muddies under historical conditions.

Figure 12 shows the spill from Jip Jip and Marcollat Watercourse wetland turnovers without diversions at Bool Lagoon, together with the potential spill and turnovers if historical and reduced inflows were diverted north. From this it can be seen that:

- Jip Jip spilled historically during 10 years between 1985 and 2004.
- Spill during an additional year may have been possible with diversions from Bool Lagoon under historical inflow conditions and given inflow reductions up to 30%.

The largest benefits, in terms of turnover of water within the wetlands, are achieved when there are 20,000 ML or more water available for diversion, although volumes greater than 10,000 ML would also provide significant benefits. As expected, the volume spilling reduces as the divertible volume decreases. However, the excess volumes at Jip Jip and the Marcollat Watercourse wetland turnovers would still be significantly larger than those without the diversions.

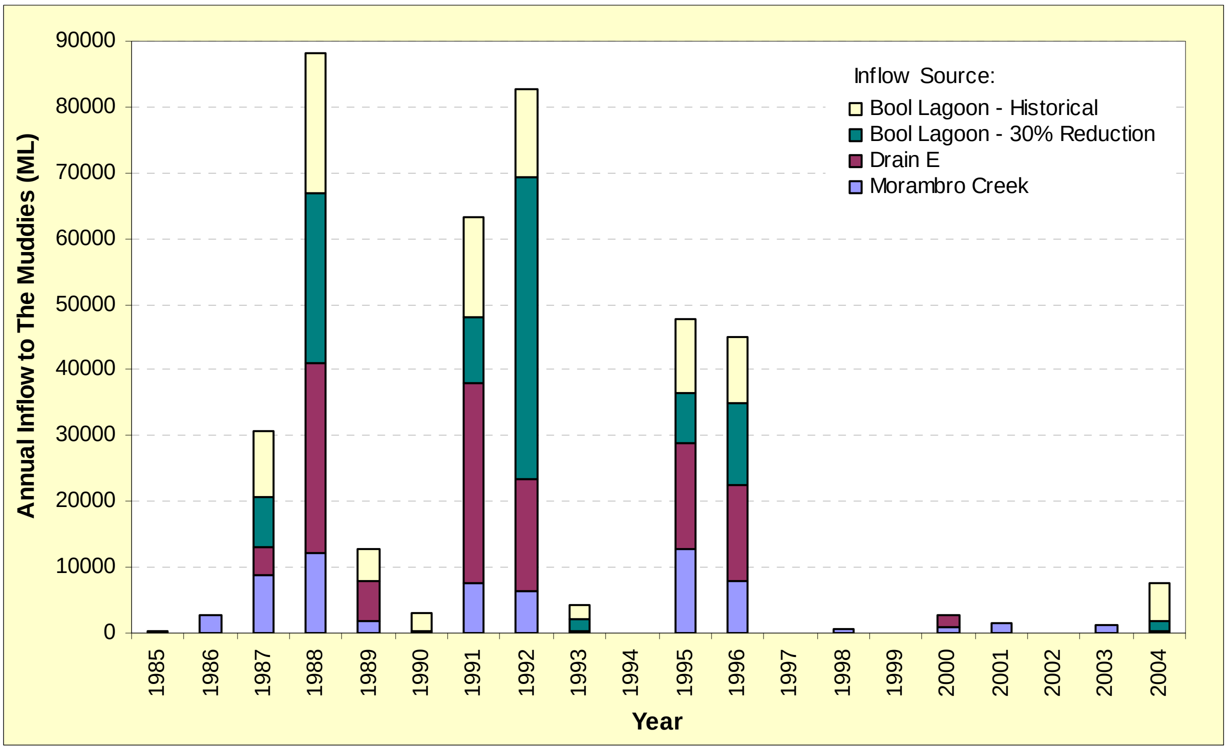

Figure 11 Potential Total Flow into Marcollat Watercourse at The Muddies.

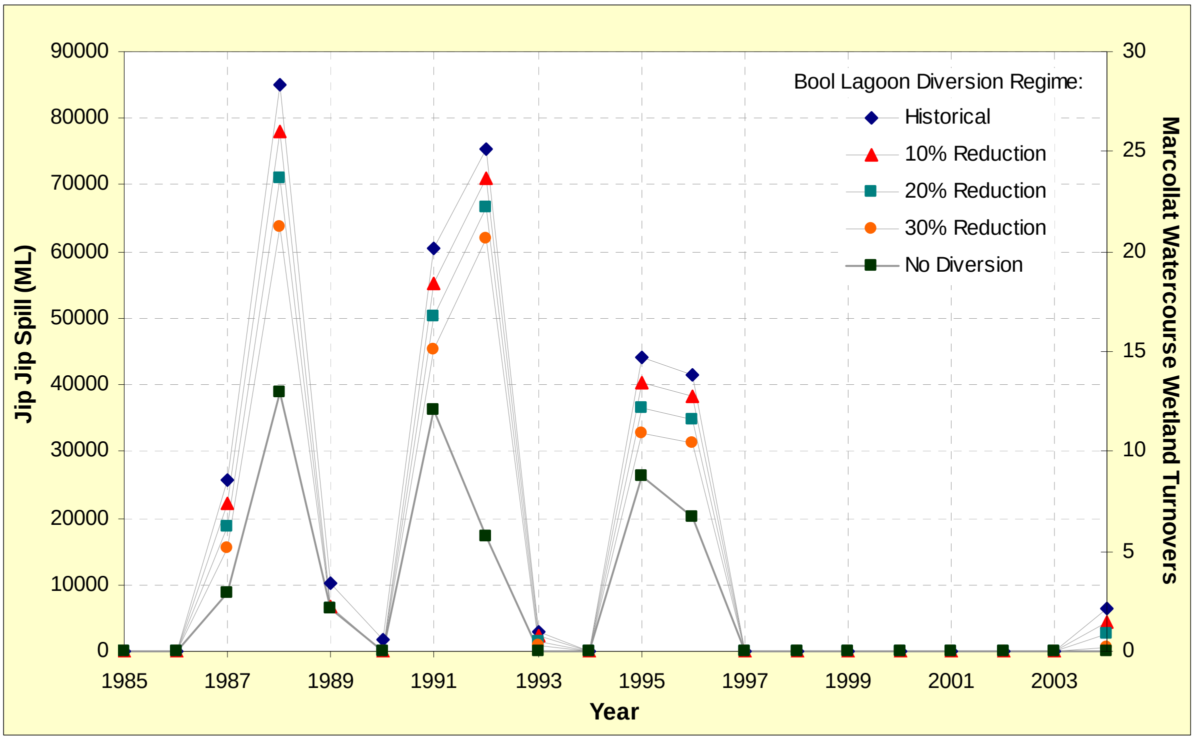

Figure 12 Jip Jip Spill and Marcollat Watercourse Wetland Turnovers.

DIVERSION TO BAKERS RANGE WATERCOURSE

The Southern Bakers Range Watercourse (including Drains A and B), Drain C and the Killanoola Drain have historically produced significant flows. These have primarily been re-directed through the Callendale Regulator, down Drain M to Lake George and the ocean since the late 1960s. Heneker (2006) detailed the design capacities of the Callendale Regulator. The aims of diverting water north at Callendale are to direct water to the wetlands along the West Avenue Watercourse via Fairview Drain and to wetlands along the Northern Bakers Range Watercourse.

The channel constraints of the Bakers Range Watercourse restrict inflow and hence volumes that can be diverted to a maximum of 11.6 m^3/s (corresponding to approximately 1000 ML/day). Using 1000 ML/day maximum diversion, an analysis was conducted at an annual time scale in terms of total available flow to determine diversion at Callendale with and without diversions to Drain E.

Unlike the availability of excess water at Bool Lagoon that generally occurs for a short period only once during a year, available flow at Callendale can occur more than once and for a longer period. Water is not able to be stored in Drain M at Callendale for extended periods as it is in Bool Lagoon. Therefore, operational considerations needed to be taken into account when calculating the potential diversion volumes.

Heneker (2006) assumed that flow would primarily be diverted during higher flow events and months to minimise losses as a proportion of total flow. A range of minimum threshold flows for the start and finish of any diversions were considered. Once the flow from an event receded below the threshold flow, the diversions were assumed to cease and all flow passed Callendale and down Drain M. It was shown that flow through Callendale may fluctuate above and below the minimum diversion rate over a year such that rules developed behind the diversion of flow into Bakers Range Watercourse would aim to minimise post-diversion losses and hence ensure that real environmental benefits are delivered. A compromise is needed between the total volumes diverted (which increase the lower the threshold flow is set) and the continuous diversion period (more likely the higher the threshold flow is set) as well as providing minimum flows down Drain M.

Heneker (2006) showed that a large proportion of the flow at Callendale has the potential to be diverted, particularly at threshold flows between 100 and 200 ML/day. Threshold flows at these levels appeared to provide a good compromise between total volumes diverted, period of continuous diversion and total number of diversion days, particularly when compared with a threshold flow of 43 ML/day. A significant limiting factor was the 1000 ML/day capacity of Bakers Range Watercourse and this increases the importance of the number of diversion days. Hence, if large volumes of flow only occur over a small number of days, it may not be physically possible to meet the requirements of those systems where the water is being directed. Refer to Heneker (2006) for a detailed analysis of various diversion threshold flows and the associated impact on water availability and diversion days.

The analysis conducted here follows the same methodology as Heneker (2006), considering the diversion potential with a diversion threshold flow of 100 ML/day for:

1. Diversion at Callendale with no diversion to Drain E (1972 to 2004) considering reductions in inflows to both Bool Lagoon and Callendale.
2. Diversion at Callendale with maximum diversions to Drain E (1985 to 2004) considering reductions in inflows to Callendale only (no spill from Bool Lagoon).

POTENTIAL REDUCED FLOWS AT CALLENDALE

Flow at Callendale comprises runoff from both the Mosquito Creek Catchment (through Bool Lagoon), the Killanoola Drain, Drain C and the Southern Bakers Range Catchment. Hence, reductions in the volume of runoff from any of these sources will reduce total flows.

Flows recorded at the gauging stations downstream of the Callendale Regulator (A2390514) were adjusted for 10 to 30% reductions in Mosquito Creek flows. Figure 13 shows the results for the period 1972 to 2004 assuming the following:

- 1972-1984: Assume all inflow greater than 20,000 ML is released if there is more than 20,500 ML inflow from Mosquito Creek. Apply this to 10 to 30% reduced Mosquito Creek inflow hydrographs to estimate releases.
- 1985-2004: Subtract volume of reduced Mosquito Creek inflow (under 10 to 30% reductions) from recorded Bool Lagoon outflow.

The height of the "30% reduction" (blue) shows the amount that would be released from Bool Lagoon if there was a 30% reduction in inflows. The "20% reduction" (maroon) then shows the additional volume available if there was only a 20% reduction in inflows. Hence, the total height of the columns indicate the volumes currently released and hence available for diversion. Figure 13 shows that the impact of reduced Mosquito Creek inflows would be greatest during years where low volumes of water were released from Bool Lagoon. In a number of years, reductions in inflows are likely to mean that no flow would be released.

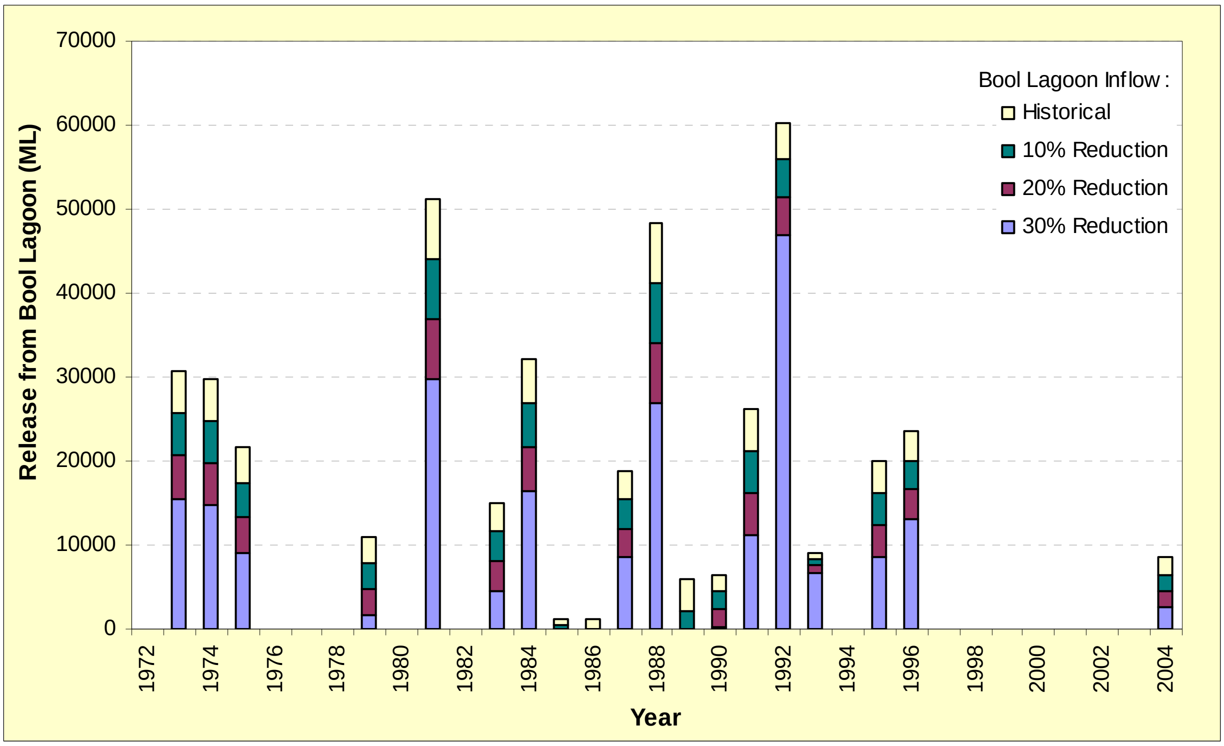

Figure 13 Releases from Bool Lagoon.

Heneker (2006) showed that in most years the majority of the recorded flow at Callendale has occurred from the Southern Bakers Range Watercourse, Drain C and the Killanoola Drain. The estimated runoff volumes from these areas were reduced by 10% increments to quantify reductions in contributing areas and hence runoff. Figure 14 shows the historical estimates together with reductions of up to 30%. If the contributing flows were reduced by 30%, total volume could be reduced by 10,000 to 30,000 ML in some years.

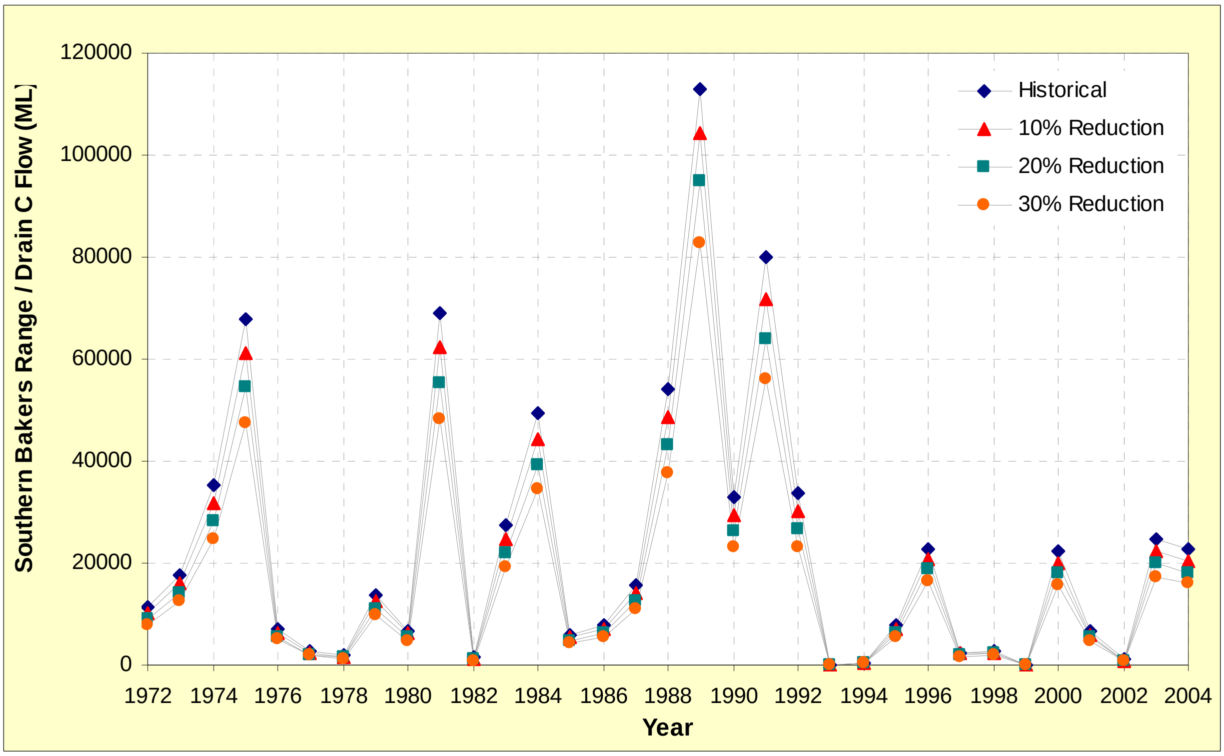

Figure 14 Reduction in Flows from Southern Bakers Range Watercourse and Drain C at Callendale.

The combined impact of reduced Bool Lagoon releases and reduced runoff from the Southern Bakers Range area were then considered and the results are presented in Figure 15.

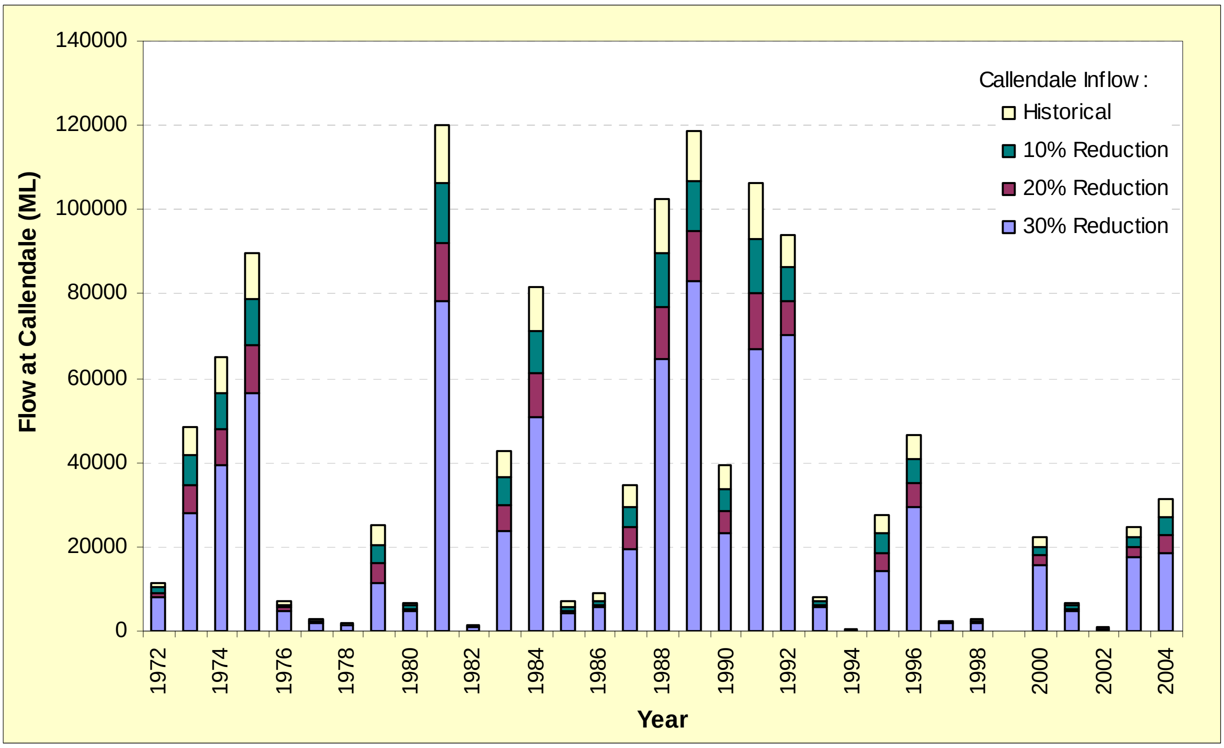

Figure 15 Reduction in Total Flow at Callendale.

The "30% Reduction" (blue) flow component represents the inflow to Callendale if both the inflow to Bool Lagoon and flow from the Southern Bakers Range area were reduced by 30%.

DIVERSION ONLY AT CALLENDALE

The reduction in Bool Lagoon outflows and hence the reduced flows arriving at Callendale at an annual scale can be estimated for the period 1972 to 2004. However, without recorded Bool Lagoon release data from 1972 to 1984, it is difficult to determine the intra-annual distribution of these reduced outflows and hence how the hydrograph at Callendale is affected. Therefore, an analysis of diversions was only possible for the period 1985 to 2004. It was assumed that the reduced inflows would cause Bool Lagoon to require a longer time to fill and hence a delay in releases of surplus flows. Therefore, for those years during this period when there were releases from Bool Lagoon, the reduction in the volume released was subtracted from the beginning of the outflow hydrograph.

Following these assumptions, Figure 16 shows the adjustments to the 1988 Bool Lagoon release hydrograph. With a 10% reduction in inflow, 7,142 ML less would be released and this is removed from the beginning of the historical hydrograph. Similarly, for a 20% reduction in inflows, 14,283 ML are removed from the historical hydrograph.

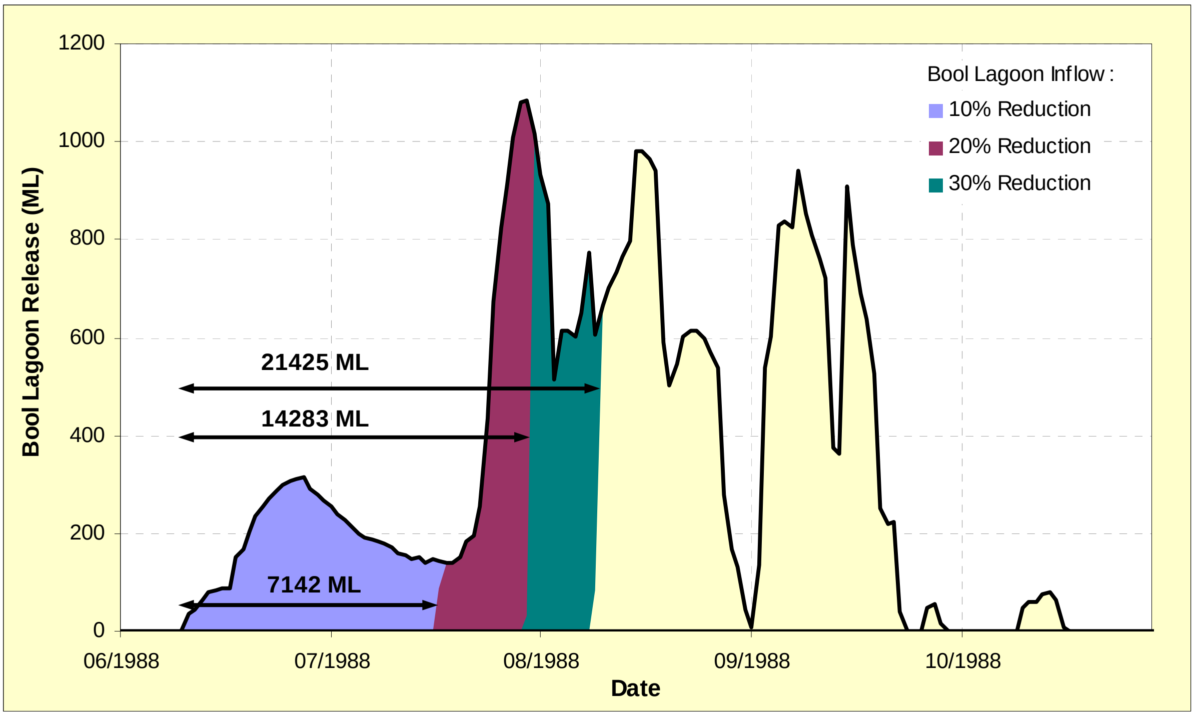

Figure 16 Adjustment to 1988 Bool Lagoon Release Hydrograph.

The adjusted Bool Lagoon release hydrographs were then used to adjust the recorded hydrographs at Callendale (refer to Heneker (2006) for details on the routing of flow between Bool Lagoon and Callendale) and hence the divertible volumes could be calculated. Figure 17 shows the reduction in the divertible flows at Callendale when no flows are diverted north from Bool Lagoon. Despite reductions in total available flow under these reduction scenarios, the divertible flows are still substantial. However, under historical flow conditions, there was the potential to divert flow in 12 out of 20 years. Under the 20% reduction scenario, it is unlikely that flow would be diverted during one of these years and under a 30% reduction during two of these years. Figure

18 then shows the percentage reduction in divertible flows when compared to the historically divertible flows, again when flows are only diverted at Callendale.

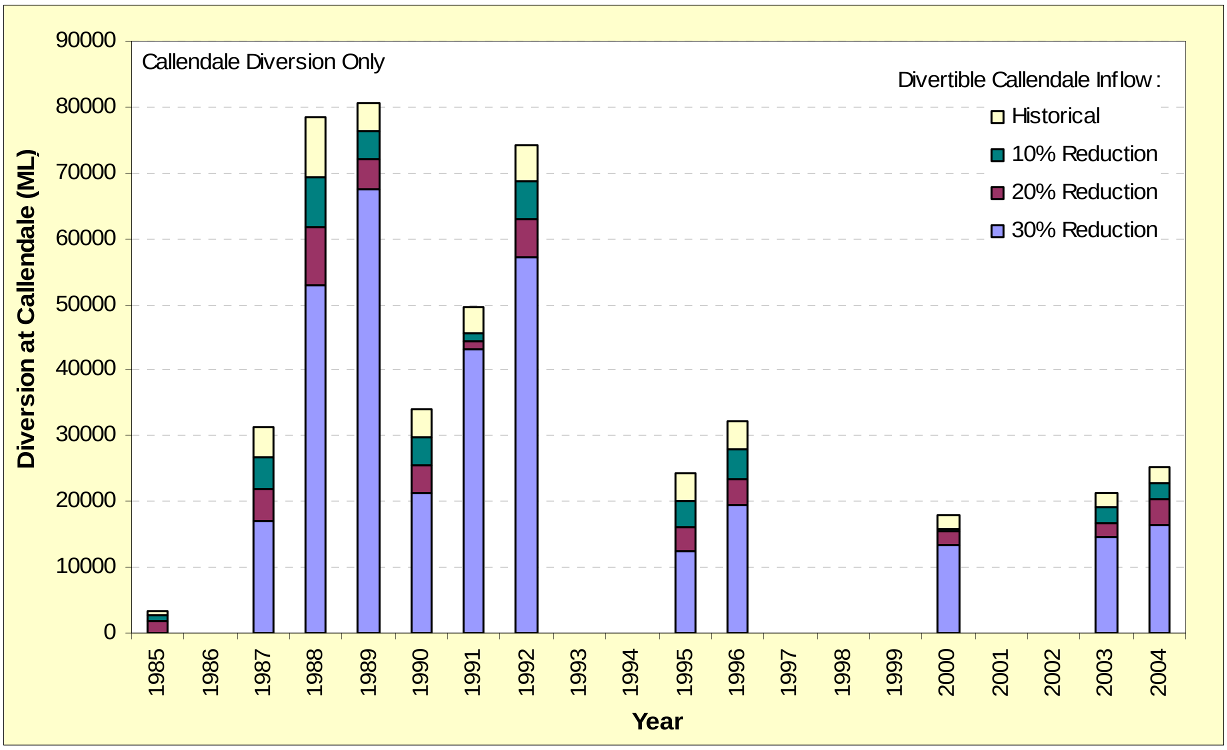

Figure 17 Reduction in Divertible Flow at Callendale (without Bool Lagoon Diversion).

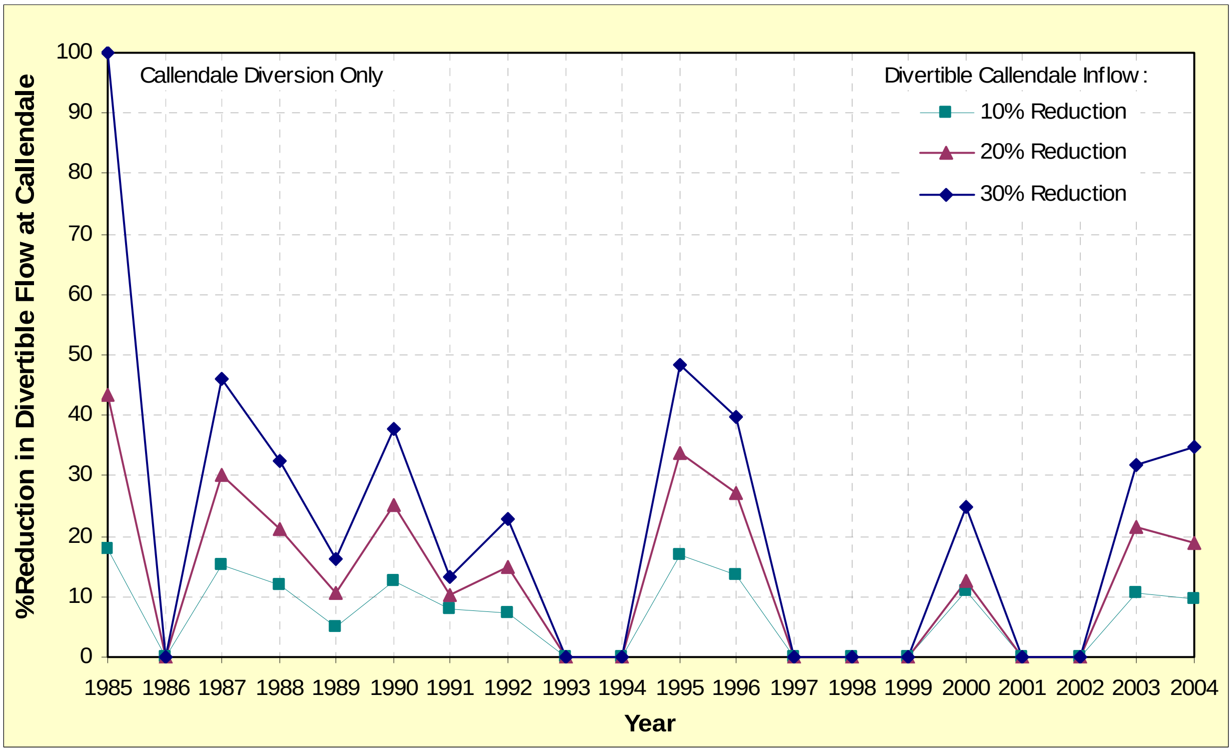

Figure 18 Percentage Reductions in Divertible Flows at Callendale (without Bool Lagoon Diversion).

Figure 18 highlights that the 10% flow reduction scenario may not necessarily equate to a 10% reduction in flow diverted. A lower percentage reduction in divertible flow (for example, divertible flow reduced by 8%) than a given reduced inflow (10% reduced inflow) is caused primarily by channel capacity limits. A percentage higher reduction generally results from a reduction in the number of events diverted. For example, an event where the total volume and number of diversion days may have provided an environmental benefit if diverted under historical conditions, may have been reduced to a point where the potential benefit is limited under reduced flows.

Table 3 shows the relative frequencies of flows available for diversion. These show that even with reduced flows, frequent diversions of significant volumes are still achievable.

Table 3 Frequency of Available Flow Volumes for Diversion at Callendale (no Bool Lagoon Diversion).

Flow Available for Diversion (ML)	No. Years*	Frequency (years)
Historical		
>10,000	11	5.5 in 10
>20,000	10	5 in 10
>30,000	7	3.5 in 10
>40,000	4	2 in 10
>50,000	3	1.5 in 10
10% Reduction		
>10,000	11	5.5 in 10
>20,000	9	4.5 in 10
>30,000	4	2 in 10
>40,000	4	2 in 10
>50,000	3	1.5 in 10
20% Reduction		
>10,000	11	5.5 in 10
>20,000	8	4 in 10
>30,000	4	2 in 10
>40,000	4	2 in 10
>50,000	3	1.5 in 10
30% Reduction		
>10,000	11	5.5 in 10
>20,000	5	2.5 in 10
>30,000	4	2 in 10
>40,000	4	2 in 10
>50,000	3	1.5 in 10

*Period of analysis 1985 to 2004

Table 3 again highlights the capacity of the Bakers Range Watercourse as a bigger limiting factor to the volumes of divertible flow than a reduction in contributing catchment area. Figure 19 shows that although the 30% reduction scenario results in a significant decrease in overall flow at Callendale, during the higher flow periods, both hydrographs are generally above the 1000 ML/day maximum diversion threshold. Hence, similar volumes would be diverted under both conditions.

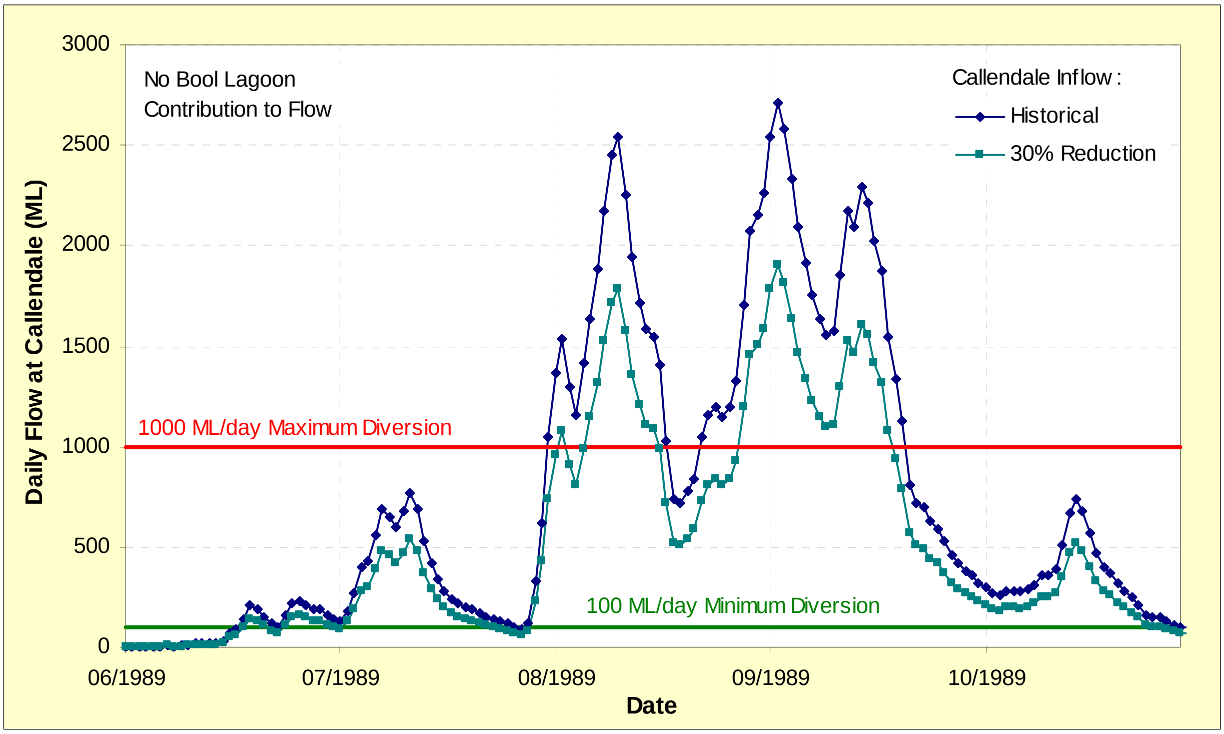

Figure 19 Comparisons of the 1989 Hydrograph under Historical and 30% Reduced Inflow Conditions (no Bool Lagoon Diversion).

CONCURRENT DIVERSIONS AT CALLENDALE AND BOOL LAGOON

The effect on available flows and hence diversions at Callendale, assuming that any excess water available in Bool Lagoon is diverted north into Drain E, was then considered. The flows from the Southern Bakers Range Watercourse and Drain C as presented in Figure 14 were evaluated.

Figure 20 shows the reduction in the divertible flows at Callendale. Despite some reductions in total available flow under these reduction scenarios, the divertible flows are still substantial. Under historical flow conditions, there was the potential to divert flow in 12 out of 20 years. Under the 30% reduction scenario, it is unlikely that flow would be diverted during one of these years.

Figure 21 then shows the percentage reduction in divertible flows when compared to the historically divertible flows, when flows were diverted at Callendale and Bool Lagoon.

Table 4 shows the relative frequencies of flows available for diversion. These show that even with reduced flows, frequent diversions of significant volumes are still achievable. However, in comparison to the diversion of flows at Callendale alone, there is a higher reduction in the frequencies of the larger volumes.

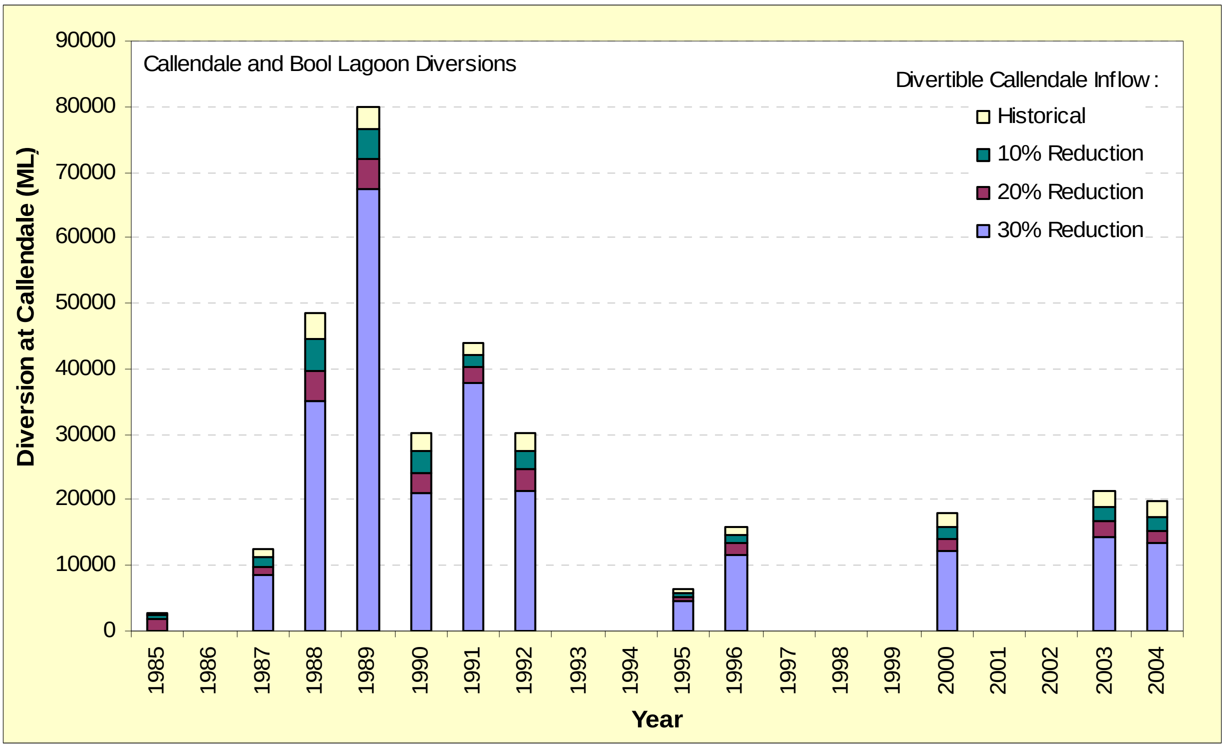

Figure 20 Reduction in Divertible Flows at Callendale (with Bool Lagoon Diversion).

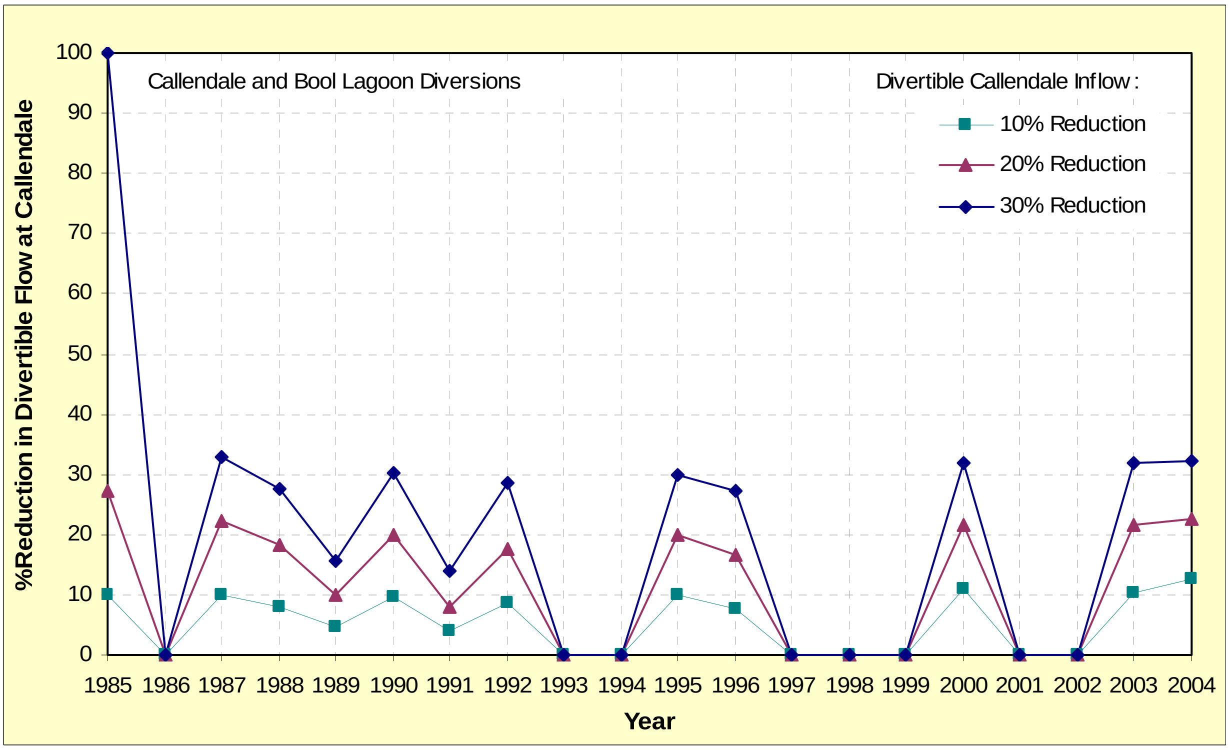

Figure 21 Percentage Reductions in Divertible Flows at Callendale (with Bool Lagoon Diversion).

Table 4 Frequency of Available Flow Volumes for Diversion at Callendale (with Bool Lagoon Diversion).

Flow Available for Diversion (ML)	No. Years*	Frequency (years)
Current		
>10,000	10	5 in 10
>20,000	6	3 in 10
>30,000	5	2.5 in 10
>40,000	3	1.5 in 10
>50,000	1	0.5 in 10
10% Reduction Inflows		
>10,000	10	5 in 10
>20,000	5	2.5 in 10
>30,000	3	1.5 in 10
>40,000	3	1.5 in 10
>50,000	1	0.5 in 10
20% Reduction Inflows		
>10,000	9	4.5 in 10
>20,000	5	2.5 in 10
>30,000	3	1.5 in 10
>40,000	2	1 in 10
>50,000	1	0.5 in 10
30% Reduction Inflows		
>10,000	9	4.5 in 10
>20,000	5	2.5 in 10
>30,000	3	1.5 in 10
>40,000	1	0.5 in 10
>50,000	1	0.5 in 10

ADDITIONAL FLOW TO WEST AVENUE WATERCOURSE

The West Avenue wetlands are generally considered to be of high environmental value and significance within the Upper South East. Historically, these wetlands received significant flows from the region south of Drain M including the Bakers Range Watercourse. Since construction of the Blackford, Jacky White and Fairview Drains, the local catchment area has become the single source of inflow (Vivian, 2004) and the wetlands are in danger of degradation due to a lack of significant flows. As a result, the design of the Bald Hill Drain (adjacent to the West Avenue Watercourse) will consider a connection to the Fairview Drain. This would allow the diversion of flow from the southern watercourses and drains into West Avenue.

Heneker (2006) showed that the diversion of flows at Callendale, with or without diversions north from Bool Lagoon, have the potential to provide significant benefits to the wetlands along West Avenue Watercourse. It was also shown that estimates of current conditions within the West Avenue and Wimpinmerit Catchments are extremely unreliable. Therefore, as in Heneker (2006), only the potential additional wetland turnovers (those above current conditions) have been estimated. Table 5 and Table 6 show these potential water turnovers, with and without diversions from Bool Lagoon. While the number of additional turnovers decrease with decreasing flow diverted, the channel capacity of Fairview Drain (195 ML/day) is the primary limiting factor in terms of total deliverable flows.

Table 5 Water Turnover in West Avenue Wetlands (no Bool Lagoon Diversion).

Year	Current		10% Reduction		20% Reduction		30% Reduction	
	Diversion to West Avenue	Additional Turnover	Diversion to West Avenue	Additional Turnover	Diversion to West Avenue	Additional Turnover	Diversion to West Avenue	Additional Turnover
1985	3934	0.7	1979	0.4	1584.7	0.3	0.0	0.0
1986	4814	0.9	0	0.0	0.0	0.0	0.0	0.0
1987	14075	2.5	10832	1.9	9872.0	1.8	8821.8	1.6
1988	24680	4.4	21183	3.8	20129.3	3.6	19298.8	3.4
1989	26742	4.8	25077	4.5	23994.1	4.3	23314.0	4.2
1990	11194	2.0	10356	1.8	10085.2	1.8	9820.6	1.8
1991	16251	2.9	13416	2.4	13154.5	2.3	12870.0	2.3
1992	26904	4.8	22568	4.0	21213.1	3.8	20590.5	3.7
1993	3345	0.6	0	0.0	0.0	0.0	0.0	0.0
1994	0	0.0	0	0.0	0.0	0.0	0.0	0.0
1995	5778	1.0	5277	0.9	4746.1	0.8	4423.9	0.8
1996	15497	2.8	13591	2.4	10545.8	1.9	8212.9	1.5
1997	0	0.0	0	0.0	0.0	0.0	0.0	0.0
1998	0	0.0	0	0.0	0.0	0.0	0.0	0.0
1999	0	0.0	0	0.0	0.0	0.0	0.0	0.0
2000	13363	2.4	12923	2.3	12091.5	2.2	11172.0	2.0
2001	3906	0.7	0	0.0	0.0	0.0	0.0	0.0
2002	0	0.0	0	0.0	0.0	0.0	0.0	0.0
2003	12708	2.3	9351	1.7	8898.1	1.6	8576.9	1.5
2004	11754	2.1	9581	1.7	9051.3	1.6	8540.0	1.5

Table 6 Water Turnover in West Avenue Wetlands (with Bool Lagoon Diversion).

Year	Current		10% Reduction		20% Reduction		30% Reduction	
	Diversion to West Avenue	Additional Turnover	Diversion to West Avenue	Additional Turnover	Diversion to West Avenue	Additional Turnover	Diversion to West Avenue	Additional Turnover
1985	3874	0.7	1947	0.3	1585	0.3	0	0.0
1986	3717	0.7	0	0.0	0	0.0	0	0.0
1987	11736	2.1	9774	1.7	8708	1.6	7773	1.4
1988	21070	3.8	19059	3.4	17628	3.1	16776	3.0
1989	26528	4.7	25077	4.5	23994	4.3	23314	4.2
1990	11194	2.0	10356	1.8	10085	1.8	9821	1.8
1991	15305	2.7	13070	2.3	12744	2.3	12015	2.1
1992	17122	3.1	14114	2.5	13675	2.4	12555	2.2
1993	0	0.0	0	0.0	0	0.0	0	0.0
1994	0	0.0	0	0.0	0	0.0	0	0.0
1995	4986	0.9	4632	0.8	4344	0.8	4015	0.7
1996	11413	2.0	7220	1.3	6737	1.2	6020	1.1
1997	0	0.0	0	0.0	0	0.0	0	0.0
1998	0	0.0	0	0.0	0	0.0	0	0.0
1999	0	0.0	0	0.0	0	0.0	0	0.0
2000	13363	2.4	11485	2.1	10824	1.9	10089	1.8
2001	3906	0.7	0	0.0	0	0.0	0	0.0
2002	0	0.0	0	0.0	0	0.0	0	0.0
2003	12708	2.3	9351	1.7	8898	1.6	8577	1.5
2004	11726	2.1	8920	1.6	8362	1.5	7933	1.4

IMPACT ON FLOW TO LAKE GEORGE

Community opposition to a reduction in flow to Lake George from Drain M is considered one of the main factors against redirecting flow from the Lower South East into the Upper South East. Heneker (2006) showed that if significant volumes of water were diverted prior to Callendale, the mean annual flows entering Lake George would likely be reduced by an average of 50%. This reduction would be greater in higher rainfall and hence flow years.

Figure 22 shows the potential impact that reduced flows from Mosquito Creek, the Southern Bakers Range Watercourse and Drain C may have on recorded Drain M flows at Woakwine. These flows were determined by subtracting the volume of the reduced inflow to Callendale from the flow data recorded at Woakwine.

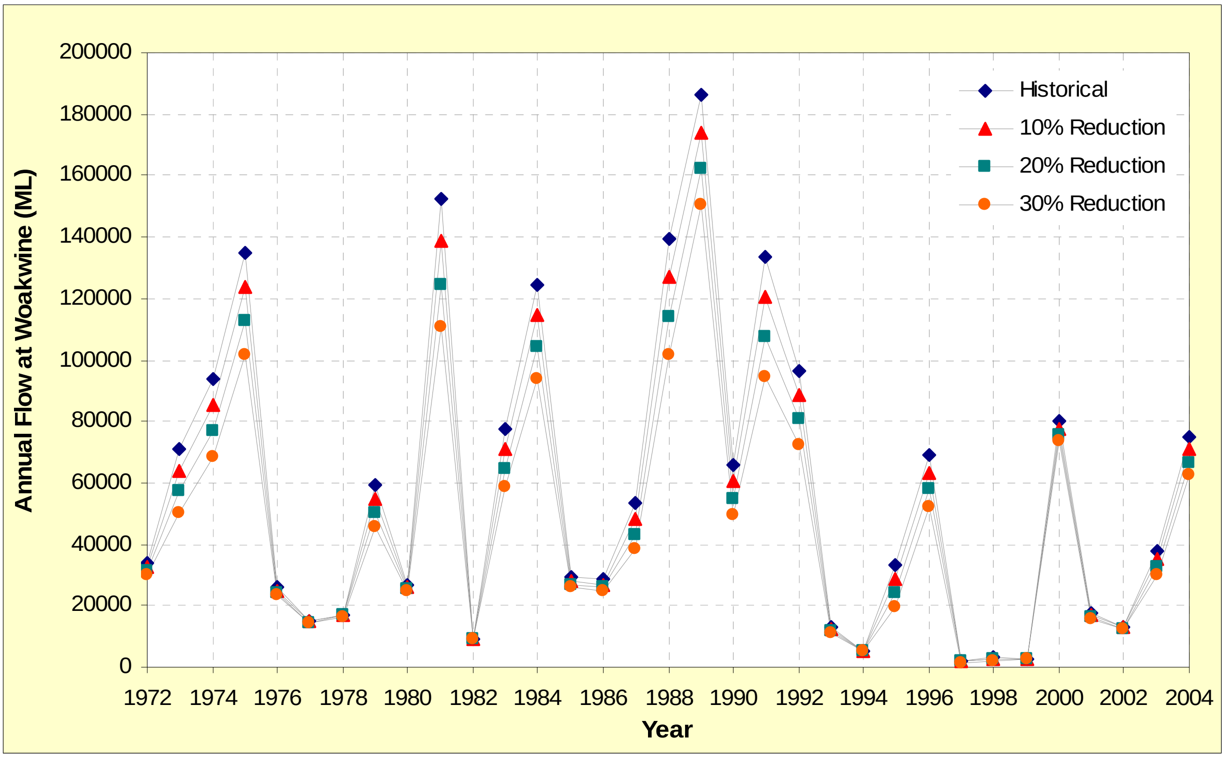

Figure 22 Reduction in Flows from Mosquito Creek, the Southern Bakers Range Watercourse and Drain C recorded at Woakwine.

Figure 23 shows the reduced inflows to Lake George if the inflows to Bool Lagoon and Callendale were reduced by 30% with no diversions northwards from Bool Lagoon into Drain E. The "Woakwine - 30% Reduction" (blue) flow component represents the inflow to Lake George under the 30% reduction scenario and associated diversions at Callendale. The "Woakwine - Historical" (maroon) flow component represents the <u>additional</u> flow into Lake George under historical conditions and associated diversions at Callendale. The significance of the reduced runoff varies between years because as the flows at Callendale decrease, it may not be beneficial to divert flows north during that year. As such, under the 30% reduction scenario it is possible that higher flows may enter Lake George than under the 20% reduction scenario.

The "BR Diversion - 30% Reduction" (green) flow component represents the amount of flow diverted at Callendale under the 30% reduction scenario. The "BR Diversion - Historical" (yellow) flow component then represents the <u>additional</u> flow diverted under historical conditions.

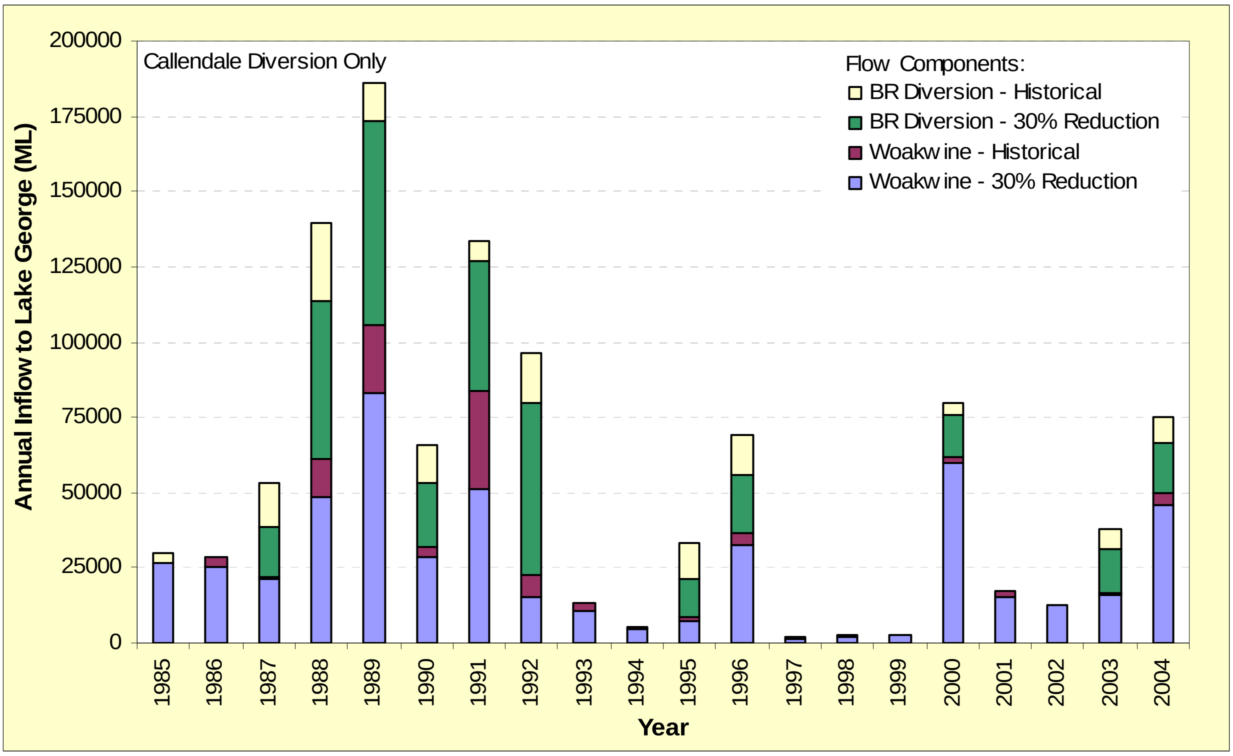

Figure 23 Annual Inflow to Lake George under Historical and 30% Reduced Conditions (no Bool Lagoon Diversion).

Figure 24 shows the reduced inflows to Lake George if the inflows to Bool Lagoon and Callendale were reduced by 30% with diversions northwards from Bool Lagoon and Callendale.

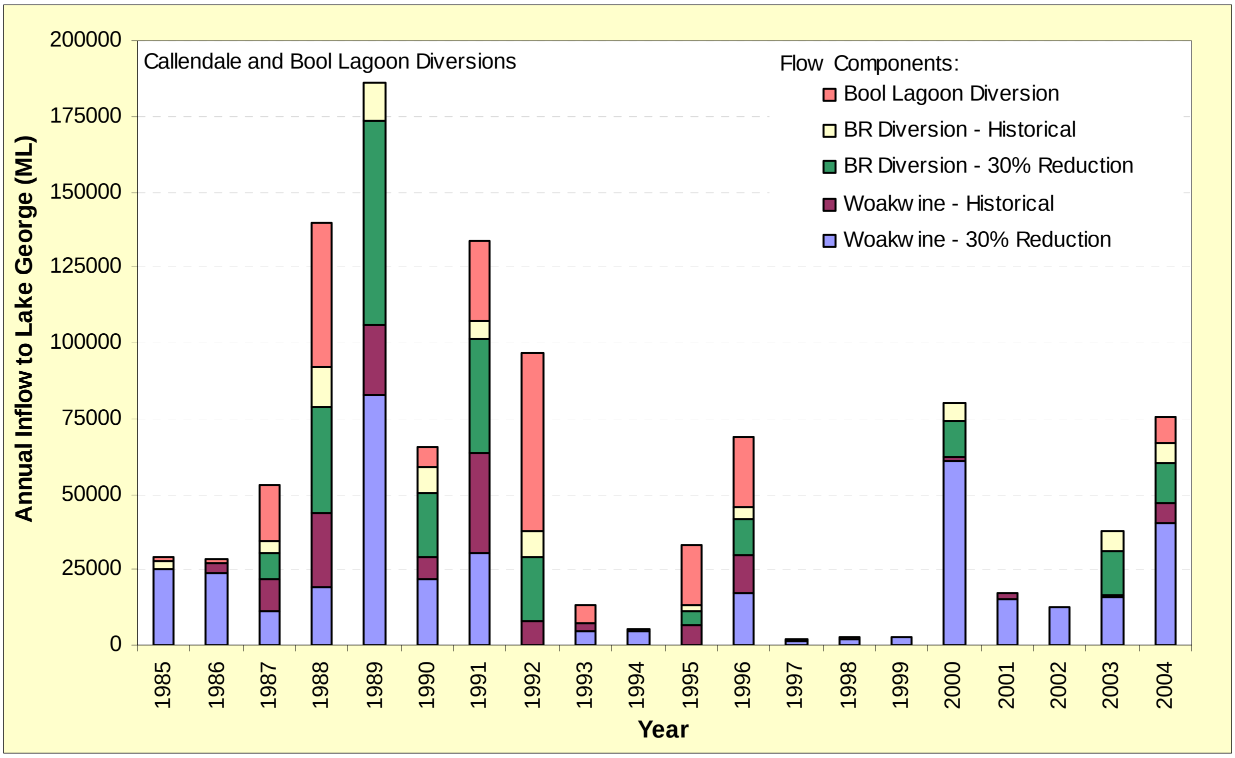

Figure 24 Annual Inflow to Lake George under Historical and 30% Reduced Conditions (with Bool Lagoon Diversion).

Again, the “Woakwine - 30% Reduction” (blue) flow component represents the inflow to Lake George under the 30% reduction scenario and associated diversions at Callendale with no flow released from Bool Lagoon. The “Woakwine - Historical” (maroon) flow component represents the additional flow into Lake George under historical conditions and associated diversions at Callendale. There appears limited difference in the flows entering Lake George when flow is diverted north at Bool Lagoon or not. This is because any flow not diverted at Bool Lagoon is likely to be diverted at Callendale instead. If it is only possible to divert at one point, the relative importance of the Drain E and Bakers Range systems would need to be examined to determine which diversion point is preferable.

CONCLUSIONS AND RECOMMENDATIONS

This investigation extends the preliminary hydrological investigation of the potential volume and frequency of flows available for diversion from the Lower South East into the Upper South East (Heneker, 2006) to assess the potential reductions in available flows due to plantation forestry and climate change. In addition and irrespective of the cause of flow reductions, it has examined the potential divertible volumes under a range of reduced flow scenarios.

The volumes available to divert north from Bool Lagoon into Drain E and the Marcollat Watercourse reduce as the divertible volume decreases. In particular, the diversion of larger volumes, such as those in excess of 40,000 ML, were almost eliminated once inflows to Bool Lagoon are reduced by 20 to 30%. However, the excess volumes at Jaffray Swamp and the Drain E wetland turnovers would still be significantly larger than those without the diversions. The same outcome was found for excess volumes at Jip Jip and for the Marcollat Watercourse wetland turnovers.

With or without diversions north from Bool Lagoon, the diversion of water north along Bakers Range Watercourse from Callendale is likely to provide significant benefits to wetland systems such as those along West Avenue, even under the 30% flow reduction scenario. It was highlighted that the capacity of the Bakers Range Watercourse was generally a bigger limiting factor to the volumes of divertible flow than reductions in contributing catchment areas (up to 30% flow reduction scenario). Similarly for West Avenue Watercourse, while the number of additional turnovers decrease with decreasing flow diverted, the channel capacity of Fairview Drain is the primary limiting factor in terms of total deliverable flows.

The impact on Lake George in terms of reduced inflows from overall flow reductions as well as diversions has also been considered. The impact of these reductions in terms of water level and ecology within Lake George has not been considered within this investigation. There appears limited difference in the flows entering Lake George when flow is diverted north at Bool Lagoon or not. This is because any flow not diverted at Bool Lagoon is likely to be diverted at Callendale instead.

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