Gippsland Lakes & Catchment Taskforce

Impacts of Bushfires on Water Quality in the Gippsland Lakes:

Exploring Options for Mitigation

Final Report
December 2008
A report prepared for the Gippsland Lakes & Catchment Taskforce

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Impacts of Bushfires on Water Quality in the Gippsland Lakes: Exploring Options for Mitigation

FINAL REPORT

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Summary

This report explores the impact of bushfires on water quality in the Gippsland Lakes and options for reducing those impacts.

In the summers of 2003 and 2006/07, bushfires burned large parts of the forested catchments of the Gippsland Lakes. Approximately 9% of the catchment area was burned in 2003 and 34% in 2006/07. Evidence of the impact of these fires on water quality in the Gippsland Lakes includes the following.

- Monitoring of runoff from catchments directly effected by fires shows large increases in loads of suspended sediment, nitrogen and phosphorus from background levels (Lane et al. 2006; Sheridan et al., 2008).
- Modelling of sediment and nutrient loads, adjusted to take account of burned areas, predicted that loads of total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) delivered to the lakes would be 8.5, 1.8 and 1.6 times greater (on an average annual basis) respectively for 1 to 2 years after the fires compared to baseline loads before the fires (Feikema et al., 2005).
- Estimates of actual loads of TP and TN to the lakes following the 2006/07 fires were the highest of any year where measurements were available (a total of 30 years). Approximate loads to the lakes were 900 tonnes of phosphorus and 6000 tonnes of nitrogen for 2007/08 compared to average loads for the period 1975-1999 of 300 tonnes of phosphorus and 2800 tonnes of nitrogen (Grayson et al., 2001; Cook et al, 2008). These high loads were caused by the intense rainfall that fell on burned catchments and carried nutrients to the lakes in the resulting floods of June/July 2007. It seems likely that these high nutrient inputs, particularly nitrogen, to the lakes resulted in the current bloom of *Synechococcus* (Cook et al, 2008).

Although these bushfires and the associated flooding are rare events, it is appropriate for the Gippsland Lakes Task Force to consider management options to mitigate the water quality impacts of similar events in the future. It is also likely that events such as these will become more common with climate change.

Climate change projections suggest that fire weather, one of the risk factors for bushfires, will become more severe. The catchment of the Gippsland Lakes is likely to become dryer and hotter as atmospheric carbon dioxide concentration increases. By 2030 summer temperatures are expected to increase by about 0.9^{o}C in east Gippsland, relative humidity will decrease, and the number of hot days (over 30^{o}C) will increase (DSE, 2008). The Forest Fire Danger Index (FFDI) in projected to increase (Hennesy, et al., 2005).

There are several options for mitigating the impact of bushfires on water quality in the Gippsland Lakes. Following a workshop with a range of specialists, the following options are considered to be the highest priority:

1) Undertake prescribed burning using procedures that will protect water quality

   Water quality impacts are related to fire intensity so prescribed burning has the potential to reduce the impacts on the Gippsland Lakes especially if riparian areas can be protected.

2) Undertake rehabilitation activities as part of fire suppression

   Often fire breaks and tracks are constructed as part of the fire fighting effort. Rehabilitation of these works should take place as soon as the immediate fire danger is over (i.e. within a one to a few days of their construction) rather than waiting until the fire is extinguished, or until the end of the fire season.

3) Identify those areas that contribute high nutrient loads to the lakes and that are cost effective to mitigate

   It is likely that the nutrient load to the lakes is not uniformly supplied from the burned areas. Instead, there are expected to be 'hotspots' that make a large relative contribution. These are likely to include eroding areas that are hydrologically well connected to waterways that drain directly to the lakes. The costs of treating these different areas will vary so it will be possible to develop a strategy that maximizes return on investment. This could build on earlier work that set priorities across the whole range of activities being undertaken to protect the lakes. It may also involve expanding and updating the Gippsland Lakes Future Direction and Action Plan (Gippsland Lakes Task Force, 2002).

4) Undertake works priority works identified in Step 3

   Once the nutrient reduction strategy has been identified it should be implemented. This would involve expansion of the current program to reduce nutrient loads to the Lakes by 40% by 2022 (Gippsland Lakes Task Force, 2002).

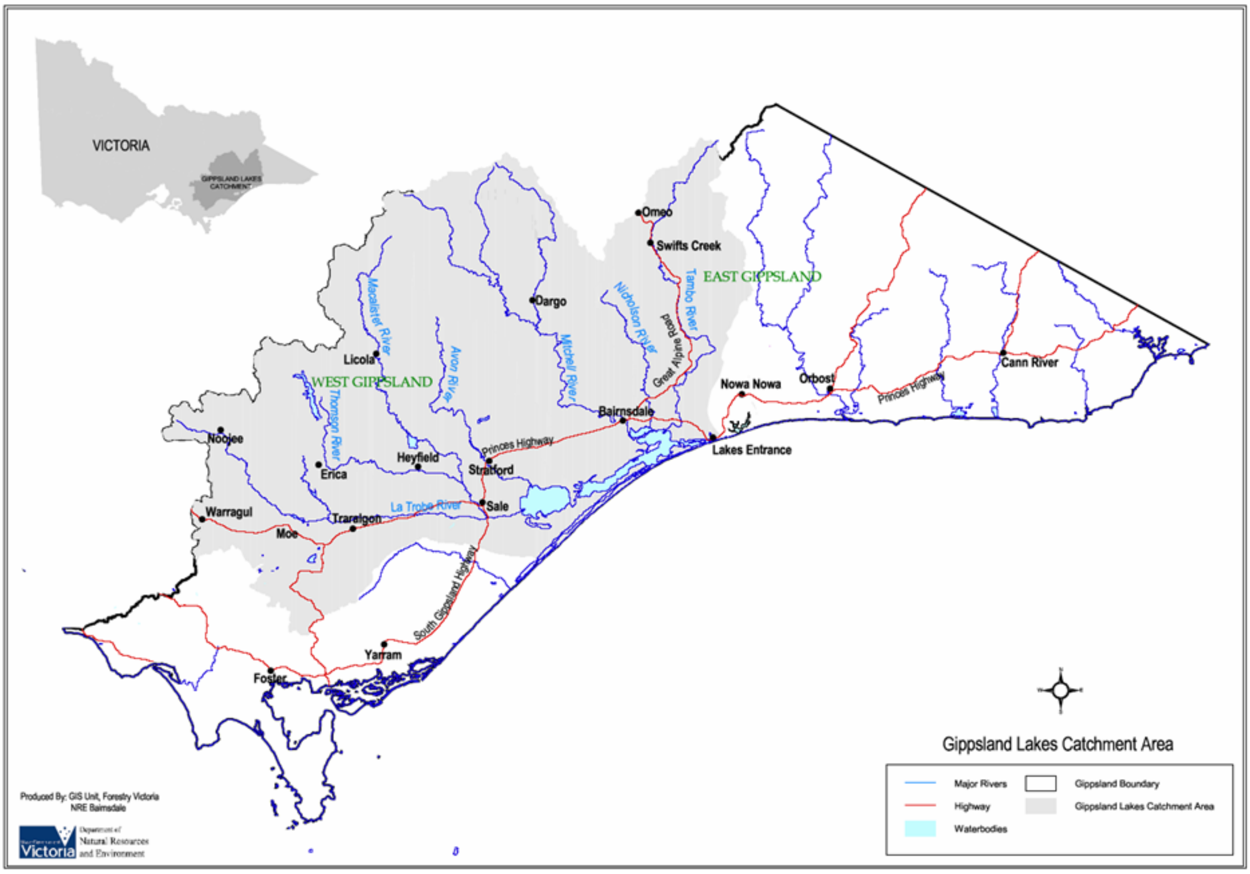
1. Introduction

This report describes a program of activities to reduce the impact of bushfires on water quality in the Gippsland Lakes. It is based on a literature review which was used to develop a discussion paper, followed by a workshop where mitigation options were discussed and prioritised. Workshop participants contributed a range of expertise in catchment management and determined the highest priority mitigation options for further investigation (Appendix 1). Comments on an earlier draft have been incorporated into this final report.

1.1. Background

The Gippsland Lakes cover an area of about 300 km^2 in eastern Victoria. Five major rivers drain to the lakes with a combined catchment area of about 20,000 km^2. The rivers, in order from west to east, are the Latrobe, Thomson, Avon, Macalister, Mitchell, Nicholson and Tambo (Figure 1).

Even in the absence of bushfires, there are water quality problems in the Gippsland Lakes caused by catchment runoff with elevated levels of sediment and nutrients. Work by Grayson et al. (2001) showed that compared to natural conditions, loads of total suspended solids (TSS), total phosphorus (P) and total nitrogen (N) were 2.2, 1.8 and 3 times higher than natural levels (Grayson et al., 2001). The Gippsland Lakes are susceptible to becoming eutrophic when large runoff events deliver nutrient loads to the lakes resulting in nutrient rich surface water. Under these conditions, algal blooms are likely, which lead to social, economic and ecological impacts. There have been extensive interventions to improve water quality over the last decade including the development and implementation of a Gippsland Lakes Future Directions and Actions Plan (Gippsland Lakes Task Force, 2002). This includes a target to reduce nutrient loads to the lakes by 40% by 2022.



- **Figure 1 Gippsland Lakes and Catchment (Department of Sustainability and Environment)**

2. The impact of bushfires on nutrient loads to the Gippsland Lakes

2.1. Nutrient release and transport following bushfires

The impacts of bushfires on the nutrient release and transport into receiving waters is complex and dependent upon factors such as:

- prior history of fires,
- fire intensity and severity,
- time since fire;
- types of vegetation,
- types of soils,
- the use of fire retardants (Adams and Simmons, 1999)
- post-fire erosion rates, and
- timing and intensity of post fire rainfall events

It is well documented that sediment, phosphorus and nitrogen loads in streams increase after catchment fires (Brown, 1972; Leitch et al., 1983; Atkinson, 1984; Chessman, 1986; Riggan et al., 1994; Lane et al., 2006) but the impact on the Gippsland Lakes of any particular fire will very depending on a range of factors.

The effect of fire increases soluble nitrogen compounds in the soil which can be transferred to waterways following rainfall. Wan et al. (2001) showed the pools of soil ammonia (NH_4) increased approximately twofold immediately after fire, then gradually declined to the pre-fire level after one year. Ammonia is produced through the decay of organic matter. The fire-induced increase in the soil NO_3 pool was small (24%) immediately after the fire, and reached a maximum of approximately threefold of the pre-fire level within 0.5 to 1 year after fire, and then declined. The decline is attributed to nutrient cycling within the soils by the processes of nitrification (NH_4 to NO_3) and denitrification (NO_3 to N_2). Ammonia, in the form of ammonium phosphate or ammonium sulphate is also contained in some fire suppressants. Nutrients can also be transferred via ash and partly burned leaf letter and other material. Atmospheric deposition of volatilised nutrients may also occur (Ice et al., 2004). The loss of vegetation and changes to soil structure also increases erosion so that there are increased rates of transport of sediment attached nutrients.

2.2. Bushfire impacts on runoff events

Fires can be considered to create a potential load of sediment and nutrients for delivery to the lakes but overland flow will be required to efficiently deliver this material. It seems likely that landscapes affected by fire are more prone to runoff events in the immediate post fire period. Studies of bushfire impacts have shown:

- A larger proportion of rainfall contributes to runoff compared to unburned areas.

  Mechanisms include reduced interception of rainfall because of loss of vegetation, and increases in water repellency of soils so that much of the rain, falling near streams, will runoff into waterways (Sheridan et al., 2007). Higher runoff coefficients have been observed where burned areas cover a large proportion of catchments (Brown, 1972; Lane et al. 2006).

- There are more frequent runoff events

  Additional runoff events have been observed in burned catchments compared to nearby unburned catchments (Townsend and Douglas, 2004). This will be caused by the same mechanisms that lead to higher runoff coefficients (see above).

In addition there are longer term impacts on runoff and catchment yield, caused by vegetation changes as the forest re-grows. These have been considered in detail for the Gippsland Lakes catchments (see section 2.5).

In hydrology, the situations leading to floods are often divided into *causes* and *modifying factors* (Ladson, 2008). For floods in the Gippsland Lakes, the cause is most likely to be intense rainfall, while bushfire effects may be considered a modifying factor if they lead to landscapes where more rain becomes runoff.

2.3. Timing of catchment responses and recovery

The literature related to fire impacts suggests that the timing of catchment effects varies but can last up to about 80 years. The timing of impacts can be summarised as follows.

- An immediate increase in pools of soil ammonia (NH_4) by approximately twofold after fire, then a gradual decline to the pre-fire level after about one year (Wan et al., 2001).
- An immediate fire-induced increase in the soil NO_3 pool (by about ~24%), then further increases to a maximum of the pre-fire level within 0.5 to 1 year after fire followed by a decline that may take up to 10-years to reduce to background levels (Riggan et al. 1994).
- An immediate increase in sediment runoff generation followed by an exponential decline to background levels over 2 years as vegetation cover increases (Sheridan et al., 2007).
- An increase in event runoff for a given amount of rainfall with recovery over about 5 years (Brown et al., 1972).
- An initial increased followed by a decrease in catchment runoff, peaking after about 20 years as the re-growing forest ages (Section 2.6).

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- Return to normal hydrologic response after about 80 years (Section 2.6), provided there is a stable climate and no further fires.

2.4. Recent bushfires in the Gippsland Lakes catchment

In the summer of 2003 and again in 2006/07 extensive areas of the Gippsland Lakes catchments were burned (Figure 2). The 2003 fires affected an area of 1.3 million ha in north east Victoria and Gippsland including approximately 9% of the total catchment area of the Gippsland Lakes. The 2006/07 fires are believed to be the longest running bushfires in Victoria's fire history continued for over two months, and burned nearly 1.2 million hectares of public and private land. These fires affected about 34% of the catchment area, with large areas suffering high fire severity (Table 1, Figure 3). Some areas were burned in both the 2003 and 2006/07 fires or in earlier fires (Figure 4). These fires have had, and will continue to have, a large impact on both runoff quantity and quality and will adversely affect the water quality in the Gippsland Lakes.

- **Table 1 Extent of the 2003 and 2006/07 fires in the Gippsland Lakes Catchment (SKM, 2008a; Feikema et al., 2005).**

Catchment	Total Area (km^2)	Forested Area (km^2)*	2003 Fires			2006/07 Fires		
			Area burned (km^2)	% of catchment burned	% of forest burned	Area burned (km^2)	% of catchment burned	% of forest burned
Avon River	2,000	1,600	0	0	0	1,030	51	64
Macalister River	2,300	1,800	0	0	0	1,800	78	100
Mitchell River	5,300	4,000	1,070	20	27	2,360	45	60
Nicholson River	1,100	900	0	0	0	440	40	50
Tambo River	2,900	2,300	670	23	29	470	16	20
Thomson River	1,650	1,200	0	0	0	620	38	52
Latrobe River	5,200	2,000	0	0	0	271	5	14
Gippsland Lakes	**20,500**	**13,800**	**1,740**	**9**	**13**	**7,000**	**34**	**51**

* Forested areas estimated from DWR (1989)

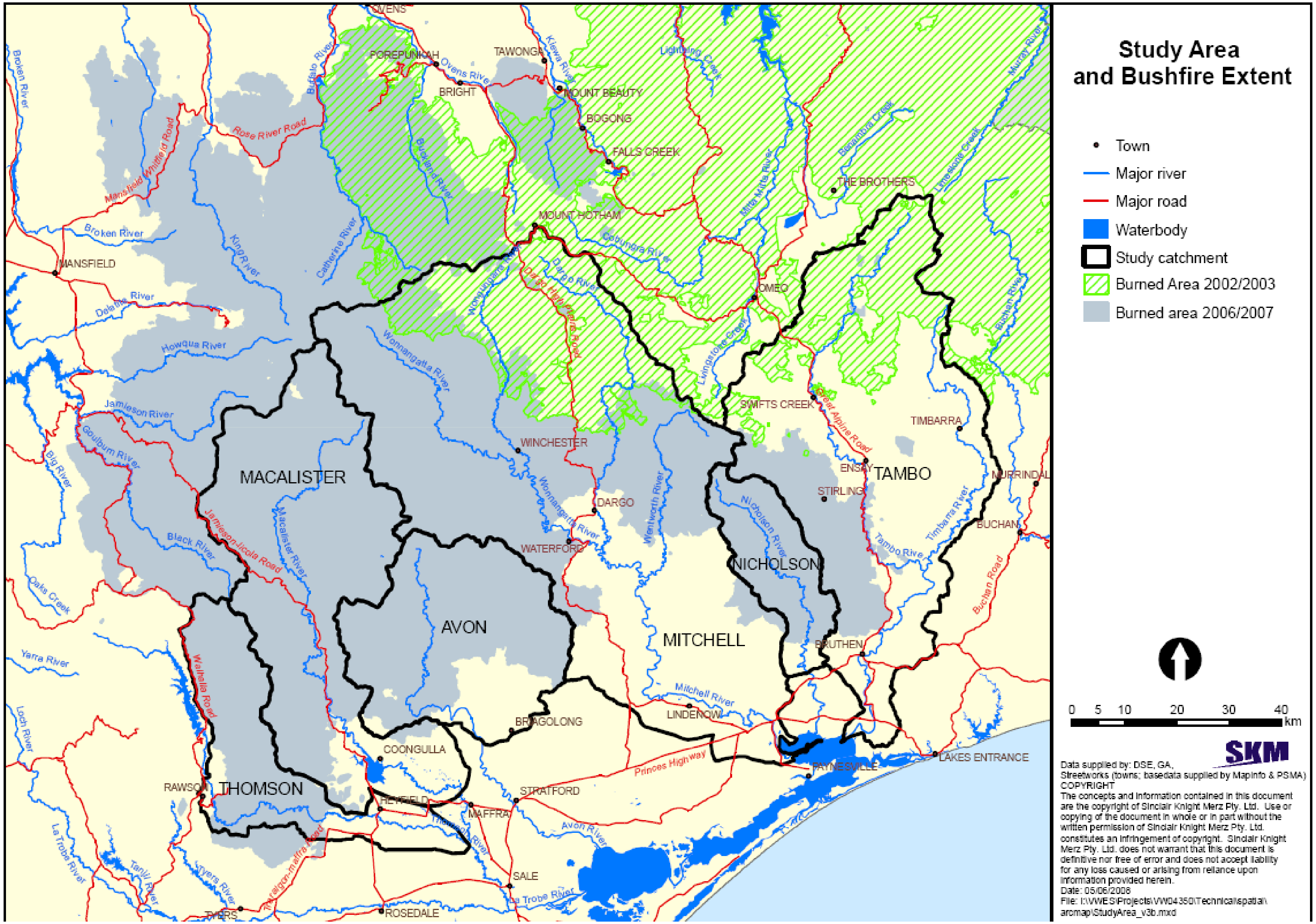
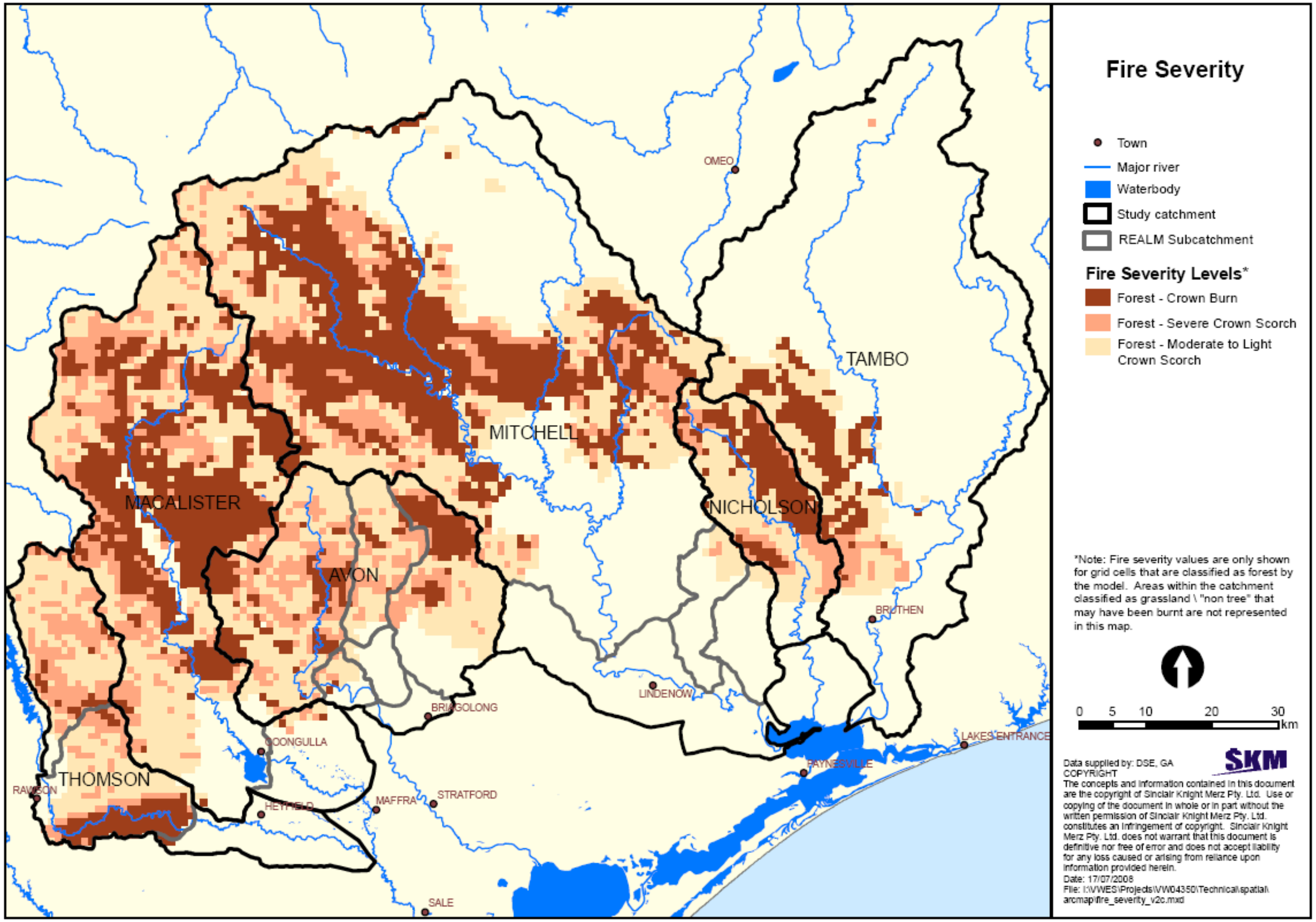
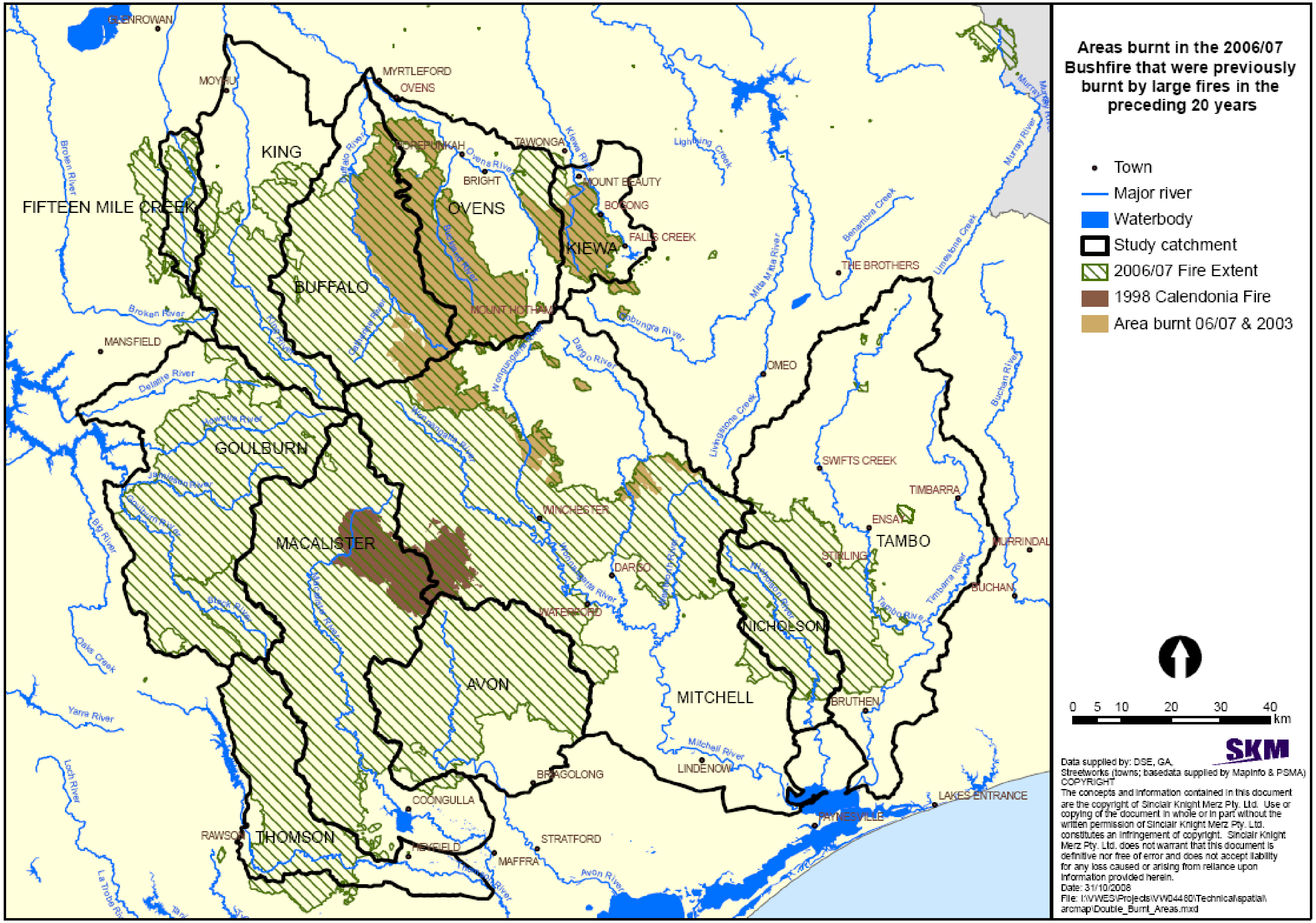


Figure 2 Extent of the 2003 and 2006/07 Bushfires (SKM, 2008a, See Appendix 3 for details on source data)



■ **Figure 3 Fire severity of the 2006/07 fires (SKM, 2008a, See Appendix 3 for details on source data)**



- **Figure 4 Areas burnt in the 2006/06 bushfires that were previously burnt in the proceeding 20 years (SKM, 2008a, See Appendix 3 for details on source data)**

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2.5. Loads to the Gippsland Lakes from the recent fires

Extensive bushfires, such as those in 2003 and 2006/07 can result water quality impacts. Studies of earlier bushfires indicate the likely effect on water quality (Brown, 1972; Chessman, 1986; Leitch et al., 1983) that include:

- Large increases in sediment and nutrient loads immediately following the fire; and
- Return to pre-fire sediment and nutrient loads over about 5 years as the catchments recover.

Sheridan et al. (2008) calculated sediment and nutrient loads based on a program of water quality monitoring that was initiated by the Department of Sustainability and Environment following the 2003 fires. There were several sites within the Gippsland Lakes catchment where reasonably reliable estimates could be made of pre and post fire loads. In all cases, large increases were observed in the loads of sediment and nutrients exported from these catchments (Table 2).

- **Table 2 Increases in sediment and nutrient loads following the 2003 fires for selected sites in the Gippsland Lakes catchment (Sheridan et al. 2008).**

Site	Approximate factor increases in loads following the 2003 fires			Reduction in loads as catchment recovered from fires
	TSS	TP	TN	
Dargo River @ Lower Dargo Rd	20	10	7	No recovery over 3 post-fire years
Tambo River @ Bindi	1500	400	90	No information as site was decommissioned in July 2003
Tambo River at Swifts Creek	25	6	3	Load increases persisted through 2003 and 2004 then declined in 2005.

The increases are largest immediately downstream of the fire affected areas then decrease downstream. Unburned areas of catchments, downstream of fire affected areas, effectively dilute the polluted runoff. Similarly, large dams, such as Lake Glenmaggie will trap sediments and thus attenuate sediment and nutrient loads to the Lakes.

An estimate of the impact of 2003 fires on loads to the lakes was made by Feikema et al., (2005). An existing catchment model was adjusted to take account of burned areas and the resulting predications were that loads of TSS, TP and TN delivered to the lakes would be 8.5, 1.8 and 1.6 times greater (on an average annual basis) for 1 to 2 years after the fires, compared to loads before the fires (Table 3). Feikema et al., (2005) commented that the extent of the increase in nutrient and sediment loads to the lakes will increase the risk of algal blooms and are likely to reduce ecosystem health, cause economic loss and threaten tourism opportunities.

- **Table 3 Approximate factor increases from impacts of bushfires on loads of pollutants to the Gippsland Lakes; comparison of with natural and baseline loads.**

Pollutant	Natural (average annual)	Mid 1990s Baseline (average annual values)[1]	Immediately following 2003 fires[2]
TSS	1	2.2	18.7
P	1	1.8	3.2
N	1	3.0	4.8

[1]Grayson et al., (2001); [2]Feikema et al., (2005)

Cook et al. (2008) estimated catchment loads to the Gippsland Lakes resulting from the 2006/07 fires (and the June/July 2007 floods) and showed they were the highest of any year where measurements were available (a total of 30 years). Approximate loads to the lakes were 900 tonnes of phosphorus and 6000 tonnes of nitrogen for 2007/08 compared to average loads for the period 1975-1999 of 300 tonnes of phosphorus and 2800 tonnes of nitrogen (Grayson et al., 2001; Cook et al, 2008). These high loads were caused by the intense rainfall that fell on burned catchments and the resulting flood in June/July 2007. It seems likely that particularly high nitrate inputs to the lakes resulted in the current bloom of *Synechococcus* (Cook et al, 2008).

2.5.1. Use of fire retardants

During the 2006/07 fires approximately 40,000 kg of Phos-chek™ fire retardant was used as part of fire suppression activities[1]. Phos-chek products may contain nitrogen and phosphorus compounds including ammonium polyphosphate, diammonium phosphate (DAP), diammonium sulphate, and monoammonium phosphate which are also ingredients in some fertilizers. Therefore they are a source of bioavailable N and P. There are various types of Phos-chek which have different proportions of these, and other, ingredients[2]. Taking an ortho-phosphate based fire retardant as an example, according to USDA specifications, this must have at least 8% ortho-phosphate (PO_4) which is 32% P (USDA, 2007). Therefore, if 40,000 kg of this retardant was applied, the total amount of P added to Gippsland Lakes Catchment would be about 1 tonne. A small proportion of this would find its way to the Lakes. This compares to an approximate average annual load of

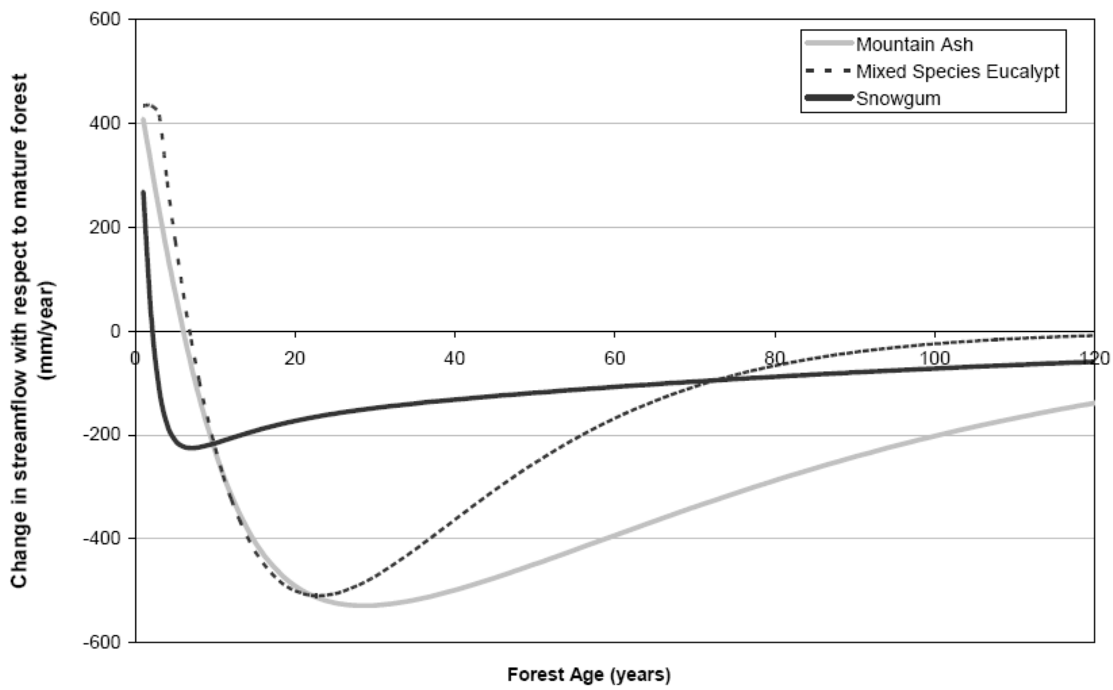
[1] Chris Barry, personnel communication

[2] See http://www.fs.fed.us/rm/fire/wfcs/products/index.htm

phosphorus to the lakes of about 300 tonnes (Grayson et al., 2001) which suggests retardants are not a significant additional source of phosphorus.

2.6. Impact of bushfires on water yield

As well as water quality impacts, bushfires affect the quantity of water leaving a catchment. Initially following fires, runoff increases because tree death reduces catchment interception and transpiration. Then, after about 5 years, young forests re-growing after fire consume considerably more water than the mature forest that existed before the fire. The change in catchment streamflow depends on forest type as shown in Figure 5. Most of the Forested areas of the Gippsland Lakes Catchment is mixed species Eucalypt (SKM, 2008a).



■ **Figure 5 Change in streamflow as a forest recovers from fires (SKM, 2008a)**

The impact on water yield is quantified in SKM (2008). In the short term (up to approximately 5 years) it is estimated that there will be an increase in streamflow resulting from reduced interception and evapotranspiration (plant water use) in areas where the bushfire causes forest mortality. It is estimated that the maximum increase in inflows to the Gippsland Lakes will be approximately 900 GL/year; an increase in catchment inflows of 30% assuming long-term average climatic conditions.

In the medium to longer term, a significant reduction in streamflow will occur in most catchments, with implication for water availability for environmental flows and downstream users. The largest reductions will occur approximately 20 to 30 years after the fires. For the Gippsland Lakes the estimated maximum reduction in inflows for the 2006/07 fires alone is between approximately 530 GL and 730 GL/year which represents 18-24% of catchment inflows. Inflows return to pre-2006 fire levels by about 2090, assuming climatic conditions remain constant and there are no further fires. Note that there is on-going work to refine these estimates and include the impact of the 2003 fires.

Impacts of streamflow reduction are likely to be greatest in spring. Best estimates of the flow changes with seasons are Spring (40%), Summer (21%), Autumn (11%) and Winter (27%).

- **Table 2 Summary of the maximum reduction in streamflow resulting from the 2006/07 fires assuming average climatic conditions, interim result, lower bound and best estimate case (SKM, 2008a)**

Study Catchment	Reduction in streamflow[1]					
	Lower Bound			Best Estimate		
	GL / yr	% MAF	Year	GL / yr	% MAF	Year
Avon River	-33	-15%	2022	-59	-27%	2025
Macalister River	-170	-25%	2028	-241	-35%	2028
Mitchell River	-275	-21%	2027	-337	-26%	2028
Nicholson River	-16	-31%	2019	-21	-42%	2018
Tambo River	-21	-5%	2016	-23	-5%	2016
Thomson River	-16	-9%	2027	-49	-28%	2028
Gippsland Lakes[2]	-530	18%	2028	-730	-24%	2028

Note 1: More recent work since the publication of SKM (2008a) suggests that the impact of the 2006/07 fires on yield is likely to lie between the lower bound and best estimate published in that report. This is being refined through on-going work which will also include the impact of the 2003 fires.

Note 2: The impact to the Gippsland Lakes includes the impact from the six rivers considered in this study. The mean annual flow volume of the Gippsland Lakes has been estimated as the sum of the inflows from the Latrobe, Thomson, Macalister, Mitchell, Nicholson, Avon, Perry and Tambo Rivers using a combination of REALM data and gauged streamflow records. Average streamflow to the Gippsland Lakes is estimated to be about 3,000 GL/year (SKM, 2008a).

2.6.1. Effect on water yield reductions on water quality in the Gippsland Lakes

It is likely that the decrease in water yield following the fires will affect water quality in the Lakes. Possible effects include

- Increase in salinity as freshwater inflows will decrease relative to marine influences
- The lower lakes will become more marine and Lake Wellington will become brackish
- Decreased turbidity levels in Lake Wellington because of flocculation of suspended clay particles as salinity increases

- Reduced nutrient inputs from catchments because of decreased inflows (provided nutrient generation from burned areas returns to pre-fire levels, which is likely after about 5 years). Lower inflows were associated with reduced nutrient inputs during the low runoff years between 1998 and 2006 (Cook et al., 2008)
- Reduced flushing of nutrients from the lakes. Sediment and nutrients are removed from the Lakes when the surface water layer is flushed out of the system to the sea (Webster, et al. 2001). Changes in the rate of freshwater inflow will affect the rate that nutrients are lost to the ocean
- Algal blooms will probably continue to occur due to high nutrient loads in sediments that are already there but the increased salinity may favour *Synechococcus* rather than *Nodularia*
- Freshwater wetlands around the lake margins will degrade due to lack of freshwater inflows and increased salinity. This may degrade their ability to buffer nutrient inputs
- Fish community composition may change to become dominated by more marine species.

There has been recent work on the environmental water requirements of the Gippsland Lakes (ECOS, 2008). Current inflows are about 3,000 GL/yr which have been decreased from natural inflows by about 20% through extraction. The reduction in yield caused by bushfires may decrease inflows by about 24% from current levels by about 2028; which would be about a 36% reduction from natural inflows which is likely to be sufficient to cause water quality and environmental impacts. If projected climate change is considered, inflows could be even lower.

3. Likely future fire regime

Are the 2003 and 2006/07 fires an unfortunate series of events or are they part of a new regime of more frequent fires that will result from climate change?

In a risk management framework, account must be taken of both consequence and likelihood of occurrence. The occurrence of severe and extensive fire like these is rare but their consequences are severe. Therefore it is appropriate for managers to attempt to reduce the consequences, likelihood, or both, of similar events. What would be concerning, from a risk management perspective, is if these types of extreme events were to become more common in the future.

The occurrence, severity and duration of fire depends on:

- Frequency of ignition (natural and anthropogenic);
- The quantity, location and distribution of fuel;
- Terrain;
- Management activities to suppress fire; and
- Weather, with temperature and humidity being most important (Williams et al., 2001)

3.1. Fire weather

The McArthur Mark 5 Forest Fire Danger Index (FFDI) is used to determine fire hazard and declare Total Fire Ban days (Hennessy et al., 2005; Noble et al., 1980).

The Forest Fire Danger Index FFDI is a function of:

- Relative humidity (0% - 100%);
- Air temperature (^{o}C);
- Wind speed (ms^{-1} at 10 m above the ground); and
- A drought factor (0-10) which is based on number of days since rain and evapotranspiration (Griffith, 1999);

Daily average values of FFDI have 5 categories as shown in Table 4.

Table 4 Forest Fire Danger Index (FFDI) categories

Category	Value
Low	< 5
Moderate	5 - 12
High	13 - 25
Very high	25 - 49
Extreme	≥ 50

For the catchment of the Gippsland Lakes, FFDI peaks in summer and has a minimum in winter. FFDI can be used to predict extreme fire conditions as well as guide management of prescribed burns. Hennessy et al. (2005) calculated FFDI for a range of sites in south-eastern Australia under current climate conditions (1974-2003). The closest site to the forested areas of the Gippsland Lakes catchment was Sale which had an average of 8.7 days per year when FFDI was very high or extreme. The FFDI values further inland, in the forested areas of the catchment, are likely to be higher as humidity will decrease away from the coast.

FFDI is a useful measure of weather at the time of fires, or peak fire danger, but longer term weather also needs to be considered. For example, the 2003 fires were exacerbated by very low rainfall leading up to the fire danger period and then little rain for a long period while the fires burned (BoM, 2003).

3.2. Climate change impacts on fire weather

Since the 1950s the climate has changed in ways that are likely to increase fire frequency and intensity (Hennessy et al., 2005; CSIRO, 2007):

- The average maximum temperature in Victoria has warmed by 0.7°C;
- South-east Australia has become dryer;
- Droughts have become hotter (Nichols, 2006); and
- The number of extremely hot days has risen.

Although the relationship between climate and fire is confounded by factors such as arson and fire management, it is clear that hotter and drier years have greater fire risk (BTE, 2001).

The future climate of south east Australia under global warming is likely to lead to an increase in fire frequency and severity. The catchment of the Gippsland Lakes is projected to become dryer and hotter as the atmospheric carbon dioxide concentration increases. By 2030 summer temperatures are expected to increase by about 0.9°C in east Gippsland, relative humidity will decrease, and the number of hot days (over 30°C) will increase (DSE, 2008).

Several studies have found that fire weather will increase with the expected changes in climate (Williams, et al., 2001; Pitman et al., 2007). Hennessy et al. (2005) modelled climate change impacts on fire-weather in south-east Australia. Periods of high FFDI are likely to start earlier in the season and finish later. The number of days per year when FFDI is very high or extreme could increase by 16% to 60% by 2050.

The implications of these climate changes are:

- The number of days of extreme forest fire danger will increase, which is likely to increase the frequency of fires;
- Once ignited, future bushfires will spread faster, be more intense and more difficult to suppress;
- The period when prescribed burns can be undertaken will need to move to earlier in spring and later in Autumn; and
- The risk of severe water quality events in the Gippsland Lakes will increase.

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4. Options for mitigating the impacts of bushfires on water quality

There are a large number of possible approaches for mitigating the impacts of bushfires on water quality. General options were listed in a discussion paper that that provided background to a workshop of fire management and catchment management specialists (SKM, 2008b). These options are summarised in Appendix 2. This section explores the top three options that were agreed at that workshop.

4.1. Undertake prescribed burning in the Gippsland Lakes Catchments

Prescribed burning, or land management burning, aims to replace infrequent, uncontrolled, high intensity fires with more frequent, controlled, low intensity fires. Prescribed burning has been a management activity in Victoria's forests for many years but its use may increase in the future.

The Parliamentary Inquiry following the 2003 and 2006/07 bushfires recommended an increase in the extent and frequency of prescribed burning to mitigate the risk associated with bushfires ENRC (2008). The recommendation was that 5% of the public land estate of 7.7 million hectares be subject to prescribed burning each year which is equivalent to an annual area of 385,000 ha. This is 3 times the current annual target of 130,000 ha. The actual area burned has often been less than the target area so if the recommended area is to be reached it will represent a major change in fire regime for Victoria's public land in general and the catchments of the Gippsland Lakes in particular. ENRC (2008) describes an increase in landscape scale prescribed burning as the key strategy for minimising the fire risks associated with climate change. The State government has yet to respond to the ENRC inquiry.

There is evidence to support the use of prescribed burns to achieve better water quality outcomes for the Gippsland Lakes if they reduce the frequency and extent of large uncontrolled burns similar to those in 2003 and 2006/06.

- Several catchment experiments show that prescribed burning can result in better water quality outcomes; and
- Soil temperatures during controlled burns are lower than in intense bushfires and may avoid soil damage or nutrient loss.

These points are discussed in more detail below. In addition, there is evidence that prescribed burning strategies can decrease fire size, number of fires, fire severity and fire intensity associated with unplanned fires (King et al., 2006; Fernandes and Botelho, 2003; Gill et al. 1987).

Prescribed burning is used to manage sediment and nutrient loads to receiving water bodies in other areas. For example, low intensity burning has been recommended as a sediment management tool in forests in California (Wohlgemuth et al., 1999).

Discussion with fire specialists, and review of the literature related to fires, suggests that success of prescribed burning in reducing water quality impacts will depend on the following:

- The prescribed burn must be low intensity;
- The fires must result in a landscape that has patches of burned and unburned areas; and
- Riparian areas should remain unburned.

It is likely to be possible to achieve these effects if prescribed burning is undertaken by skilled and experienced operators during appropriate weather conditions when the moisture content of riparian areas is higher than surrounds.

The adopted fire regime for a forest must be specified to satisfy a number of competing demands and will therefore be a compromise. For example, it may be difficult to keep fire out of riparian areas in all instances in a drying climate. The challenge then becomes one of balancing the risk of letting fuel (and hence risk) accumulate compared to undertaking burning under conditions that are still significantly more favourable than severe wildfire. Also, in some instances, higher intensity fires will be required for stand replacement and ecological management (Penman and Towerton, 2008).

4.1.1. Evidence that prescribed burning can improve water quality.

At sites in Kakadu National Park, when burning of tropical savannas in the north of Australia was changed to a less intense fire regime, there were improvements in water quality (Townsend et al., 2005).

In Australia's tropical Savannas most fires occur late in the dry season when there are high fuel loads which result in intense fires. Fires early in the dry season are typically 33% less intense and patchier.

Shifting to less intense fire regimes halved soil erosion, decreased wet season storm runoff sediment concentration by 80%, decreased the number of episodic storm runoff events and decreased N and P concentrations in episodic events by about 70%. They also resulted in improved canopy cover, more leaf litter, and more grass cover. Nutrient concentrations in wet season runoff and baseflows were not affected by the fire regime but they were already low as this area has nutrient poor soils (Townsend and Douglas, 2000).

In one catchment, which had been unburned for 10 years, an early dry season burn resulted in little impact on water quality. The limited effect on water quality was attributed to the low intensity of the burn (Townsend and Douglas, 2004).

A study of six catchments in the San Dimas Experimental Forest in California, of which 2 were kept unburned, 2 were burned under controlled moderate-intensity conditions and 2 were burned under bushfire conditions, showed an increase in nitrate export with an increase in fire severity (Riggan et al. 1994). Severely burned catchments had approximately 7 times greater nitrate export than the moderate-intensity burned areas and 40 times greater than from unburned catchments. The observed increase in nitrate levels also persisted for up to 10 years after the fire. Notably, nitrate concentrations in previously burned catchments were lower than their unburned counterparts (Riggan et al. 1994).

Similar experiments in South Carolina showed the positive effects of prescribed burns (Richter and Ralston, 1982). Hydrologic fluxes of nitrogen and phosphorus from areas burned with low intensity fires were found not likely to have appreciable impacts on water quality. Similar results were found following prescribed burns in the Lake Tahoe basin on California (Stephens, et al., 2004).

Prosser and Williams (1998) argue that relatively mild fires appear to have no influence on long term erosion rates. Increases in the frequency of mild fires as a result of Aboriginal burning of Eucalyptus forest, recorded as large increases in charcoal content of deposits, are not associated with any increase in rates of accumulation of sediment in valleys (Prosser, 1990). However, if a large storm follows an intense fire, then annual soil erosion can be 1000 times larger than the long term average (Atkinson, 1984).

4.1.2. Soil temperature may be low enough to avoid loss of nutrients.

The impact of fire on soil depends on the resulting temperature within the soil (Figure 6). Temperatures around 200°C can lead to the formation of water repellency and loss of nitrogen (Table 5). At high temperatures (i.e. 200 to 400 °C), nutrients from burned organic matter (i.e. plant material) are either lost as gases or converted (mineralised) into forms that are more readily transported by surface runoff or drainage water (e.g. nitrate). Atmospheric deposition of volatilised nutrients may also occur.

The effects of temperatures less than about 125°C are reasonably benign. During low intensity fires associated with controlled forest burns, soil temperatures are less than 125°C for most of the soil profile (Penman and Towerton, 2008; Raison et al., 1986).

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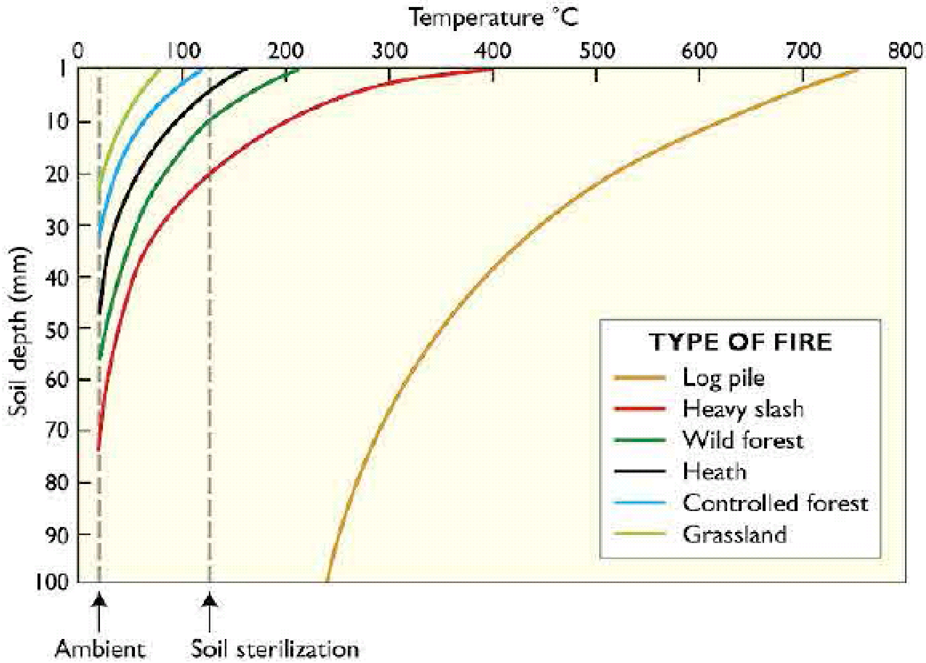

- **Figure 6 Soil temperature variation with depth for different types of fire (Raison and Walker, 1986)**
- **Table 5 Changes in soil and plant material after heating (after Raison and Walker, 1986)**

Dominant type of change	**Temperature °C**	**Change**
Physical	>1200	Loss of calcium as gas
	950	Clay minerals converted to different phases
	600	Maximum loss of potassium and phosphorus Fine ash produced
	540	Little residual nitrogen or carbon left
	420	Water lost from within clay minerals causing change in type
	400	Organic matter carbonized
Chemical	300	Maximum amino acid nitrogen released
		Loss of sulphur and phosphorus begins
		Organic matter charred
	200	Water repellence caused by distillation of

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Dominant type of change	Temperature °C	Change
		volatiles
		Loss on nitrogen commences
	125	Soil sterilization
	110	Soil water lost
	100	Soil ammonium production starts
	70	High nitrate mineralisation
Biological	50	Mild sterilization owing to water loss
	37	Maximum stimulation of soil micro-organisms
	<25	Usual soil temperatures

4.2. Improve rehabilitation as part of fire response

Fire response includes activities associated with suppressing fires such as clearing fire breaks, constructing access tracks, back burning and aerial application of water and fire retardants. *Rehabilitation* is also part of the fire suppression effort. Rehabilitation mainly consists of work to decrease the risk of erosion associated with fire breaks and tracks that have been constructed with bulldozers.

For fires in parks and forests (where DSE has responsibility for suppression), rehabilitation occurs as soon as practicable whilst machinery is still in place, but resourcing rehabilitation will always have a lower priority to fire suppression. When setting priorities for rehabilitation it is recognised that values other than erosion control must be considered which means some fire control lines and tracks will remain in place after the fire. These reasons can relate to cultural heritage, endangered species, salvage harvesting and seed collection. A risk management approach is used to prioritise areas and tracks for rehabilitation but for large fires, such as those in 2002/03 and 2006/07 this can be a large task and take months.

It is well known that unsealed roads are a major source of sediment (and attached nutrients) in forested areas so high loads would be expected from rapidly constructed and unmaintained fire breaks and tracks. Motha et al. (2004) found that unsealed roads produced 500 times the sediment loads from forest per unit area. Grayson et al. (1993) showed that roads were a much more significant source of sediment than logging operations in mountain ash forests.

Remedial measures can greatly reduce the amount of sediment that is discharged from roads to streams. Sheridan and Noske (2005) suggest that additional drainage (discharging to the forest floor) is a highly effective stream protection measure and can decrease sediment transport to streams by 90%.

Rehabilitation work, as required by The Code of Practice for Fire management on Public Land, is always done after fires; our suggestion is that these efforts could be improved by

- Making them part of daily planning activities undertaken during fire suppression;
- Implementing them as soon as the immediate fire danger is over (i.e. within a one to a few days of break construction) rather than waiting until the fire is extinguished, or until the end of the fire season;

Procedures to improve rehabilitation are likely to include:

- Mapping of fire breaks and tracks in close to real-time using GPS tracking of bulldozers and other earth moving equipment;
- Overlaying tracks and breaks on digital terrain models to identify stream crossings and long and steep slopes;
- Identifying areas of risk to water quality e.g. steep areas that are well connected to waterways;
- Setting priorities for rehabilitation works as part of day-to-day planning of suppression activities;
- Incorporating rehabilitation activities into incident management and incident action planning; and
- Undertaking works as soon as possible i.e. within days rather than weeks or months.

Day-to-day planning of activities is already undertaken as part of fire response and rehabilitation but could be more closely integrated with these efforts.

4.3. Incorporate fire sources of nutrients into overall planning for the Gippsland Lakes

Recent work for the Gippsland Lakes Task Force (Cottingham et al., 2006; Grayson and Cottingham, 2006; Ladson and Tilleard, 2006) established priority nutrient reduction activities for the Gippsland Lakes catchments. They found that the greatest gains in terms of reducing nutrient loads to the Lakes will be achieved by applying the most cost-effective Best Management Practices (BMPs) to the sub-catchments contributing the greatest proportional load. Highest priority activities were to apply BMPs to:

- Irrigation areas in the western catchments that contain the Macalister Irrigation District (MID);
- Point sources in the Western sub-catchments, and then
- Streambank erosion in dryland/ areas in the Western sub-catchments and in the Lower Mitchell and Upper Tambo.

At the time, this work did not explicitly consider the effects of fire on nutrient loads to the lakes, or the efficacy of Best Management Practices in reducing fire impacts. This work should now be reviewed to incorporate fire impacts and mitigation options.

Tasks are likely to include:

- Quantification of the effect of fires on loads to the lakes. This would build on the work of Feikma et al. 2005 and expand the Gippsland Lakes model to incorporate the additional areas that were burned in 2006/07 compared to 2003.
- A review of the effectiveness of best management practices in reducing fire impacts. This would build on this report but would need to quantify the effectiveness of proposed activities. The approach could be similar to that documented in Ladson and Tilleard (2006) where a simple computer model that was created to calculate load reduction was used to guide discussion as a workshop to identify the key management activities.
- Incorporation of bushfire loads and mitigation effectiveness into the framework developed by Cottingham and Grayson (2006) to determine priorities for all the nutrient management activities in the Gippsland Lakes catchments. This would allow activities to reduce nutrient loads from burned areas to be compared to, for example, best management practices to decrease runoff from the Macalister Irrigation District.

The result of this work would provide a defensible and reliable guide to future investments in managing nutrient inputs to the Lakes.

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Appendix 1 Workshop Participants

The following people attended a workshop on Oct 31, 2008 to identify options to mitigate the impacts of bushfires on water quality in the Gippsland Lakes

- Bonnie Atkinson, SKM
- Chris Barry, Gippsland Task Force
- Tony Ladson, SKM
- Pat Lane, University of Melbourne
- Rose Mannik, SKM
- Julie Morris, SKM
- Peter Sandercock, SKM
- Simon Roberts, Monash University
- Ian Rutherfurd, Department of Sustainability and Environment
- Rob Stewart, Department of Sustainability and Environment

Appendix 2 Additional Options

The following table outlines additional options for the mitigation of impacts of bushfires on water quality in the Gippsland Lakes and explains why they are not considered a high priority for the Gippsland Lakes Task Force (GLTF).

Option	**For details see**	**Comment**
Improve fire prevention	Code of practice for fire management on public land (DSE, 2006)	Only prescribed burning is explored further. There is already an extensive effort to achieve high fire preparedness so that any further effort by the GLTF would only have a marginal affect on fire risk in the Gippsland Lakes
Improve fire response	Code of practice for fire management on public land (DSE, 2006); ENRC (2008)	Fire response is an important but costly activity that is the responsibility of DSE. The GLTF is not likely to be able to influence most aspects of fire response in a way that will decrease water quality risks to the Gippsland Lakes. Rehabilitation aspects of fire response is considered in this report
Aerial seeding to encourage revegetation following fires		Not feasible for non-commercial species that are found in the forested areas of the Gippsland Lakes Catchment
Decrease phosphorus availability in the Gippsland Lakes through the application of phoslock	www.phoslock.com	Not feasible. Preliminary analysis by the Gippsland Coastal Board suggested costs could be >$500 million
Biomanipulation of the lakes to decrease *Synechococcus*	e.g. Vighi et al. (1995)	Biomanipulation has been successfully applied to improve water quality in small lakes (~2000 m^3) but is not likely to be feasible in the Gippsland Lakes (~1300 × 10^6 m^3)
Offset nutrients loads from fires by decreasing loads from other areas e.g. the MID	Gippsland Lakes Future Directions and Action Plan (Gippsland Lakes Task Force, 2002)	Nutrient reduction targets for non-fire related loads are already ambitious. There is limited opportunity to increase these further.

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Appendix 3 Data sources, additional copyright and disclaimer statements

The following datasets were used to create the map in Figure 2, 3 and 4. The additional disclaimers and copyright statements listed in the table apply.

Dataset Supplier	Dataset Name	Figures in this report	Year Data Supplied	Copyright and disclaimer statements
Department of Sustainability and Environment (DSE), on behalf of the State of Victoria	Fire Extents	2, 3 & 4	2008	The stated sourced data is copyright by the State of Victoria and licensed from DSE. The State of Victoria does not warrant the accuracy or completeness of information in this publication and any person using or relying upon such information does so on the basis that the State of Victoria shall bear no responsibility or liability whatsoever for any errors, faults, defects or omissions in the information
Geoscience Australia (GA)	Mainlands PopulatedPlaces Rivers WatercourseAreas Reservoirs Lakes	2, 3 & 4	2007	This document incorporates data which is: © Commonwealth of Australia (Geoscience Australia) 2007 Topographic data has been used in this document with the permission of Geoscience Australia. Geoscience Australia has not evaluated the Data as incorporated within this document, and therefore gives no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose.
Streetworks	Localities	2, 3 & 4	2003	Topographic data supplied by MapInfo and PSMA.